Quantified analysis of selected land use systems in the Larissa region, Greece

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Proefschrift

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ABSTRACT

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A dynamic crop-growth simulation model was developed, based on the "Wageningen modelling approach", calibrated and applied for quantified land evaluation purposes in the Larissa (east Thessaly) plain, Greece.

The soil and climate conditions were studied in detail in three sample areas with a total extent of about 10,000 hectares. The geology, geomorphology and hydrology, and the human environment were studied as well.

Crop data were collected in field experiments with maize, cotton and wheat in 1987 through 1989. The growth of widely used maize and cotton cultivars was studied in Larissa and Thessaloniki in 1987 and 1988; a durum (spring) wheat cultivar was studied in Larissa in 1989 and in Spata (Athens) in 1991.

Land data were collected for calculation of the water-limited production potential, which is within the reach of the farmers in the Larissa area. A full land evaluation of the whole area was not done. Rather, it was demonstrated that the model developed allows to quantify the impact of selected limitations on the performance of land-use systems as a basis for land suitability classification.

PREFACE

The increased availability of affordable computers in the past two decades sparked the exchange of information among such disciplines as biology, plant physiology and agronomy, and led to a remarkable development in the modelling of the soil-plant-atmosphere continuum. The best known work in this field is that of Professor C.T. De Wit, in mid 1970's, and the joint research by the Centre for World Food Studies, the Agricultural University of Wageningen, and a number of other research institutions in the Netherlands. The "Wageningen approach" was further developed to support quantified land evaluation and introduced in the curriculum of the Agricultural University of Wageningen in 1984.

The author, with a background in land evaluation, sought to introduce the approach to Greece, where quantified land evaluation is needed to support accelerated development of the agricultural sector. The Larissa plain, one of the largest lowland formations in the country, was chosen as study area.

The publication of this thesis is a first step towards quantified land evaluation in Greece. The remaining weaknesses and the fact that only a few commodities were studied should not keep researchers from probing further into a field that provides invaluable support to land use planning in the future.

I am grateful to my promotor Prof. Dr. L.J. Pons for his support during the work in Wageningen, his stimulating visits to the project areas and experimental sites in Larissa and Thessaloniki, and for his guidance, especially on the aspects of soils and geology.

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Last but by no means least, I am indebted to the staff of the Department of Soil Science and Geology, W.A.U. for their providing facilities and hospitality. I particularly which to mention Mr. F.A.H.M. Schelbergen and Ir. D. Legger for their support. Many other colleagues expressed their interest in this study and were prepared to help if needed. Mr. J.D.J. van Doesburg helped with clay mineral analyses, Mr. M. Lubbers mended some computer problems, and Dr. A. Stein solved some statistical problems. Ir. R. Jordens has been and will remain more than a supporting colleague.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Plate 1A- A south facing quarry, 1.5 km west of Nikea. Clay, sandy clayey and gravelly deposits can be seen. A fault is also visible with a horizontal layer displacement of about 1.5 m, belonging to the subsiding Larissa (Karla) basin.

Plate 1B- (facing north) the same sediments; the sandy layers appear as empty pockets.

Plate 1C- Homogeneous clayloamy sediment, characteristic of many slopes in the northern part of the Nikea area.

Plate 1D- Hard conglomerate sediment about 1.5 km south of Nikea, on the fringe of the studied pilot area. Folding caused strata to dip under an angle of 5 degrees (9%) as is visible in the right part of the photo.

Plate 1E- Deposit of alternating gravel and sandy clayey layers, occurring 1.5 km south of Nikea, west of the road to Farsala. In the lower gravel layers, large quantities of semi-rounded chert were found.

Plate 2A- A three-meters thick, calcareous clayey layer between two very calcareous, gravel layers.

Plate 2B- Deposit of alternating very calcareous gravel and sandy clayey layers.

Plate 2C- Thin calcareous clayey deposit over very calcareous sand and gravel.

Plate 2D- A very thick petrocalcic horizon is formed in calcareous gravel material (Petrocalcic Palexeroll) probably by subsurface throughflow of $CaCO_3$-rich water, thickening the petrocalcic horizon from above rather than from below.

Plate 2E- A two-meters thick, calcareous, sandy clay layer over a thick gravel deposit.

Plate 2F- Homogeneous clayloamy sediment.

Plate 3A- Shallow Calcixerollic Xerochrept (unit 1Ic3).

Plate 3B- Moderately deep Calcixerollic Xerochrept; note that the topsoil is not dark enough to qualify as a mollic epipedon (unit 2Id4).

Plate 3C- Typic Calcixeroll (unit 2Mt).

Plate 3D- Typic Chromoxerert (unit 3Vt).

1 INTRODUCTION

1.1 Introduction

Greek agriculture has rapidly modernized since the late 1950's when self-sufficiency in wheat production was attained. Since then, soil amelioration, mechanization, increased use of fertilizers, better pest/disease control, introduction of improved varieties and, most importantly, a dramatic expansion of the total irrigated area have led to greatly increased agricultural output (Fig. 1.1).

The country's food situation had substantially improved already before Greece became the 10th member of the EEC in 1981. After that, agricultural development focused on maximization of fodder and cash crop production which resulted in intensive arable cropping on all fertile, irrigable lands. Further mechanization and expansion of the irrigated area to 1 million hectares were realized soon after the country became a full member of the EEC (Boyatzoglou, 1984); the national production targets of major crops (maize, cotton, sugarbeet, etc.) were achieved as early as in 1985. Wheat production did not quite follow this development; wheat became increasingly confined to hilly, non-irrigable lands but the introduction of new, higher yielding varieties mitigated the adverse effects of this change.

The impression exists that agricultural development proceeded more rapidly on the farm level than could be accommodated on a regional and national scale. Surpluses in the Mediterranean region became a problem to EEC strategists, particularly in the last decade, and this problem was aggravated when Spain and Portugal entered in the Common Market. Considering the present (target) rate of expansion of irrigated land (40,000 ha per year), towards a potential of 1.9 million hectares (Benatos, 1991), it may be expected that surpluses in some commodities will increase even further while other agricultural sectors lag behind in development. Huge quantities of fruits and vegetables have to be destroyed each year. At the same time, Greek imports of meat and milk products (exports of which are virtually nil) total a staggering 1.5 billion ECU.

Alternative scenarios for land use planning are not always in line with the Community's long term agricultural policy which is already under pressure by existing surpluses in other EEC countries. The recent geo-political changes in Europe and the possibility of widening the EEC to the north and/or east create further uncertainties. All these factors make the tasks of Greek land use planners more difficult than ever.

Medium- and long-term planning have to take into account existing and projected relationships between agro-technical and socio-economic factors, both in the national context and in the context of the Common Market. This definitely requires a multidisciplinary approach. A detailed description of the physical environment constitutes the first step, as it controls the actual and potential agricultural production. Conventional land evaluation procedures are not always adequate for the purpose. They are of a qualitative nature, whereas planners and policy makers require quantitative information on the productive capacity of actual and projected Land Use Systems.

Considerable progress has been made in the development of quantified methods of land evaluation in recent years. Mathematical models become increasingly fit to handle (complex) Land Use Systems. Baier (1979) discerns three kinds of crop production models:

1. empirical statistical models,
2. crop/weather-analysis models, and
3. crop-growth simulation models.

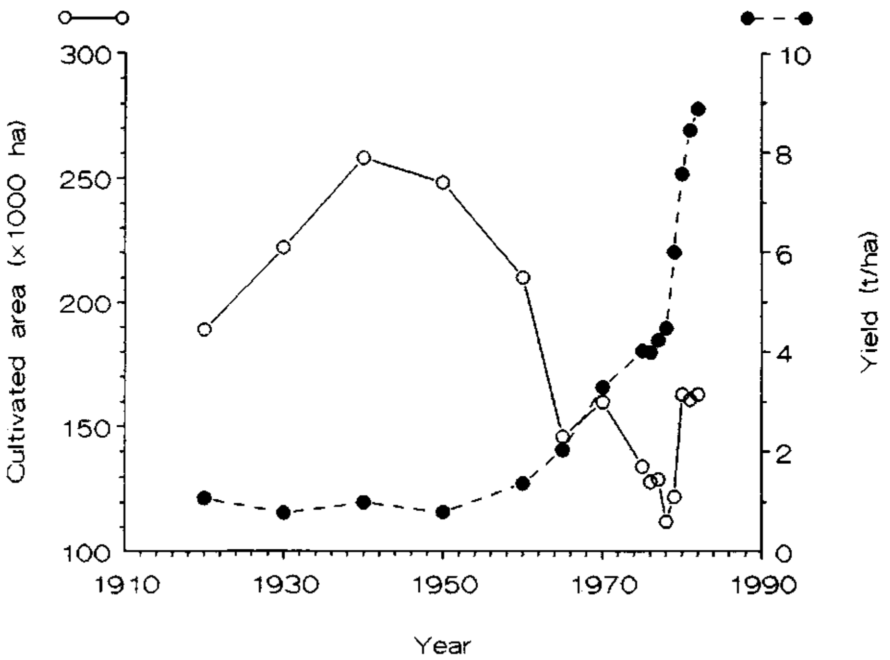


Fig. 1.1. Evolution of the cultivated area of maize and the average grain yield in Greece in the period 1920-1982 (after Institute of Cereal Crops, 1984).

Empirical models correlate yield and weather data to define system-specific 'coefficients' of an empirical nature. Such regression models do not explain (observed) cause-effect relationships but merely evaluate trends (Slabbers, 1980). Examples of this type of models are the regional prediction models for wheat, barley, and oats by Williams *et al.* (1975).
Crop/weather-analysis models relate system characteristics such as the soil moisture content and/or the evapotranspiration rate, to crop yield. The model presented by BAIER (1973) is an example.
Crop-growth simulation models describe the effects of meteorological variables on essential processes in plants such as photosynthesis or respiration, with the final aim to describe (potential) crop growth. Examples of this kind are ELCROS, BACROS, PHOTON, SPAN.

A comparatively recent (1986) and trendsetting work in this field is WOFOST, a model developed by the Centre for World Food Studies, in co-operation with the Agricultural University of Wageningen and other research institutions in the Netherlands. WOFOST is a comprehensive, dynamic crop-growth model which benefits from insights gained with detailed analytical models (SUCROS, BACROS, etc.), many of which have been described in the PUDOC "Simulation Monograph Series". The potential of dynamic crop-growth simulation models for Quantified Land Evaluation (QLE) was stressed by Driessen (1986; see also Driessen and van Diepen, 1986). The urgent need for quantified land evaluation procedures in Greece prompted the present study. Attention is focused on (1) the development of a dynamic and Land-Use-System specific crop-growth model, based on the "Wageningen approach" but adapted and calibrated for Greek conditions, and (2) evaluating its adequacy for quantifying the yield potentials of some of the country's most important crops, viz. maize, cotton and wheat.

Maize production increased spectacularly in the period 1971-1981 (Fig. 1.1) when maize growing became one of the most capital-intensive land uses in Greece. Only 15 years after the crop was deemed 'unsuitable to the country's climate' (Fasoulas & Fotiadis, 1966), Greece became the country with the highest average maize yield per hectare in the world (Institute of Cereal Crops-I.C.C., 1984; based on data by FAO, 1981). However, the recently attained self-sufficiency in food grain production does not mean that further development of maize production is not needed. Future development of the Greek cattle-breading sector is unimaginable without simultaneous development of the country's maize production. The production potential of maize must be investigated with special attention for the (optimum) input requirements. A comparative study of american and local maize cultivars is of importance to individual farmers and to the national economy since import of seedling material involves considerable cost.

Cotton production has always been a capital-intensive land use in Greece. The crop is grown on some 200,000 ha, of which 75 percent are irrigated. Cotton production advanced from a meagre 20,000 ha in 1930 (yielding an average of 530 kg seed cotton per hectare) to 168,000 ha in 1983, when the average yield amounted to 2.5 tons of seed cotton per hectare. In 1983, Greece ranked 5th among the world's cotton producing nations (Greek Cotton Organization, 1985). Cotton yields remained rather stable over the last decade which might indicate that the yields obtained are not much different than the potential. Total crop failure in some years and places suggests that Greece lies close to the northern border of the cotton belt and that the potential for cotton production might be comparatively limited. It was therefore decided to investigate whether cotton production can be further increased using advanced management and modern techniques such as drip irrigation.

Wheat is by far the most widely cultivated crop in Greece. Rainfed wheat is grown on some 1 million hectares (25.5 percent of all cultivated land), and produces 3.14 million tons of grain with a value of some 640 million ECU (prices of 1991). Efforts to reduce the share of wheat cultivation (since 1957) were less than successful. The opposite occurred in many instances, as wheat replaced other crops in hilly areas. Its tolerance to extreme conditions and the fact that wheat offers a secure family income are reasons for its continued popularity. Future reduction of the area under wheat might perhaps be achieved if per area yields can be substantially increased. This, in turn, presumes increased use of capital inputs, notably (supplementary) irrigation and fertilization. However, no decision can be taken in this matter without thorough knowledge of the crop's production potential. Assuming that the production potential is substantially higher than the present (rather conservative) estimate of 6 tons per hectare (I.C.C., 1985), it seemed worthwhile to study the yield potential and input requirements of this crop.

The actual and potential performances of the selected crops were studied in the Larissa area. This area occupies the eastern part of the Thessaly plain, which extends over some 500,000 hectares in the central part of Greece and comprises the largest lowland formation of the country.

Chapter 2 of this text discusses the physical environment (Land and Land Use). Section 2.1 gives a brief introduction to the Larissa area in general. Sections 2.2 through 2.4 give a detailed description of three 'representative' pilot areas (the Nikea area, the Platanoulia area and the Peneios delta) with a total extent of about 10,000 ha). Section 2.5 is concerned with the Karla area; this area was not studied in detail but its brief description complements the global overview of the Larissa region. The soil and climate conditions of the pilot areas were studied as well as their geology, geomorphology and hydrology, to obtain an in-depth understanding of the physical production environment. Additionally, the human environment, and particularly farmer attitudes, management, labour availability and cost, distribution of land, market orientation and prices were considered.

The present text adheres to the concepts and principles outlined in the FAO Framework for Land Evaluation (FAO, 1976); the reader is assumed to be acquainted with the Framework terminology. The developed algorithm follows the "Wageningen approach" in that it consists of a hierarchical arrangement of Land Quality analyses. The availability and impact of light and temperature on crop performance are evaluated at the highest hierarchical level. Analyses at this level address "Production Situation 1" or "PS-1". As temperature and light regimes cannot be manipulated, PS-1 analyses explore the "bio-physical production potential" of the crop. This potential serves as a reference for production calculations at lower hierarchical levels.

The influence of moisture availability on transpiration and crop production is additionally taken into account in analyses at the second hierarchical level (PS-2). It follows that system performance in PS-2 is determined by intercepted irradiance, temperature <u>and</u> availability of water.

At the third hierarchical level (PS-3), the availability of nutrients is additionally taken into account. And so forth.

The more Land Use Requirements and Land Qualities are considered in an analysis, the closer the resemblance between the simulated Production Situation and the situation in which Greek farmers generally operate. However, data needs and analytical complexity will also increase and soon reach the limit beyond which meaningful analysis is no longer possible.

For the first 2 Production Situations, the performance of Land Use Systems is simulated using the "state variable approach": dependent variable values are made invariant for the duration of specific intervals and reflect the state of the system. All values are adjusted after completion of the calculations of an interval. The major advantage of this technique is that interactions between Land Quality-Land Use Requirement combinations, positioned at different hierarchical levels, are accounted for automatically (Driessen & van Diepen, 1986).

Yield and production figures are the outcome of the PS-1 and PS-2 calculations. From PS-3 on, production and yield are treated as independent quantities (in practice the outcome of PS-2 analyses). They represent target values; PS-3 calculations estimate the inputs that must be made to realize the system's full potential.

The production estimates generated by a model (i.e. any model) are ultimately determined by the model user who defines the characteristics of the production environment in the set of basic data. In other words, the value of model output depends ultimately on the quality of the available basic data. Early runs of the model were fed with default values for crop data and showed great variation in crop performance under Greek conditions. Good quality crop and weather data, indispensable for realistic simulation of the production potential (PS-1 level), were gathered in a number of field experiments with the mostly used cultivars of maize, cotton and wheat in the study area.

The methodology is discussed in the third Chapter. The reader acquainted with the models WOFOST and QLE will find many similarities. As a matter of fact the present algorithm was developed in parallel with the latest versions of the above models (1991).

Chapter 4 is concerned with the collection of crop/cultivar specific input and calibration data for maize, cotton and wheat. The field experiments were carried out in Larissa and Thessaloniki in 1987 through 1989; some additional information from Spata, Athens (1991) and Aliartos (1988) is discussed as well.

Chapter 5 deals with land evaluation. A complete land evaluation of the Larissa area on the basis of the Framework is not attempted. Rather, it is demonstrated that the model developed allows to quantify reference yield levels and the impact of selected limitations on land use system performance as a basis for Land Suitability Classification. First, the key attributes of relevant Land Utilization Types (involving the 3 major commodities), and the inputs required to realize the calculated production potentials are evaluated for selected Land (mapping) Units. Next, the cost-benefit ratio of scenarios with present and future inputs will be discussed on the basis of simple economic considerations and under the assumption that the water-limited production potential is within the reach of the farmers in the study areas.

2 LAND AND LAND USE

2.1 Geology and agroclimate of the region

2.1.1 Location and geology

Thessaly, one of the thirteen provinces of the country, lies in the eastern part of central Greece. Larissa, its capital, has a population of 120,000 and is situated about 350 km north of Athens and 150 km south of Thessaloniki. The Pindos mountain range, with a north-north-west to south-south-east orientation, divides the country in two parts and borders Thessaly in the west. In the east, Thessaly is closed from the sea by the high mountain chain Olymbos (2917)-Ossa (1978)-Peleion (1930) (Fig. 2.1). In the central part, lower hills occur alternating with depressions that form an almost continuous plain extending towards the centre of Greece. This Thessaly plain, with an area of approximately 500,000 ha, constitutes the largest of the Greek lowland areas.

The basement of the Thessaly plain is a part of the old crystalline massif which extends to eastern and north-eastern Greece and is composed of gneiss, schists and marbles of Palaeozoic to Triassic age (the Pelagonian massif).

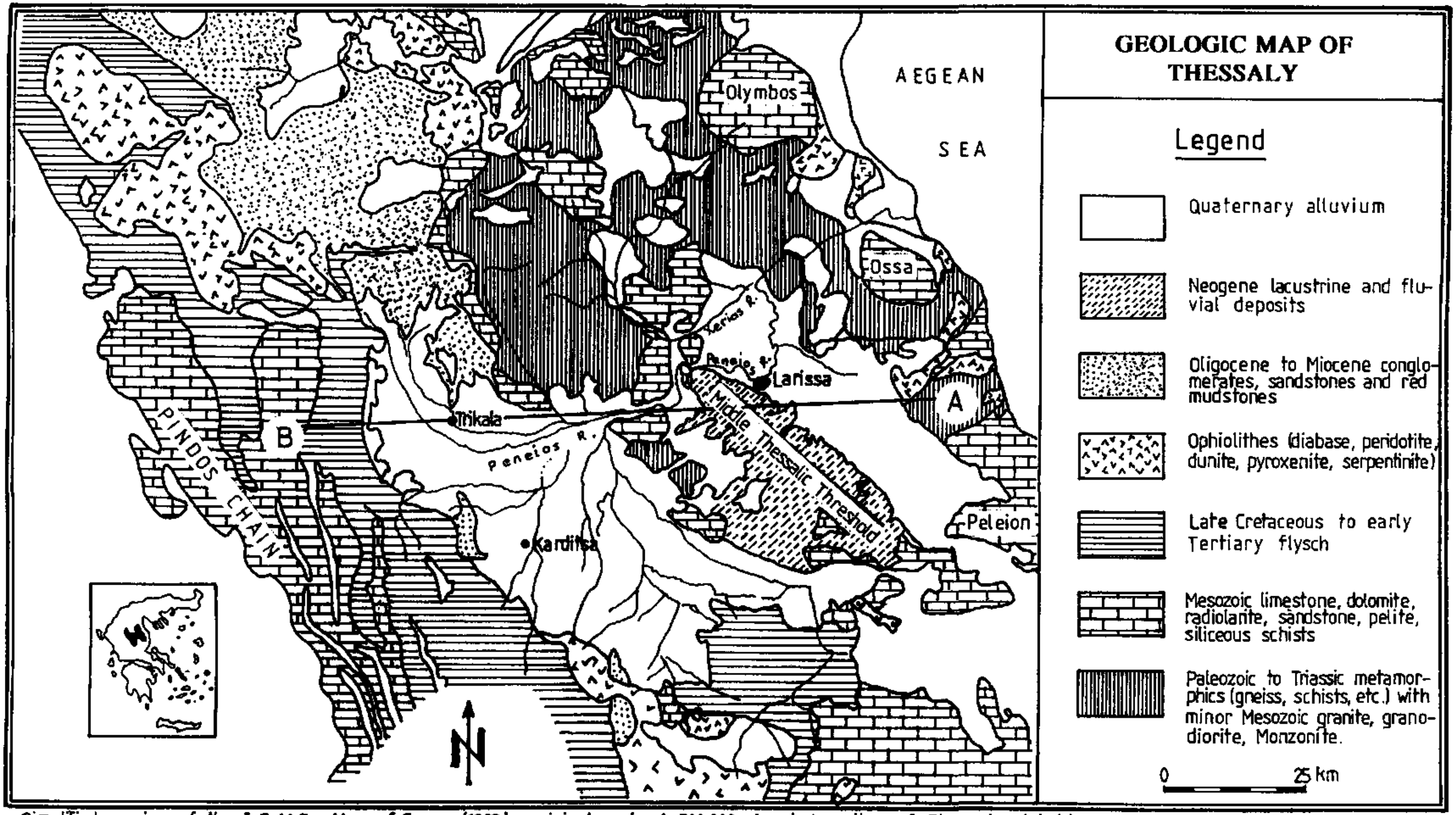
The bordering mountain ranges were uplifted during the Hellenide (Alpine) orogeny of the Pliocene (Philippson, 1950). The Pindos range in the west consists of Mesozoic to Cretaceous limestones and dolomites, associated with late Cretaceous to Tertiary flysch, and contains major ophiolithic inclusions. The eastern mountain chain is a part of the Pelagonian massif, covered with Mesozoic (Cretaceous) limestones and dolomites which now constitute the highest peaks (the "Olymbos window"; Dercourt *et al.*, 1980). The depression between the mountain ranges contained a shallow sea during Oligocene and Miocene times (Aubouin, 1965), and an extensive lake in the early Pliocene (Schneider, 1972) in which many streams from the surrounding mountains deposited alluvial fans of silt, sand and gravel. The conglomerates of the Meteora rocks are most likely formed in this way.

Tectonic activity in the middle Pleistocene caused subsidence of the depression into two grabens, the Larissa and the Karditsa plains (Schneider, 1968; Doutsos, 1980), which together form the Thessaly plain. Between the two grabens, lacustrine deposits (mostly marls, sandy marls and carbonatic conglomerates) of the Pliocene lake form the Middle Thessalic Threshold with a north-west to south-east orientation (Fig. 2.1).

The Peneios river and its tributaries make up the principle drainage network of the Thessaly plain. Originating from the Pindos range, the river passes the Karditsa plain and enters the Larissa plain through the Kalamakiou Narrows in the north-western part of the Middle Thessalic Threshold. In the city of Larissa, the river turns abruptly to the north, passes the Rodia Narrows and flows through the valley of Tempe before debouching into the Thermaic Gulf (Aegean Sea) (Figs. 2.1 & 2.3).

Pleistocene footslope sediments stretch along the mountain chains bordering the Thessaly plain. Only the river and lake deposits are recent. The schematic cross-section A-B (Fig. 2.2) presents the most important formations in the region.

The Larissa plain, i.e. the east Thessaly plain, is further concerned in this study.



Simplified version of the I.G.M.E. Map of Greece (1983); original scale 1:500,000. Inset: Location of Thessaly plain(s).

Fig. 2.1. The geology of Thessaly. Simplified version of the Greek Geological Service (I.G.M.E.) Map of Greece (1983) at an original scale 1:500,000. Inset: location of the Thessaly plain(s).

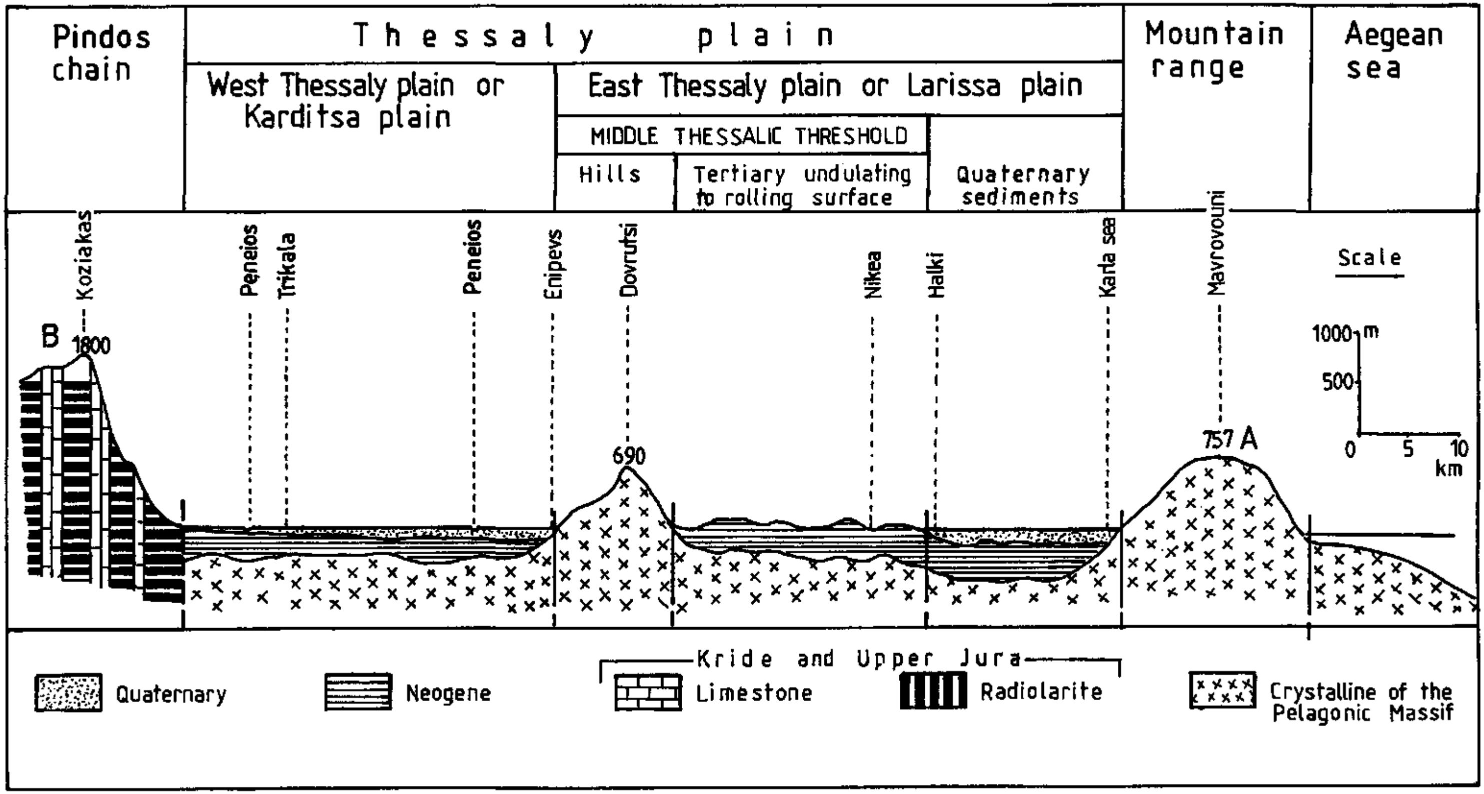


Fig. 2.2. Geological cross-section A-B (see geologic map in Fig. 2.1).

2.1.2 Geomorphology

The Larissa plain is an actively subsiding graben, and tectonic movements have conditioned its geomorphology. The plain can be divided in two parts: the Tertiary surface and the Quaternary deposits (see Figs. 2.2 and 2.3).

The Tertiary surface

The Middle Thessalic Threshold forms the highest part of the Larissa plain. Incision, fracturing, folding and erosion during the Tertiary to middle Pleistocene produced the present landscape: a dissected, undulating to rolling plain with intersecting broad dry valleys and sloping interfluves with shoulders. The soils developed in parent materials of Tertiary age, originating from the surrounding limestone and marly hills, and are rich in calcium carbonate. The lime hardens if exposed by erosion, especially on the summits and convex slopes, and this results in the formation of petrocalcic horizons. The Tertiary surface will be described in more detail in Section 2.2 (The Nikea pilot area).

The Quaternary sediments

In the lower part of the Larissa plain, Pleistocene and Holocene sediments cover the Pliocene lacustrine deposits which occur at a depth of 40 to 60 m (Sogreah, 1974).

A well preserved Pleistocene terrace lies between 5 and 15 m higher than the present Peneios flood plain. This terrace constitutes the most extensive occurrence of the former flood plain ("Niederterrasse"; Schneider, 1968) of the Peneios and its tributary the Xerias river. It is built from calcareous sands, silts and clays. The sediments of the Peneios river are finer textured than those of the river Xerias; they reach a thickness of 6.5 meters and rest on top of Pliocene bedrock. In this landscape, a long period of surface stability resulted in the formation of well-developed soils with a fine-textured argillic horizon and a calcic horizon. At least one cycle of dissection resulted in two different terrace levels.

Especially due to a decrease of the rate of subsidence of the basin floor and, to a lesser extent, also to the increase of the erosive power of the river (especially in the Rodia Narrows where the gradient of the river is controlled) the river channel became cut off, and a system of river terraces developed between the Pleistocene terrace and the meandering flood plain. This surface between Larissa and the Kalamakiou Narrows lies 5 m lower than the Pleistocene terrace and borders it between Larissa and the Rodia narrows.

The present Peneios flood plain includes late Holocene infillings of gravel, sands, silts and clays which rest on truncated older surfaces.

The lowest parts of the Larissa plain are the Mavrovouni and the Karla basins (see Fig. 2.3). They are the areas of maximum subsidence, where subsequent (fluvio-)lacustrine sedimentation resulted in the present flat land types. The Karla lake, which was drained in 1956, existed in the south-eastern Larissa plain for most of the Quaternary Era (Sogreah, 1974) but, according to Halstead (1984), its water surface was always below the 63 m contour. In this part of the Larissa plain, "Niederterrasse" deposits are lacking, which implies that the Peneios river, although flowing towards the Lake, has never reached it; the river lies at an altitude of 15 m above the former lake bed in the Rodia Narrows. The subsidence of the (Karla) basin might have forced the elbow of the river to the south-east as far as the city of Larissa.

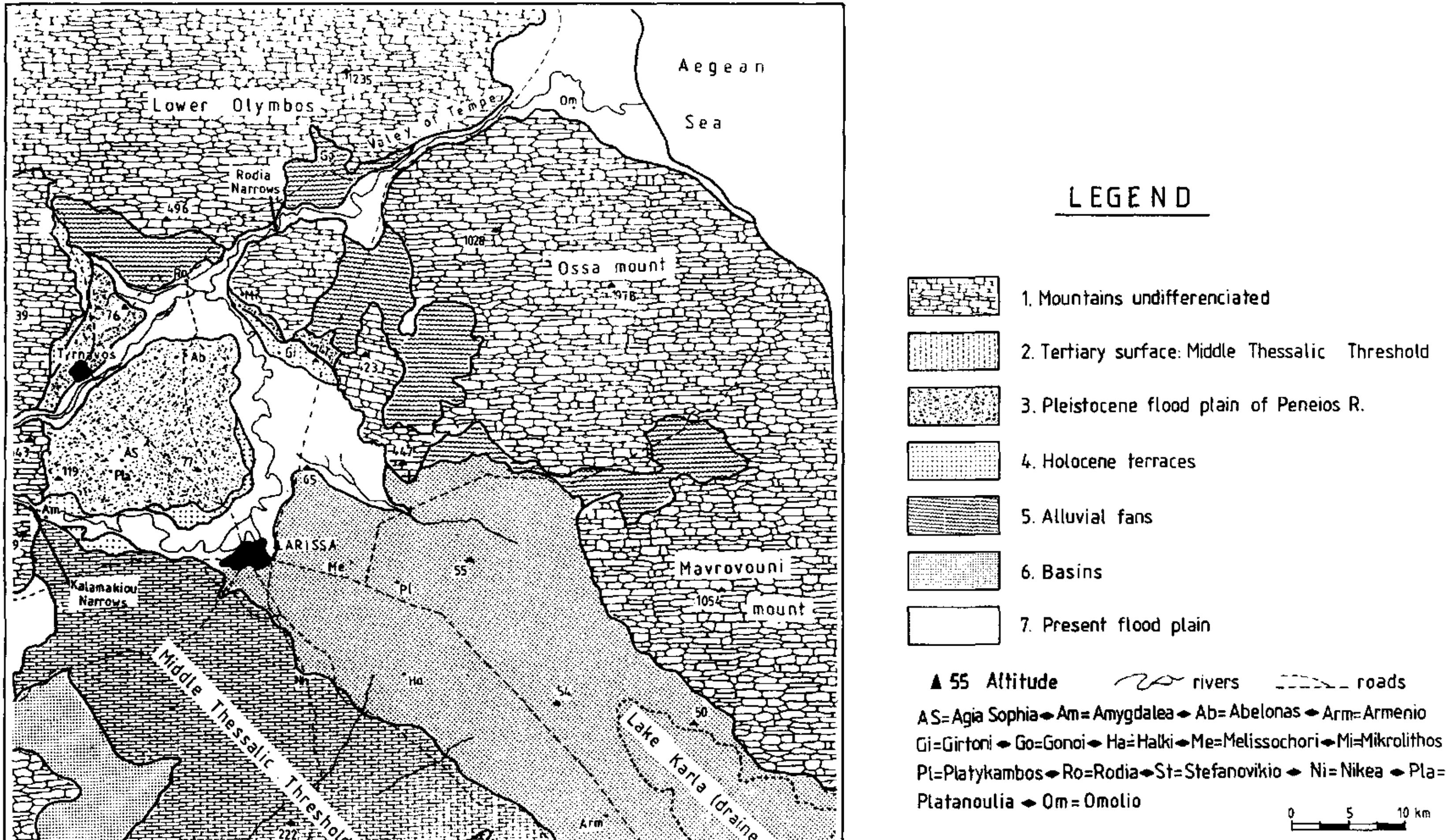


Fig. 2.3. Major landforms in the Larissa area.

Sedimentation of material of colluvial-alluvial nature took place around the margins of the Larissa plain through the late Pleistocene and Holocene, forming piedmont plains and alluvial fans. Fan building along the margins of the plain (see Fig. 2.3) was pronounced in the late Holocene (Demitrack, 1986).

2.1.3 (Agro)climate

The climate of the Larissa plain is Mediterranean, with hot dry summers and cold humid winters. More precisely, it is "Continental Mediterranean" as defined by Papadakis (1970), as Larissa (and the Macedonian plains to the north) is situated in a climatic transition zone between the Mediterranean climatic zone to the south and the Continental climatic zone to the north. A summary of climatic data is given in Table 2.1.

The annual rainfall in the Larissa area varies from about 450 to 550 millimetres with a peak in the months October-December. About one-third of the annual rainfall falls in summer, mainly in heavy downpours of short duration. Despite the comparatively high proportion of summer rainfall, moisture is the most limiting factor for producing crops during the summer; the considerable variation in annual precipitation is mainly responsible for the observed year-to-year fluctuations in crop production.

The mean annual temperature is 16.1 degrees Celsius (Table 2.1). The winter starts around the middle of December. The average temperature is well below 10 degrees Celsius from December to March. January is the coldest month with 5.2 degrees Celsius; temperatures lower than -10 degrees are not exceptional. Frosts may occur at any time between the beginning of November and the end of March but not for prolonged periods of time. The winter is often interrupted by short mild spells ("alkyonides"), when areas of barometric high pressures extend to Thessaly. The spring is short and the transition from winter to summer is normally sharp. The summer is hot, sunny and dry. July and August are the warmest months with an average temperature of about 27 degrees Celsius.

The mean annual relative humidity is 66.3 percent; maximum and minimum values are 83 and 45 percent, respectively. The potential evapotranspiration rate, calculated according to the modified Penman method (Frère, 1979) reaches its maximum (171 mm) in July (Fig. 2.4).

During the winter, cold north-east winds cause the temperature to drop. From the beginning of June onwards, hot dust-laden "livas" winds may occur. In early summer, these are particularly damaging to winter cereals (especially late maturing varieties), as they induce premature ripening and shrivelling of the grain. They also affect the setting of the maize grains and cause fruits to drop and shrinkage of immature fruits. However, as Table 2.1 indicates, the mean annual wind velocity is not too high (0.7 m/s); the average monthly wind velocity varies between 0.5 and 1.0 m/s.

The water balance tentatively calculated according to Thornthwaite-Mather (1955), using the data of Table 2.1 and a soil-water-storage value of 150 mm, is presented in Fig. 2.4. From this first approximation it appears that precipitation exceeds evapotranspiration from October till March and that, in an average year, the precipitation surplus is sufficient to fill the assumed storage capacity. The water balance will be examined more extensively for a number of land use systems later in this text.

The FAO Agroecological Zones Project (1978) quantifies indicative growing-period lengths (in days) assuming suitable temperatures. These growing periods commence when precipitation exceeds half the potential (Penman) evapotranspiration rate and continues until

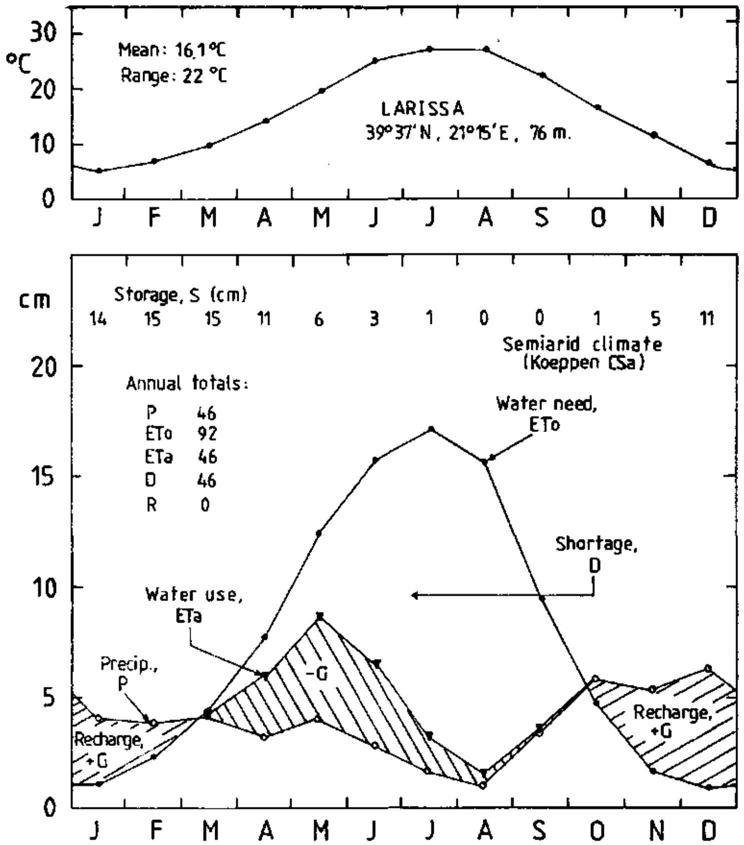


Fig. 2.4. Soil water balance sheet of the Larissa area. A maximum storage capacity of 150 mm is assumed.

an evapotranspiration deficit of 100 mm of water has built up. The growing period may thus include a humid period with excess precipitation over potential evapotranspiration.

According to the FAO definition of a growing period, the precipitation and evapotranspiration values recorded in Table 2.1 indicate an average growing period of about 220 days.

According to Koeppen (1931), Larissa has a temperate rainy climate with dry hot summers, Csa.

Thornthwaite's classification (1948) is based on water requirements and uses the following moisture index:

$$Im = Ih - 0.6 * Ia,$$

where

Ih is the humidity index (100*S/ETo),
Ia is the aridity index (100*D/ETo),
S is the precipitation surplus over pot. evapotranspiration (mm/year),
D is the precipitation deficit from pot. evapotranspiration (mm/year), and
ETo is the potential evapotranspiration (mm/year).

Table 2.1. Climatic record of the Larissa Airport station (39°37' N, 21°15'E., 76 m), over the period 1961-1985.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
average daily temperature (℃)	5.2	7.1	9.6	14.3	19.8	25.2	27.2	27.0	22.4	16.6	11.8	6.7	16.1
average max. daily temperature (℃)	9.7	12.5	15.0	20.1	25.8	31.1	33.7	33.3	28.8	22.6	16.6	11.3	21.7
average min. daily temperature (℃)	0.7	1.6	3.4	6.5	10.9	15.2	17.9	17.5	14.1	10.2	6.4	2.2	8.9
average maximum temperature (℃)	17.0	19.4	23.0	26.9	32.9	37.6	39.5	39.5	35.7	29.9	23.1	18.4	28.6
average minimum temperature (℃)	-6.8	-5.1	-3.1	0.7	5.5	10.4	13.5	13.3	8.5	4.1	-1.7	-4.6	2.8
absolute maximum temperature (℃)	21.0	24.0	31.8	31.8	38.5	41.8	45.0	45.0	40.0	36.6	26.0	22.6	45.0
absolute minimum temperature (℃)	-11.8	-9.5	-7.0	-2.6	3.1	7.0	10.6	10.6	6.0	0.3	-6.0	-14.0	-14.0
average relative humidity (%)	81	76	73	69	63	51	45	47	58	70	80	83	66.3
average absolute humidity (mbar)	5.1	5.5	6.6	7.8	10.2	11.1	11.3	11.8	11.0	9.5	7.4	5.9	8.6
average precipitation (mm)	41.6	38.8	42.0	32.3	41.5	28.6	17.5	10.2	34.1	57.9	53.5	63.4	461.4
max. precipitation in 24 hours (mm)	46	37	36	30	33	38	27	38	43	86	44	69	86
number of clear days	4.5	4.6	4.5	4.9	4.0	7.4	15.9	16.7	11.9	8.1	4.6	4.6	91.7
number of overcast days	13.2	9.9	11.0	7.5	5.3	2.0	0.5	0.9	2.5	7.7	10.9	12.4	83.8
average wind speed (m/s)	0.7	0.7	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.5	0.6	0.5	0.7
potential evapotranspiration (mm)	11.2	22.2	43.6	76.1	124.7	158.6	171.3	155.5	93.3	46.1	16.8	9.2	928.6

(Source: National Meteorological Service, 1986)

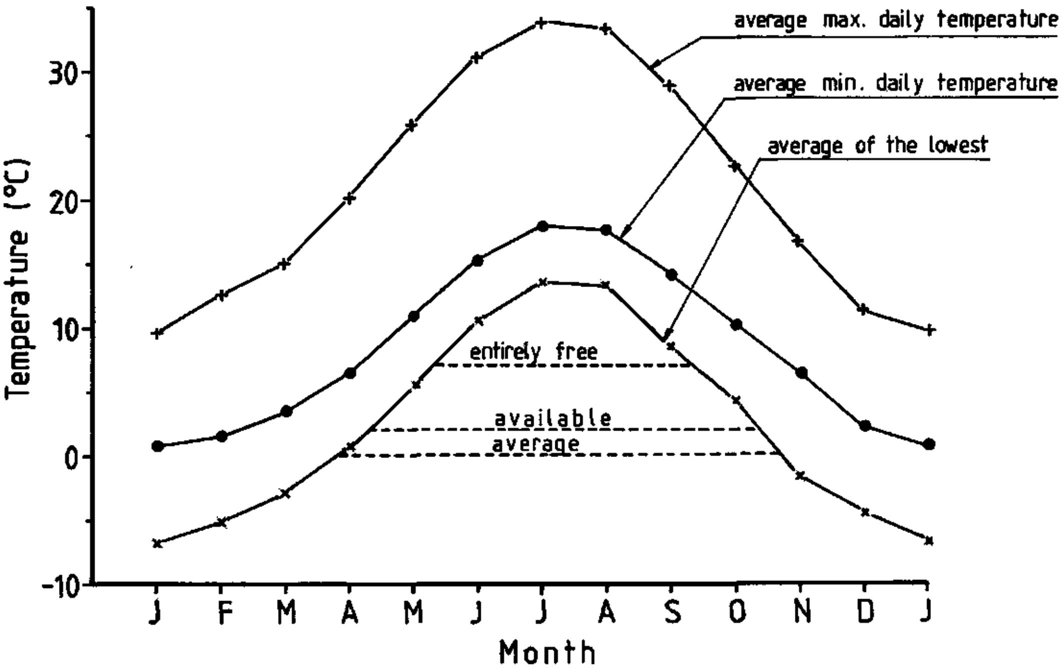


Fig. 2.5. Average max. and min. daily temperatures and approximate frost-free season in Larissa, based on the average lowest monthly temperature (see text). (Source: National Meteorological Service, period 1961-1985).

The precipitation surplus has a higher impact on the moisture-index value than the precipitation deficit to compensate for runoff. According to this classification the climate of the Larissa area is semi-arid with little or no water surplus and coded Dd.

Many Greek authors have stressed the importance of the low winter temperatures and of the great temperature amplitude over the year (always in excess of 20 degrees Celsius) and underlined the continental character of the climate of the Thessaly Plain (Fasoulas & Fotiadis, 1966; Giolas *et al.*, 1972).

Papadakis (1961, 1970, 1975) considers in his climatic classification of the world, apart from the water-balance concept also the following special features:

- average daily maximum and minimum temperatures, whereby great importance is attached to the vernalization effects of low temperatures;
- wind speed and length of the frost-free season;

The 1970 version of this classification labels the climate of the Thessaly plain as Continental Mediterranean, with a combination of a continental temperature regime of the "avena winter" type and warm "cotton summer" type zone, and a dry Mediterranean moisture regime. Practically all plains in Greece belong to the cotton summer type zone (Papadakis, 1985) and therefore the classification of Greek climates is mainly based on the winter types. The data of Table 2.1 suggest a climate code 6,73 (av-G,Me), indicating that the Larissa area -and the Thessaly plain in general- belongs to the north-eastern climatic zone of Greece. This zone is too frosty for citrus and too cold for olives, and forms a transition between the Mediterranean climatic zone to the south and the Continental climatic zone to the north. Fig. 2.5 shows the frost-free period for the Larissa area (Papadakis, 1975). Its approximation is based on the average of the lowest temperatures curve: when the curve is above 7°C there is no risk for any crop (entirely free period); when it is above 2°C, the risk for crops like maize is negligible (available period); when it is between 0 and 2°C, the risk is significant for sensitive crops or organs (average period). Papadakis identified a similar climate for Turkey, North Italy, South Bulgaria, Spain and parts of the USA (Davis CA).

The soil temperature regime is "thermic" according to the Soil Taxonomy (1975), assuming that the mean annual soil temperature is between 15 and 22 degrees Celsius and a difference between mean summer and mean winter soil temperature of more than 5 degrees Celsius at a depth of 50 cm.

The "xeric" moisture regime applies to all soils that do not receive runoff from adjacent areas; their control section is dry for more than 45 consecutive days in the months following the summer solstice, in more than 6 out of 10 years. Assuming a soil moisture storage of 150 mm, the area has approximately 90 dry days in an average year (Fig. 2.4).

2.2 The Nikea pilot area

2.2.1 Introduction

The northern part of the Middle Thessalic Threshold (approximately 61,500 ha) has been surveyed in reconnaissance by ITC (1983) and represents 51% of the 1:100,000 ITC Soil Map of the Larissa Area (Van der Meeren and Shrestha, 1984) (see Fig. 2.10). In the summer of 1989, the area below the 200 m contour was surveyed by the staff of the Institute for Soil Mapping and Classification, Larissa, in the framework of the National Soil Map of Greece compilation project.

A representative area was chosen and studied in detail for the collection of the soil data to support quantified land evaluation. This is the "Nikea area", named after the nearest village Nikea (see Fig. 2.6 and location in Fig. 2.10).

The Nikea pilot area is located 10 km south of Larissa along the Larissa-Farsala road. It lies between 39°31'30'' and 39°34'00'' North and 22°24'58.8'' and 22°27'58.8'' East and covers approximately 1,815 ha. Its elevation varies from 95 m ASL in the central valley to 180 m ASL in the south-eastern part. The Nikea area can be reached by car over paved and unpaved roads throughout the year.

The following paragraphs discuss this pilot area as well as the geogenetic history of the region as a whole.

Fig. 2.6. The Nikea area

2.2.2 Geogenesis

Geology

Fig. 2.7 presents the main geologic formations in the Middle Thessalic Threshold; a cross section and a number of stratigraphic columns are presented in Fig. 2.8, based on (simplified) data of the Institute of Geology and Mineral Exploration (I.G.M.E).

The substratum of the area belongs to the pre-Cretaceous tectonic nape of (Jurassic) chlorite and epidote schists with intercalations of crystalline limestone and blue-grey marble. This strongly folded formation has a thickness of 400 m and is exposed in the southern part of the zone and in the area south of the town of Mavrovouni (Fig. 2.7).

This crystalline massif is widely covered with Cenomanean (Lower Cretaceous) ultrabasic serpentine, peridotite and dunite rock formations, which have a thickness of 300 m (see Fig. 2.8a-C1 and C2, and Fig. 2.8b) and are exposed in the southern part of the area (Fig. 2.7). These formations are absent in the northern part of the area (Fig. 2.8b), where Cretaceous limestones overly the crystalline massif.

The limestones vary in composition and in age from Lower to Upper Cretaceous. The most extensively exposed (see Fig. 2.7) are the Upper Cenomanean to Senonian light-grey to grey-black, medium bedded limestones, in places clastic and brecciated, with a thickness of 400 m (Fig. 2.8). These formations may under- or overly flysch.

The flysch, exposed in the Agnanderi and Velestino areas (Fig. 2.7) is buried under an Early Cretaceous light grey, microcrystalline, carstic limestone (Figs. 2.8a-C3 and 3b), and under Upper Cretaceous limestone on the Chalkidonion and Mavrovouni mounts (the highest summits in the region). The "lower" unit of flysch consists of fine to coarse grained sandstones containing quartz, feldspar, muscovite, sericite and calcite and has intercalations of sandy conglomerates. In the lower flysch area near Velestino, olistoliths are present with limestones, dolomites, serpentines, cherts, pyroxenites and diabasic rocks with an accumulated thickness of approximately 150 m. Flysch is included also in Upper Cretaceous limestones as their (<20 m) coarse-grained sandstone slams with olistoliths of diabasic-dioritic rocks and cherts. These formations crop out in the south of the Neo Perivoli and Velestino areas (Fig. 2.7).

The younger flysch is covered with lacustrine deposits of the Miocene lake, which are still exposed in the central part of the Threshold, at elevations of 160 to 400 m ASL. These deposits consist of grey to whitish friable marls, in beds of 5-20 m thickness, are laminated - in places- and occasionally argillaceous and greenish. In the upper parts of the marls, hard marls and travertinoid, whitish limestones occur in places, which are generally resistant to erosion and have a thickness of up to 15 m. Sandstone layers and intercalated conglomerates with particles up to 10 cm in diameter occur locally; they are cemented by clayey-marl. The total thickness of the Miocene unit is approximately 100 m.

Pontian to Lower Pleistocene fluvio-terrestrial deposits cover the Miocene marls. They are exposed in large parts of the region (Fig. 2.7) and consist of red clays and clayey sandy materials, with dispersed rounded and angular pebbles or coarser-grained elements of varying lithological composition and with little or no orientation. The same formation contains breccio-conglomerates with locally particle sizes up to 10 cm (and in some cases up to 1 m) in a clayey sandy matrix. The fluvio-terrestrial formations are of heterogeneous composition. The lower parts of these deposits are lacustrine and contain considerable amounts of marly materials, which grade downward into pure Miocene marl. Unlike the Miocene deposits, the

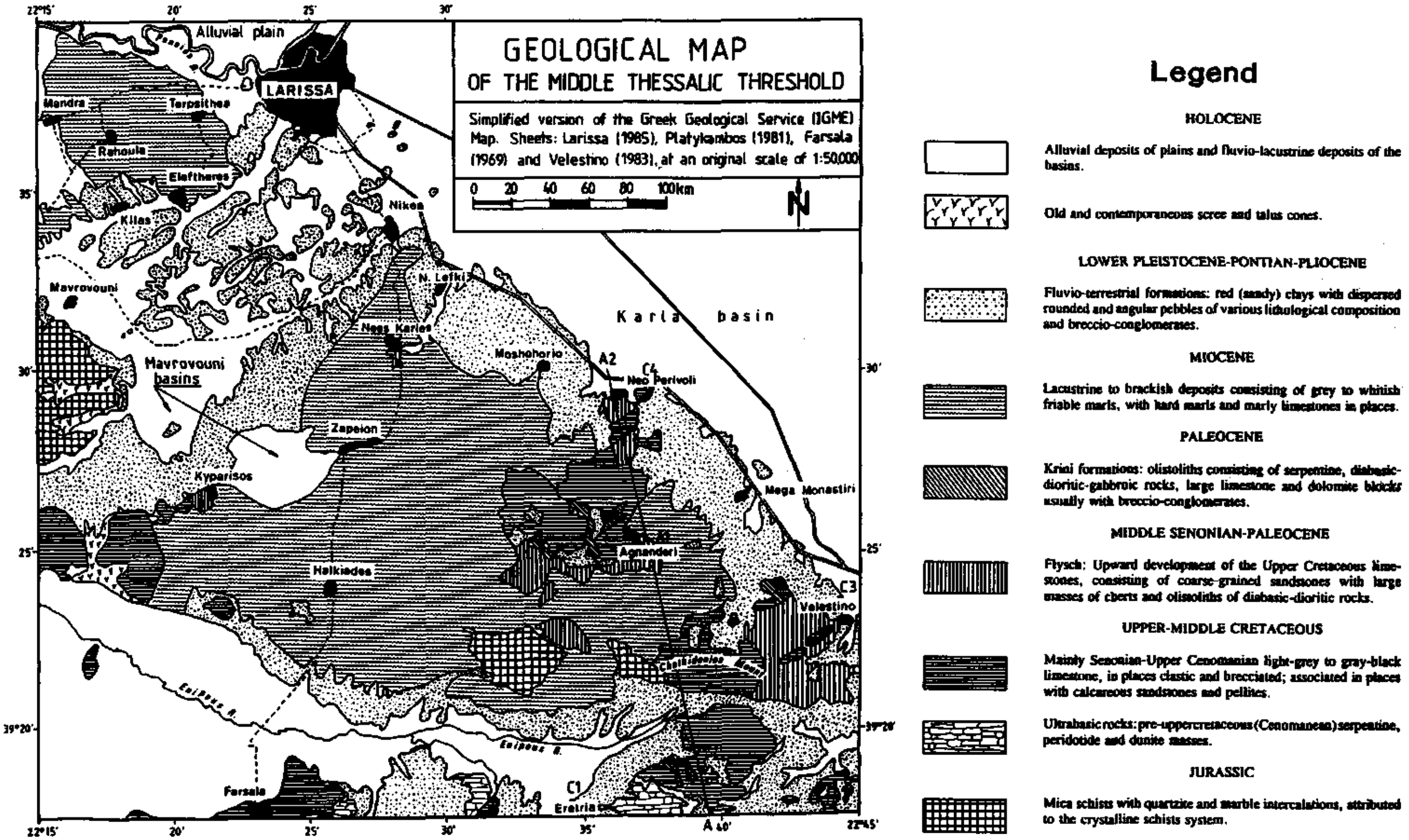


Fig. 2.7. The geology of the Middle Thessalic Threshold

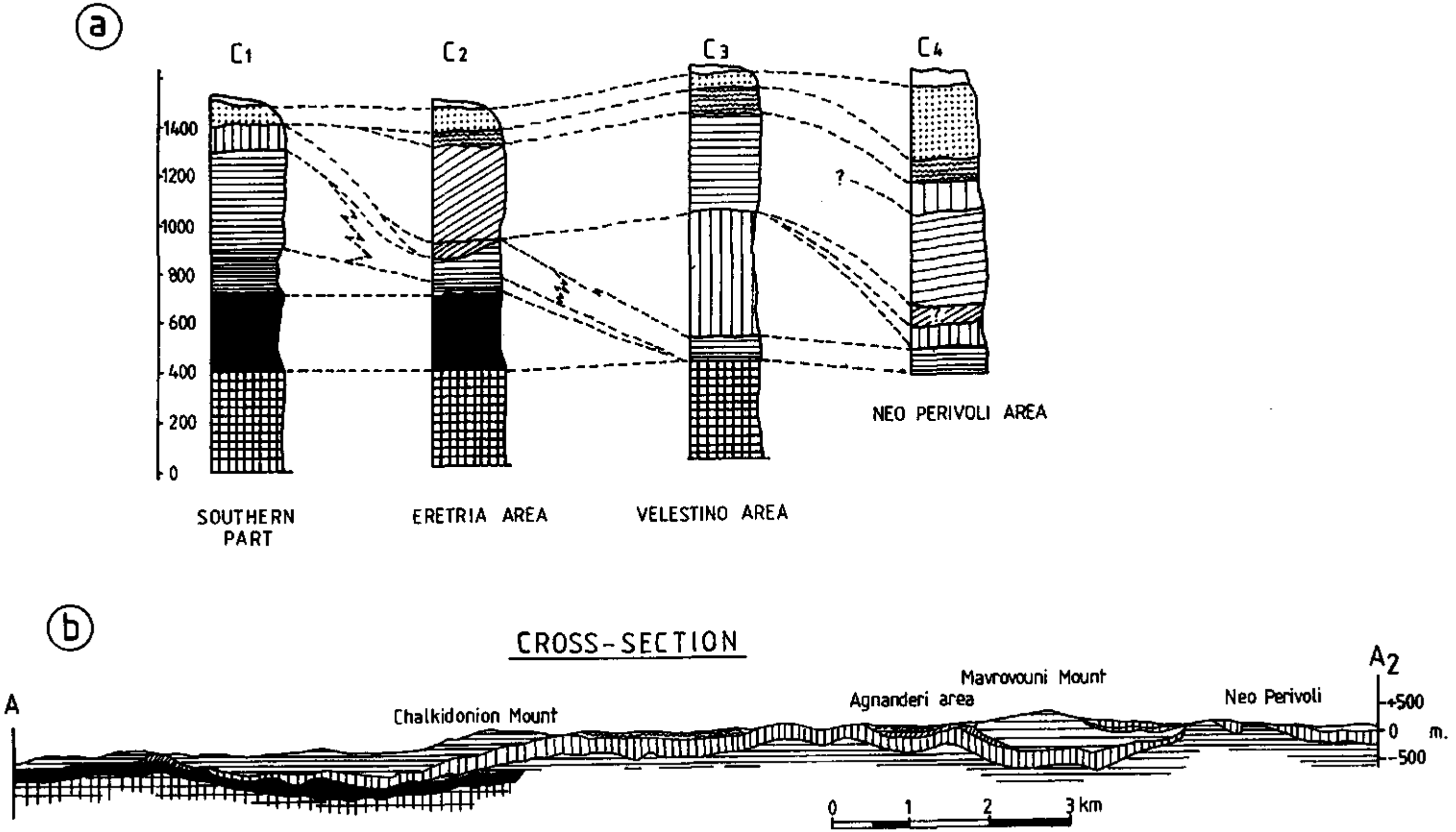


Fig. 2.8. (a) Stratigraphic columns in the Middle Thessalic Threshold; C1-C4: locations shown in the geologic map in Fig. 2.7. (b) cross-section A-A2 in the same geologic map (same legend).

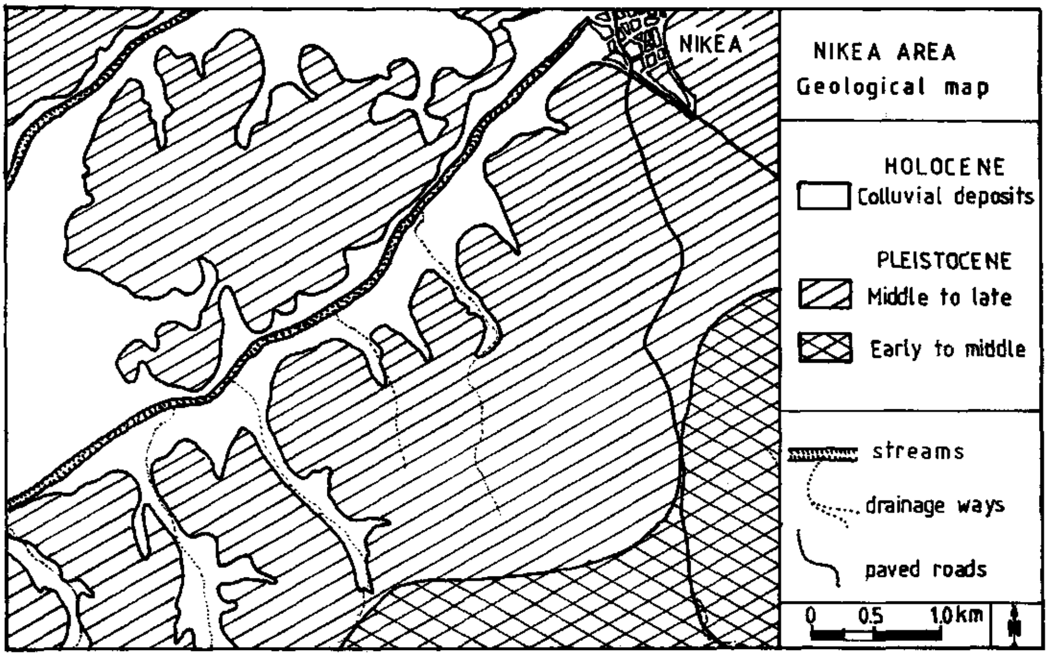


Fig. 2.9. The geology of the Nikea area.

fluvio-terrestrial formation vary in thickness, viz. from nil (central part of the Threshold) to 300 m along the subsiding fringe (Neo Perivoli area; see Figs. 2.7 and 2.8a-C4, etc.).

The recent (Holocene) deposits (see Fig. 2.7) include calcareous, finely textured colluvium in the valleys, and fluvio-lacustrine material in the basin areas (Fig. 2.10). Along the basin borders, the material is coarse-grained and becomes increasingly finer-grained towards the centre.

Scree and talus cones consist mainly of loose angular and rounded pebbles.

The Middle Thessalic Threshold formed during the last tectonic disturbance of Thessaly in the middle Pleistocene, when the subsiding Thessalic depression split into two grabens and the fluvio-lacustrine deposits of the post-Neogene lake were uplifted to their present level. Studying the difference in depth to bedrock in an area close to Halkiades, Demitrack (1986) calculated an equivalent subsidence rate of 1.5 m/1000 years. Actually, the highest Pliocene level near Halkiades is 360 m, but, below the 90 m contour, the same lake deposits occur at a depth of 40-60 m (in the deeper strata). Dating the beginning of the subsidence at 250,000 years BP (U/Th disequilibrium dating of pedogenic carbonate on the Pliocene surface), confirms Demitrack's calculations. This subsidence rate, however, does not apply to the whole plain, because of the great variation in the depths to bedrock in the Larissa area: 100 m along the margins to >500 m in the vicinity of Larissa (Greek Land Reclamation Service-YEB), and because Pleistocene alluvium is still at the surface today (refer to the Platanoulia pilot area; Section 2.3).

Apparently, the tectonic activity slowed down since the Upper Pleistocene, but continues until the present day. Numerous earthquakes and tremors in the Larissa area testify to this. The most recent severe earthquake occurred in March 1941; it had an intensity of 6.25 on the Richter scale (epicentre north-east of the city of Larissa) and destroyed approximately 20% of the buildings in Larissa (Galanopoulou, 1955). Another severe earthquake occurred in 1892 but is poorly documented.

Fig. 2.9 shows that Pleistocene deposits constitute the interfluves in the Nikea area, whereas the valleys are infilled with recent colluvium.

The Pleistocene deposits consist of sands, clayey sands and clays of variable thickness and are generally intercalated with gravel layers, 1.5 to several meters thick and with rounded and sharp elements with diameters up to 10 cm. The gravel layers are very slightly orientated, if at all.

Plates 1A and 1B (p. 57-a) pertain to clayey, sandy clayey and gravelly deposits. On Plate 1B, the sandy layers appear as empty pockets. Plates 1E, 2B and 2E show deposits of alternating gravel and sandy clayey layers, whereas in Plate 2A (p. 57-b), a 3 meters thick clayey layer rests between two very calcareous, gravel layers. In the lower gravel layers shown on Plate 1E, large quantities of semi-rounded chert are present. These are related to the Cretaceous flysch in the Neo Perivoli area southwest of Nikea. Plate 2C shows a thin calcareous clayey deposit overlying very calcareous sand and gravel, whereas Plate 2F shows a homogeneous clayloam deposit.

The deposits become less oriented and of lower cohesion towards the north and northeast. In the same direction, textures become finer and gravel intercalations less abundant. Conversely, thick hard conglomerates were found to occupy the highest elevations (Plate 1D) near the southern and southeastern borders of the Nikea area; these are presumed to be of Pliocene to Lower Pleistocene age (Fig. 2.9).

Geomorphology

ITC (1984) distinguished the following main landtypes in the Middle Thessalic Threshold (Fig. 2.10):

Symbol	Landtype	Area (ha)
M	Mountains	14,360
T	Dissected Tertiary Plain	43,610
B	Mavrovouni basins	3,975
Total		61,945

The mountains (Landtype M) consist mainly of limestone and schists, with limestone occupying the highest peaks (e.g. Chalkidonion, 726 m), and schists at lower altitudes. Vegetation, other than some sparse grasses, is absent on the higher slopes and summits. Surface runoff from these bare slopes is severe and leads to surface erosion and accumulation of soil material in the footslope zone.

In the central part of the Threshold (between the villages Mavrovouni and Zapeion, Fig. 2.10), two small internal basins occur, the "Mavrovouni" basins (Landtype B). These are covered with recent, calcareous, very finely textured alluvium in which homogeneous, finely textured and strongly swelling soils are formed (Vertisols).

Besides the areas occupied by mountains and basins, there are dissected undulating to rolling plains with intersecting valley systems between 90 and 400 m ASL (Landtype T).

Landtype T was further subdivided into 3 land subtypes as follows (Fig. 2.10):

T		Dissected Plain	(total area 43,610 ha)
	T1	Rolling plain	(29.8%)
	T11	Subparallel drainage pattern	(13.3%)
	T12	Trellis drainage pattern	(14.0%)
	T13	Contorted drainage pattern	(2.5%)
	T2	Gently undulating plain	(26.1%)
	T21	Interfluves	(>99.9%)
	T22	Isolated hummocks	(<0.01%)
	T3	Valley system	(44.1%)
	T31	Concave valleys and foot slopes	(91.0%)
	T32	Level valley bottoms.	(9.0%)

(After: Van der Meeren and Shrestha, 1984).

Land subtype T1 refers to a rolling plain with an average slope of 10 percent in the north-west, south and south-east of the area (Fig. 2.10). In Land subtype T1, three land units may be further distinguished, i.e. T11, T12 and T13.

Land unit T11 includes areas with a subparallel drainage pattern of very high density and narrow valleys running from south to north-northwest. The unit occurs in the south-eastern and north-western parts of the area.

Land unit T12 has a trellis drainage pattern (lower drainage intensity than T11) with a general south to north orientation and east-west tributaries. The ridges are broader and smoother than those of unit T11 with generally less than 10 percent slope. The unit occurs at various locations in the area (see Fig. 2.10).

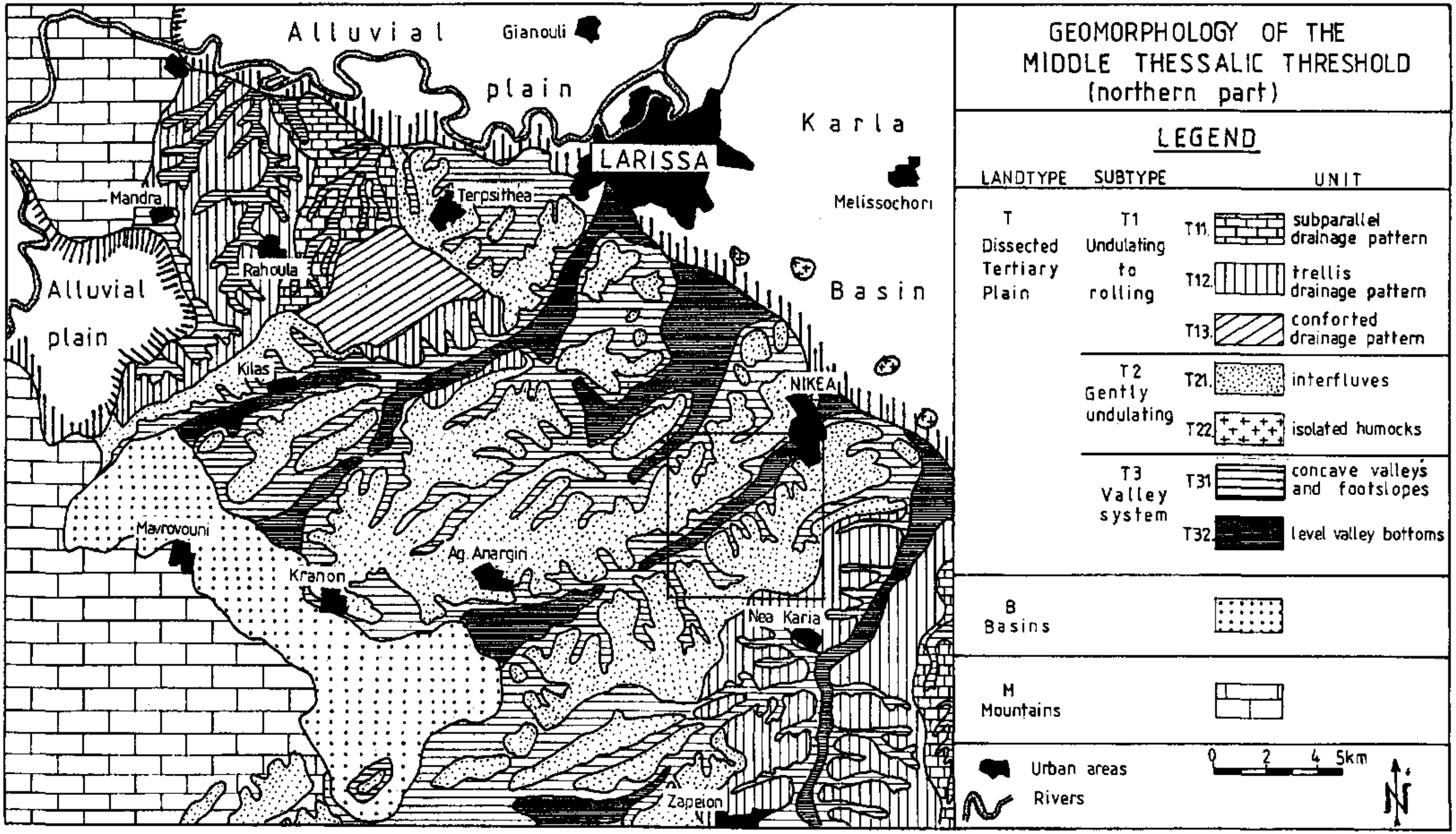
Land unit T13 is characterized by a contorted drainage pattern of very high density. Slopes are generally steeper than 10 percent. This unit is limited to the area southwest of Terpsithea (see Fig. 2.10).

Land subtype T2 refers to "gently undulating plains", with gentle ridges (average slope 5 percent) and many gentle summits. The tops have lower elevations than the tops in the rolling parts (Subtype T1). Miocene marls and thick, hard conglomerates are absent from this subtype.

The Land subtype T2 is associated with broad valleys running in a SW-NE direction and covered by recent alluvium (Land unit T32), and represents approximately half of the Landtype T on the ITC map (Fig. 2.10). It occurs in the north-central part of the Nikea area, and extends from the Mavrovouni basins in the south-west to the Karla basin to the north-east (see also Fig. 2.3). At both ends it borders on the rolling plain (Fig. 2.10), referred to as "Tertiary surface" on the geological map (Fig. 2.7).

Tectonic activity has played a major role in the landscape evolution of the dissected plain. Folding resulted in the drainage pattern described above. Plate 1A presents a fault with a horizontal layer displacement of about 1.5 m. It occurs 1.5 km east of Nikea and is related to the subsiding Larissa (Karla) basin. Plate 1D shows a hard conglomerate sediment about 1.5 km south of Nikea, on the fringe of the studied pilot area. Folding caused strata to dip under an angle of 5 degrees as is visible in the right part of the photo.

A close relation exists between landform and soil material. Marl, for instance, is susceptible to erosion and therefore is often associated with dissected terrain, with a very high drainage intensity (physiographic unit T11; see above). Quaternary deposits are coarser, more



Adopted from I.T.C., 1984. In the inset margins the Nikea pilot area.

Fig. 2.10. The geomorphology of the Middle Thessalic Threshold

permeable and generally more resistant to erosion, especially layers of hard conglomerates. The Quaternary landscape is less dissected, but folded, hard conglomerates may produce a rolling topography with slopes 10% or more (Plate 1D) as in Land unit T12. The ITC map indicates land units T11 and T12 to exist in the north-western part of the area (Fig. 2.10), for which little geological information is available, however. Marl was found there on many hillsides and low hills at elevations up to 125 m ASL. Conglomerates were seen in higher places (up to 200 m ASL). Accordingly, the boundary between Tertiary and Quaternary deposits along the north-western border of the rolling plain (in Fig. 2.7) was designed along the T1-T2 physiographic border line, and indicates the existence or absence of marl deposits.

The tectonic movements in the late Tertiary and early Quaternary led to accelerated erosion and deposition of conglomerates and other fluvio-terrestrial deposits, particularly along the subsidence fronts, where these Plio-Pleistocene deposits attained their greatest depths (see Fig. 2.7). Erosion seems to have been most severe in Land subtype T2. The higher erodibility of these materials is attributed to the absence of hard conglomerates, and the generally low cohesion of the deposits. Land subtype T2 is perhaps formed in an area with younger Pleistocene subsidence, filled up later with sand, clay and gravel from the surrounding uplands. This theory takes into account that both the south-western and north-eastern parts of Land subtype T2 border on the subsided (Mavrovouni and Karla) basins. Dissection in a SW-NE orientation could have produced the main valley system (Land unit T32).

The Nikea area is situated in an undulating to rolling plain with a trellis drainage pattern. It is undulating (Land subtype T2; ITC, 1984); only the south-eastern corner falls within the transition to the rolling plain (Land subtype T1).

Three physiographic units were distinguished in the Nikea area: tops, slopes and valley bottoms. Other than in the ITC legend, footslopes were not lumped together with the valley bottoms but included in the slopes.

Tectonic movements are largely responsible for the shaping of the Nikea area as elsewhere in the region. Erosion varies with soil texture and permeability due to differences in water runoff. Where runoff reaches gravel it ceases or slows down resulting, through inversion of the landscape, in the present undulating plain with Pleistocene gravel on the tops of most summits.

Sandy materials with intercalated gravel layers are extensive in the southern part of the Nikea area. There, the summits have flat tops with gravel at or very close to the surface (see soil map). The horizontal variance of the gravelly materials determined the extent of the summits; their width does rarely exceed 50 m.

Summits with clayey parent materials are present in the northern part of the area. They lack flat tops or have only small ones and are not very different from the slopes. In this case, the vertical variance in parent material has played a major role in the morphology: if the clay layer covers a (thick) gravel layer at less than 10 meters below the top, this may stabilize the top, resulting in a flat to gently undulating surface. It is also possible that the calcic horizon may come so close to the (eroded) surface that it hardens and becomes petrocalcic. This process leads to an even flatter surface.

If the parent material is uniform, one finds the classic arrangement of slopes in the Nikea area, viz. convex at the top, straight in the middle and concave at the lower end (Fig. 2.11b). However, if the parent material is heterogeneous, slope morphology and angle depend on the position and erodibility of individual layers. For example a gravel layer below a more erodible layer will always result in a concave/convex slope pattern. If the lower layer is thick, a rather steep slope may be expected (Fig. 2.11a). In the case of a succession of shoulders (interconnected tops) with alternating thin gravelly and (sandy) clayey layers, the concave/convex slope pattern is repeated, but average slope angles do not exceed 5% (Fig. 2.11c).

The two main valleys in the Nikea area have a SW-NE orientation, similar to the valley orientation of the whole area. The reason for this orientation was explained above.

A number of secondary valleys run perpendicular to the main valley in the southern part of the area (Figs. 2.6 and 2.9). The same phenomenon occurs in the northern part of the undulating plain adjacent to the rolling plain, e.g. the T1-T2 Land subtype transition zone in Fig. 2.10). The orientation of these secondary valleys might be connected with the directions of old (Pleistocene) channels, which conditioned the deposition of parallel strips of clayey materials (which were eroded away) and sandy materials which form the present low hills. This is one more indication that Land subtype T2 is associated with a subsiding depression between the Mavrovouni and Karla basins.

In some secondary valleys of the Nikea area, gravel layers close to the surface cause irregularities in the slope of the valley bottom (Fig. 2.11d and soil map). The possibility that hard conglomerate layers occur at shallow depth below the valley bottom needs further investigation.

Hydrology

Various types of dense drainage pattern can be seen especially in the rolling plain (T1). Drainage intensity is highest in areas with marly deposits (T11). Table 2.2 summarizes drainage intensities of the various landforms (including the low mountains, M), in km of drainage channel per km^2 of mapping unit.

Table 2.2. Drainage intensity in the T Landtype

Mapping unit	Drainage intensity (km/km^2)
T11	4.0 - 5.0 - 6.0
T12	2.5 - 3.0 - 3.5
T13	3.0
T2	1.5 - 2.0
T3	2.5
M	5.0

(Source: Shrestha *et al.*, 1988)

The northern part of the Nikea area drains to the Peneios river. In the south, drainage is westward to the Mavrovouni and the Karla basins. The river Enipeus initiates from the higher ridges on the Chalkidonion mount; it flows westward through the Karditsa basin and debouches into the Peneios river before the latter enters the east Thessaly plain.

Water is scarce in the undulating to rolling plain. The longitudinal valleys transport water only during the winter periods; in the summer months they are dry. Pumped irrigation is possible in these valleys from private deep-water wells. Exploitable aquifers are found only in the Farsala area (Fig. 2.7); these draw on the Enipeus river and allow a total discharge of 0.3-7.9 $m^3h^{-1}m^{-2}$ (Pagonis, 1987).

2.2.3 Vegetation, Land Use and Land Tenure

Until the beginning of the century, cultivation in the Larissa plain was limited to the flat parts. The undulating to rolling areas were colonized by oak forest or used for grazing. In the 1920's, Greek immigrants from Asia Minor migrated to the area and took up farming in the Tertiary hills. Since then, the undulating to rolling surface has been extensively cultivated, and the natural vegetation has disappeared.

The crops grown in the area may be subdivided in rainfed annuals, irrigated annuals and irrigated perennial crops. The present land uses in the dissected plain within the Nikea area are summarized in Table 2.3, which shows that 90 percent of the arable land is used for growing rainfed (winter) annuals.

Rainfed wheat is the main crop in the area. Yields of wheat and barley fluctuate, depending on the yearly rainfall quantity and distribution, the position in the landscape and the soil conditions. Early in the century, average yields of (unfertilized) wheat were 900 kg/ha and less. Today an average of 2.9 t/ha is attained in the Nikea area. The improved "Mexicali" (durum wheat) variety fertilized with 150 kg N/ha and 80 kg P/ha, may produce as much as 4.5 t/ha and more on the best soils of the area. The lowest yields, of some hundreds kilos per hectare are reported for very shallow gravelly soils on summits, known locally as "asprogies"; total crop failure is common on soils with very shallow petrocalcic horizons, known locally as "typhekia". Winter cereals are increasingly grown in rotation with fodder crops, i.e. cow pea (average yield on the slopes 2 t/ha). This practice favours soil structure and fertility.

Table 2.3. Land use data on Nikea.

CROP	Area[*] x1000m^2	Arable land (%)	sowing time	harvesting time	Yield (t/ha) range	(average)
Rainfed wheat	26,895	47.9	Nov.	June	0.0- 4.5	(2.9)
barley	18,355	32.7	Nov.	June	0.0- 4.0	(2.9)
Fodder	5,515	9.8	autumn	May/June	0.5- 3.0	(2.0)
Total rainfed	50,765	90.4				
Irrigated corn	3,300	5.9	April	Sept.	9.0-13.5	(10.0)
cotton	605	1.1	April/May	Oct/Nov.	1.5- 4.5	(2.7)
potatoes	2,110	3.7	March/Aug.	June/Nov.	15.0-20.0	
Grasses+vegetables	100	0.2	spring/autumn			
Almonds	600	1.1			3 kg/tree	
Cultivated area	57,480	102.4				
Mixed cropping	1,380	2.4				
Total arable land	56,100	100.0				
Pastures	2,200					
Rivers, channels	100					
Urban area	2,600					
Total area	61,000					

([*] Source: National Service of Statistics)

Irrigated cultivation of annuals is rare. Cotton and maize are the main irrigated crops followed by potatoes and sugar beets. Maize requires much water for high production (Table 2.3). This crop is found on the lower slopes and valley bottoms, where irrigation water is, at times, available. The commonest cultivars grown are Pioneer 3183 and the Greek hybrid ARIS. Potatoes are also planted on the lower slopes. This crop needs less irrigation water because it is planted early or late in the growing season (Table 2.3) when evapotranspiration rates are lower. Sugar beets were not grown in Nikea until 1981. Today, sugar beets have replaced other crops as grasses, vegetables and orchards, on some deep clayloamy or clayey soils. Cotton is also common. Varieties of Acala are cultivated in the main valley and give reasonable to very good yields (Table 2.3). Even on shallower soils and/or with sub-optimal irrigation management, cotton still gives some yield.

The only irrigated perennial in the Nikea area is almond. It grows on deep soils where the roots can easily penetrate.

The (scarce) water in the dissected plain is pumped up from deep strata with deep-lift pumps, "Gr. pomones". The water is then applied with small or large stationary sprinklers or travelling guns. In the Community of Nikea, water is lifted by 235 water pumps from which 210 are oil-powered and the rest are electric pumps. Discharges range from about 30 to 40 cubic meters per hour. In 1981, the capacity sufficed to irrigate about 550 ha (10% of the cultivated land).

Table 2.4.I presents the number of inhabitants and families of the Nikea Community, and their occupations. The average holding in Nikea is 11 ha, slightly more than the average in the whole Larissa area. Parcel sizes decrease gradually, as land is divided among an increasing number of people (see Table 2.4.II).

Holdings in the undulating/rolling land normally include some "poorer" soils of the higher slopes and tops and some "richer" soils on the lower slopes and valley bottoms. Unfortunately, this configuration is conducive to ploughing perpendicular to the contours.

Table 2.4. Inhabitants and families in Nikea and their occupations.

I. Population of Nikea Community and occupations.

occupation	population	families
Farmers & shepherds	1,710	503
Agricultural factories	225	66
Other jobs	315	93
Total	2,320	662

II. Population increase over the period 1961-81

Year	1961		1971		1981
Population	1,885		1,975		2,250
Change		+4.8%		+13.9%	

(Source: National Service of Statistics, 1987)

2.2.4 Methods

Desk studies

Prior to the field work, topographical and geological maps, reports and other literature about the Middle Thessalic Threshold were collected and studied.

The Nikea area is well documented in the topographical maps of the Greek Army Geographical Service (G.Y.S.) at scales 1:5,000 (sheets 4392/5 and 4391/3) and 1:50,000 (sheet: Larissa). From the same source, black and white air-photos of the study area were obtained (coded 130535 and 130536, scale 1:43,000; and 76466 and 76467, scale 1:20,000).

The geological map sheet of Larissa (1985) includes the Nikea area; the undulating to rolling plain occurs on the sheets Velestino (1983), Platykambos (1981) and Farsala (1969), all at scale 1:50,000, which were supplied by the Greek Institute of Geology and Mineral Exploration (I.G.M.E.).

The ITC-Physiographic Soil Map of the Larissa Area (Van der Meeren and Shrestha, 1984) has a scale 1:100,000. Furthermore, the descriptions of the 835063-69 soil profiles were available, and (old) descriptions of some 10 soil profiles in the area were supplied by the Greek Soil Classification and Cartography Division. All these data were reviewed and gave useful preliminary information on the Middle Thessalic Threshold.

Air-photo Interpretation

Air-photos (1:43,000) of the entire area were studied under the stereoscope to get acquainted with the ITC physiographic legend. The physiographic units identified were delineated on the detailed photos (scale 1:20,000) of the Nikea area. During fieldwork, this preliminary legend was checked and modified. The still smaller scale of these air-photos if compared with the scale of the base maps (1:5,000), limited the use of these air-photos during the field survey (use of small field-stereoscope); they served as a supplementary tool for better comprehension of the surface features of the terrain.

Field methods and map compilation.

After air-photo interpretation, a number of exploratory trips were made to the undulating to rolling plain. Attention was paid to geological build-up, landforms, soils and land use. During this stage, the ITC-map was a very helpful tool. Based on the general knowledge gained, the Nikea area was finally chosen as a pilot area for this study.

The detailed soil survey was carried out in the summer of 1988. A number of cross-sections were made to study the geomorphology of the Nikea area and its relation to the soils. These cross-sections covered various physiographic units identified during air-photo interpretation. Next, the main soil boundaries were delineated on the base maps (G.Y.S. topo-sheets at scale 1:5,000). The complexity made it necessary to frequently correct these boundaries during an intensive field survey, during which some 160 routine augerings -to a depth of 1.20 m (if the soil permitted)- were described; and some 120 observations, made earlier by the Greek Cartography Division Staff, were checked.

The taxonomic units distinguished in the area are illustrated by full descriptions of representative soil profiles, made on freshly dug pits according to the "FAO Guidelines for Soil Descriptions" (FAO, 1977). They are presented in Appendix A.1.

A final soil map with a descriptive legend was compiled at a publication scale 1:10,000.

Laboratory methods

Soil samples were collected and analyzed at the Institute of Soil Mapping and Classification (ISMC), Larissa, for soil texture, pH, organic matter and total calcium carbonate content. For information about the soil fertility level, full chemical analyses were available for a number of representative profiles. These analyses were done by ISMC in support of the ITC survey. The procedures used are:

- Soil texture; hydrometric method, characterization according to the USDA system.
- Organic matter content; Walkley-Black method.
- Soil pH; 1:5 soil-water ratio (glass electrode).
- Total calcium carbonate; Bernard method.
- Electrical conductivity and total soluble salts; Wheatstone bridge (glass electrode).
- Nitrogen content; Kjeldahl method.
- Phosphorus level; Olsen method.
- Total potassium; Dirks-Sheffer method.
- Exchangeable cations (Na, Ca, Mg, and K); Ammonium acetate method.
- Cation exchange capacity (C.E.C.); Ammonium acetate, Flame-photometer for Na and K and titration with EDTA for Ca and Mg.

Infiltration experiments were done in the direct vicinity of the 9 representative soil profiles.

A number of undisturbed soil samples, taken from three of the sites were analyzed for moisture retention characteristics (pF) in Wageningen (Laboratory of Soil Sci. & Geo, WAU). Some more retention curves of representative soils from the vicinity of Nikea were earlier analyzed by ISRIC in support of the ITC research.

Three sites in the Nikea area were sampled for soil mineralogy analysis at the Department of Soil Science and Geology, W.A.U.

Cooperative links

The field work was carried out in cooperation with the Greek Institute of Soil Classification and Mapping, Dept. of Agriculture, Larissa. Three Greek officers participated in the field work: J. Sgouras, M.Sc. (geologist) assisted on the geology of the Nikea and its surrounding areas, and V. Samaras, M.Sc. and V. Diamandas participated in the reconnaissance soil survey of the area. R. Amerlaan, graduate student of the WAU, participated in the soil survey and assisted in some physical measurements and during the map compilation.

2.2.5 Soils.

Genesis and classification

Many Tertiary to old Pleistocene deposits in Greece were modified by landscape inversion during the Holocene and by erosion in recent times (Yassoglou, 1973). Therefore, the landscape surface and the soils of the study area are relatively young.

The high content of calcium carbonate of the soil parent materials and the topography are largely responsible for the genesis and morphology of the "modal soils" of the Nikea area. The high level of carbonate salts delays the translocation of clay in the profile.

In eastern Greece, semi-arid conditions promote a climax vegetation which is conducive to the formation of mollic epipedons (Yassoglou, 1973). A calcic horizon builds up below the mollic epipedon. Its depth varies with its geomorphological position, with the intensities of the effective rainfall and with soil erosion. A cambic horizon may be present between the mollic epipedon and the calcic horizon. Such a typical horizon configuration occurs in Typic Calcixerolls (USDA, 1975) or Calcic Chernozems (FAO, 1988).

In western Greece (with a much higher precipitation), Calcixerolls are formed only on extremely calcareous deposits such as the Tertiary marls. On other materials, pedogenesis is more advanced and marked by the absence of a mollic epipedon and the occurrence of an umbric or an ochric epipedon over an argillic horizon (Alfisols). In the Larissa area, Alfisols have developed in much younger deposits with more stable surfaces, e.g. the Pleistocene "Niederterrasse" and even on the Holocene terraces, etc.

The widespread occurrence of Mollisols in the undulating to rolling plain was recognized long ago. In the early reconnaissance soil map of the Larissa area (Papoutsopoulos and Svorikyn, 1936), these soils were classified as Rendzinas. Some 40 years ago, the organic matter content of the epipedons was commonly in excess of 5% (Giolas, pers. communication), but since the beginning of this century, human activity disturbed the long-established equilibrium in the area. Large scale deforestation and intensive cultivation of the undulating and rolling land was initiated in the 1920's (see earlier). This resulted in a dramatic decrease of the organic matter contents which came down to the present level (< =2.5 percent) because of oxidation, wind erosion and frequent burning of crop residues. A new equilibrium has probably not yet been reached.

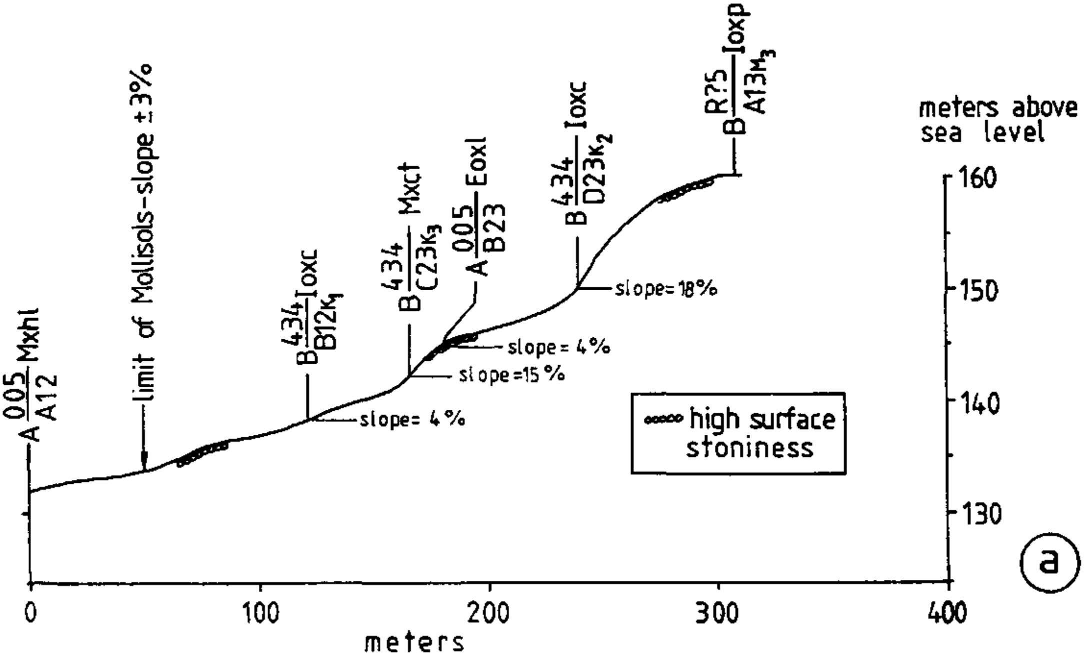
Apart from lowering the organic matter content, intensive cultivation accelerated erosion. Considerable areas on the upper slopes and shoulders are eroded. Today, mollic epipedons can hardly be found on the slopes of the Nikea area.

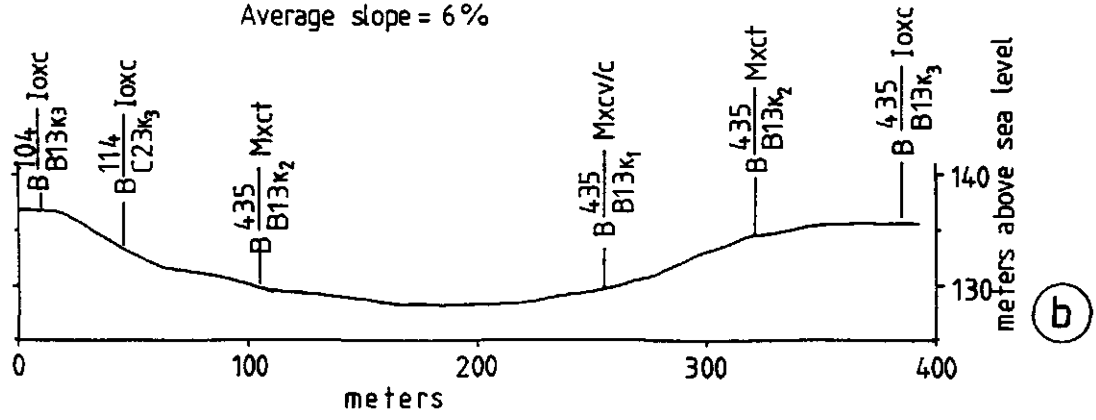
In the northern and western parts of the area, the soils are finer textured, less permeable and more erodible. Generally, the mollic epipedon has disappeared here, and the cambic or the calcic horizon became exposed (shallow Calcixerollic Xerochrepts). In the southern and eastern parts of the area, however, coarser (gravelly) deposits predominate which are more permeable (less runoff) and more resistant to erosion. The soils on middle slopes and on some of the tops in this area are dark but either not dark enough or not deep enough to have a mollic epipedon. Accelerated erosion seems to have taken place only on the higher slopes and shoulders; Calcixerolls occur on concave and lower slopes.

Cross-section B-B' (Fig. 2.11b) shows the geomorphology-soils relation without or with little variation in the parent material. Shallow Calcixerollic Xerochrepts are abundant on convex slopes near top sections. More downslope, the depth to the calcic horizon increases. In the same direction, the A-horizons become darker and thicker. On the lower slopes, they meet the requirements for a mollic epipedon (Typic Calcixerolls). Typic Calcixeroll is believed to be the "modal" soil of the area.

If the parent material is not uniform, the relation is complex as apparent from cross-section A-A' (Fig. 2.11a). In the convex parts of these slopes one finds very shallow skeletal soils (Lithic Xerorthents) associated with shallow Calcixerollic Xerochrepts. The latter are indigenous to the convex and straight upper slopes.

The soils of the tops are conditioned by the geomorphology, but less clearly than those on the slopes. The relation between interconnected tops is clearer and explained with cross-section C-C' (Fig. 2.11c). This cross-section shows the same parent material-geomorphology-soils relations as prevail in the areas of the slopes, with two differences. The variation in the slope angles and forms is less wide and more strongly related to the exposition of these units.


A 005/A12 Mxhl
limit of Mollisols-slope ±3%
B 434/B12K1 Ioxc
B 434/C23K3 Mxct
A 005/B23 Eoxl
B 434/D23K2 Ioxc
B R?5/A13M3 Ioxp
meters above sea level
160
150
140
130
slope= 4%
slope=15 %
slope= 4%
slope= 18%
high surface stoniness
a
0
100
200
300
400
meters


Average slope = 6 %
B 104/B13K3 Ioxc
B 114/C23K3 Ioxc
B 435/B13K2 Mxct
B 435/B13K1 Mxcv/c
B 435/B13K2 Mxct
B 435/B13K3 Ioxc
meters above sea level
140
130
b
0
100
200
300
400
meters

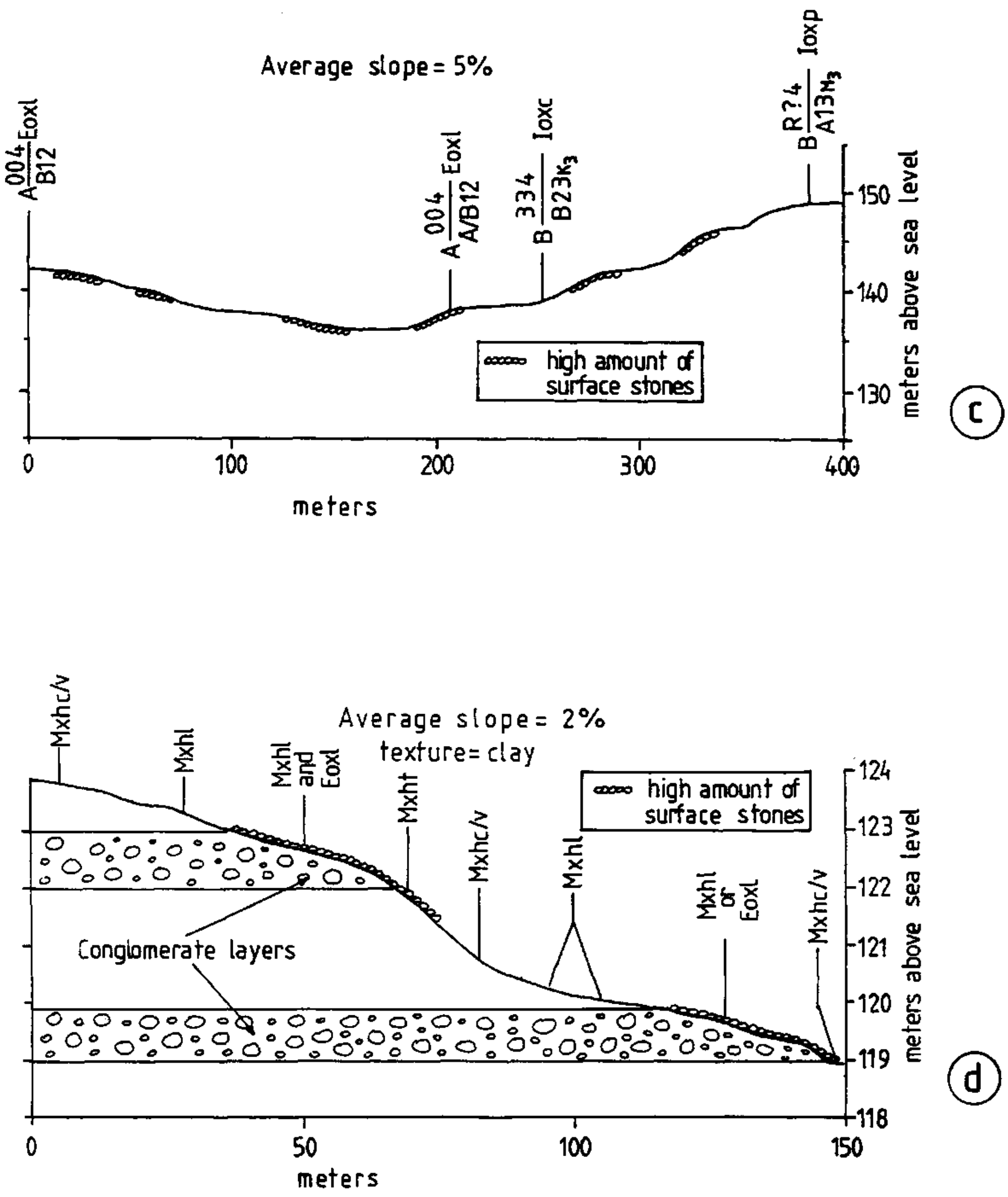


Fig. 2.11. Soils along the cross-sections A-A' (a), B-B' (b), C-C' (c) and D-D' (d). The Greek mapping unit code is used (see Fig. 2.12). The occurrence of a calcic or petrocalcic horizon is additionally indicated by K or M, respectively, whereas their depth may be (1) below 75 cm, (2) between 40 and 75 cm, or (3) within 40 cm from the soil surface.

Calcic horizons which are at or close to the surface can harden to petrocalcic horizons. In permanently dry circumstances, soft calcic horizons do not change due to lack of water; in permanently wet circumstances they remain static due to lack of CO_2. Hardening can only take place under conditions of alternating wetting and drying and in the presence of sufficient CO_2. Such conditions prevail at or close to the surface; deeper in the profile hardening is very slow, if it occurs at all. Soils with petrocalcic horizons are mostly Petrocalcic Xerochrepts. Mollisols with petrocalcic horizons (Petrocalcic Palexerolls) are too few in the study area to be recorded on the map. Some were found near the margins of the study area, in places with a deep petrocalcic horizon (Plate 2D).

The formation of thick petrocalcic horizons takes a long period of time (Elbersen, 1982). The thick petrocalcic horizons found outside the study area are probably formed by subsurface throughflow of $CaCO_3$ rich water, thickening the petrocalcic horizon from above rather than from below. This explains also why petrocalcic horizons occur in spots, not only on the tops, but also at lower positions in the landscape (see soil map).

The valleys in the study area are covered with fine-textured materials, carried down from higher positions by surface erosion ("mass flow"). The soils are calcareous but with a lower calcium carbonate content than the soils on slopes and tops, and are comparatively rich in organic matter. Generally, the calcium carbonate contents of soils in the study area are inversely proportional to their organic matter content. Smectites dominate the clay fraction, and the soils exhibit vertic properties, particularly those of the main valleys. Slickensides are common at some depth; these soils are classified as (Typic) Chromoxererts. In slightly higher positions and in the bottom areas of secondary valleys, one might find Vertic Calcixerolls and Vertic-Cumulic Calcixerolls, respectively. The latter soils have a thicker A-horizon and a finer texture than the Mollisolls of the lower slopes (Typic Calcixerolls). The existence of conglomerate layers in the higher parts of some secondary valleys had an important effect on the geomorphology and pedology of the valley (cross-section D-D', Fig. 2.11d).

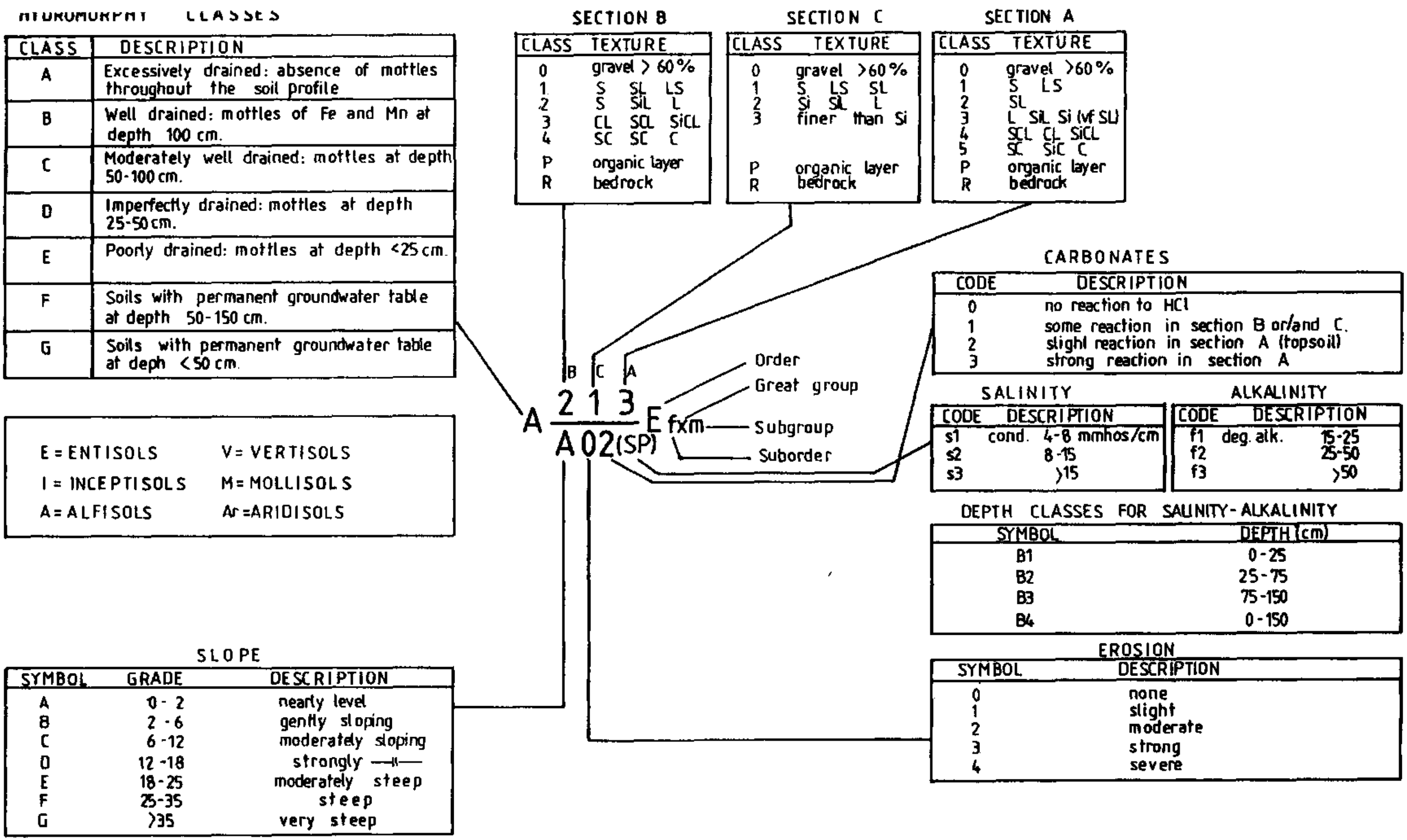
Systematics and nomenclature

During the field work, the official Greek pedon code was used (Yassoglou *et al.*, 1964). Pedon codes contain information about drainage conditions, textures at 3 depths, slope class, erosion *in situ*, carbonate content and special properties like salinity and alkalinity etc. and their depth, and the taxonomic Subgroup (USDA, 1975). An example of a mapping unit code and its explanation is presented in Fig. 2.12.

This system is currently being used for soil mapping in Greece. In the final compilation of the Nikea soil map, this code is not used; the mapping units would in part be too small to accommodate symbols with 10 digits.

Here, the legend of the soil map distinguishes at the highest level between physiographic positions, viz. (1) soils on the tops, (2) soils on the slopes, and (3) soils in the valley bottoms. This subdivision is justified by the importance of the physiography for soil formation. Another advantage is that slope grade and erosion symbols can be omitted. For example, soils in the valley bottoms belong to only one erosion and slope class (class 0 and class A respectively- see Fig. 2.12). Soils on the tops, due to landscape stability, exhibit only slight erosion (class 1) and have a slope class A (flat or nearly flat) or B/A (slope angle 1-4% undifferentiated).

To ensure that the map can be consulted for correlation purposes, etc., further subdivision at lower levels is based on taxonomic classification. In line with the Greek system, the Soil Taxonomy (USDA, 1975) has been used. The physiographic units are subdivided in a number



HYDROMORPHY CLASSES

CLASS	DESCRIPTION
A	Excessively drained: absence of mottles throughout the soil profile
B	Well drained: mottles of Fe and Mn at depth 100 cm.
C	Moderately well drained: mottles at depth 50-100 cm.
D	Imperfectly drained: mottles at depth 25-50 cm.
E	Poorly drained: mottles at depth <25 cm.
F	Soils with permanent groundwater table at depth 50-150 cm.
G	Soils with permanent groundwater table at deph <50 cm.

E = ENTISOLS
V = VERTISOLS
I = INCEPTISOLS
M = MOLLISOLS
A = ALFISOLS
Ar = ARIDISOLS

SLOPE

SYMBOL	GRADE	DESCRIPTION
A	0 - 2	nearly level
B	2 - 6	gently sloping
C	6 - 12	moderately sloping
D	12 - 18	strongly —"—
E	18 - 25	moderately steep
F	25-35	steep
G	>35	very steep

SECTION B

CLASS	TEXTURE
0	gravel > 60 %
1	S SL LS
2	S SiL L
3	CL SCL SiCL
4	SC SC C
P	organic layer
R	bedrock

SECTION C

CLASS	TEXTURE
0	gravel >60 %
1	S LS SL
2	Si SiL L
3	finer than Si
P	organic layer
R	bedrock

SECTION A

CLASS	TEXTURE
0	gravel >60 %
1	S LS
2	SL
3	L SiL Si (vf SL)
4	SCL CL SiCL
5	SC SiC C
P	organic layer
R	bedrock

CARBONATES

CODE	DESCRIPTION
0	no reaction to HCl
1	some reaction in section B or/and C.
2	slight reaction in section A (topsoil)
3	strong reaction in section A

SALINITY

CODE	DESCRIPTION
s1	cond. 4-8 mmhos/cm
s2	8-15
s3	>15

ALKALINITY

CODE	DESCRIPTION	
f1	deg. alk.	15-25
f2		25-50
f3		>50

DEPTH CLASSES FOR SALINITY-ALKALINITY

SYMBOL	DEPTH (cm)
B1	0 - 25
B2	25 - 75
B3	75 - 150
B4	0 - 150

EROSION

SYMBOL	DESCRIPTION
0	none
1	slight
2	moderate
3	strong
4	severe

Fig. 2.12. An example of a soil mapping unit code used in Greece and its explanation. [Note that Section A is the topsoil (0-25 cm); Section B is the subsoil (25-75 cm); and Section C is the "substratum" (75-150 cm)].

of mapping units whose codes reflect the taxonomic Soil Order: I for Inceptisols, M for Mollisols, V for Vertisols and E for Entisols. Suborder and Great Group identifiers could be omitted as only one Great Group per Soil Order is present in the Nikea Area, viz. Xerochrepts (I), Calcixerolls (M), Chromoxererts (V) and Xerorthents (E). Next, a code for the Subgroup is added: l for lithic, p for petrocalcic, c for calcixerollic, t for typic, v for Vertic and v/c for Vertic-Cumulic.

Soils are grouped in associations if the variation in parent material cannot be distinguished at the present scale. Associations are common on interconnected tops and shoulders, where superimposed clay and gravel layers come close to the surface, and one finds deep clayey and very shallow gravelly soils within a distance of some 10 m.

The soil mapping symbols are summarized below.

Physiography	
1	soils of the tops
2	soils of the slopes
3	soils of the valley bottoms

Soil Order	
I	Inceptisols
E	Entisols
M	Mollisols
V	Vertisols

Subgroup	
c	calcixerollic
l	lithic
t	typic
v	vertic
v/c	vertic/cumulic
p	petrocalcic

Calcixerollic Inceptisols are further subdivided as follows:

Calcic horizon		Texture	
c	within 40 cm	3[a]	sandy clay loam
d	deeper than 40 cm	4[a]	clay

([a]in line with the Greek pedon code; see Fig. 2.12)

The soil legend for the Nikea Area (key to the soil map)

1. Soils of the tops

1Ic3	Gravelly, sandy (clay)loam soils, having a shallow calcic horizon.
1Ip	(Sandy) clayloam soils, having a shallow petrocalcic horizon.
1El	Very shallow, very gravelly, loamy soils.
1I/E	Association of gravelly sandy (clay)loam soils, having a shallow calcic horizon, and very shallow, very gravelly soils.
1Ic4	Clay soils, having a shallow calcic horizon.

2. Soils of the slopes

2El	Very shallow, extremely gravelly soils.
2Ic3	Very shallow, gravelly, sandy (clay)loam soils having a calcic horizon within 40 cm from the surface.
2Ic4	Very shallow, clay soils, having a calcic horizon within 40 cm from the surface.
2I/E	Association of gravelly soils having a shallow calcic horizon, and very shallow, very gravelly soils.
2Id3	Somewhat gravelly, moderately deep and fine textured soils.
2Id4	Moderately deep, fine textured soils.
2Iv	Moderately deep, clay soils having vertic properties.
2Mt	Moderately deep, dark, clay soils.
2fIp	Shallow, fine-textured soils, having a petrocalcic horizon.
2fI/E	Association of clay soils having a calcic horizon, and shallow, very gravelly, clayloamy soils.

3. Soils of the valley bottoms

3Vt	Strongly swelling clay soils.
3Mv	Moderately deep, dark, clay soils having vertic properties.
3Mv/c	Deep, dark, cracking clay soils.
3Iv	Cracking clay soils.
E/M	Association of dark, very shallow and gravelly soils and dark, deeper, gravelly clay soils.

Soils of the tops

The soils of the tops cover 8.38% of the Nikea area, or 152.1 ha, and are divided in 5 mapping units.

Unit 1Ic3; gravelly, sandy (clay)loam soils, having a shallow calcic horizon.

Extent: 6.6 ha, 0.4% of the area, 4.3% of the tops.
1/334
Pedon code: B-------- Ioxc
A/B13
Parent material: Pleistocene fluvio-terrestrial calcareous, reddish to yellowish brown clayey sands and intercalated gravel layers with pebbles of variable composition and diameter.
Relief: Flat to very gently undulating (slope 0-3%).
Erosion: Slight surface wash; soils are somewhat susceptible to sealing.
Stoniness: Usually gravelly and stony surface.
Land use: Spring wheat and fodder crops (cow pea) in rotation.
Soils, general: Well drained, shallow, very calcareous, gravelly soils with a calcic horizon within 40 cm from the surface; an Ap-Ck horizon sequence, normally with a transitional (in colour) AC horizon that extends from 20 cm to 30-45 cm from the surface. Fine pores and roots are found to a depth of 55-60 cm;
colour: dark brown to dark yellowish brown (10YR 3.5/3-3/4) in the Ap horizon grading into light yellowish brown (10YR 6/4) in the Ck horizon;
texture: gravelly, sandy clayloam to sandy loam; range: 18-25% clay, 24-28% silt, 51-56% sand, gravel up to 30% and occasionally 50% (by volume);
structure: Ap horizon: moderate, fine, subangular blocky; AC (if any) and Ck: weak, fine, subangular blocky in the upper part to structureless below;
consistence: slightly sticky (wet), friable (moist), hard to very hard and occasionally slightly hard (dry) in the topsoil grading to non sticky (wet), friable (moist), and soft (dry) at some depth with increasing calcium carbonate content;
chemical properties: very calcareous topsoil over extremely calcareous subsoil. The total $CaCO_3$ is around 30% in the Ap and exceeds 45% in the calcic horizon (Fig. 2.13a). pH-H_2O ranges between 8.1 and 8.4. The organic matter content is 1.6% or more in the Ap horizon and decreases gradually with depth. For more chemical properties see Table 2.5(a);
mineralogy: the relative amount of clay minerals present is 41-55% smectite, and 11-25% each one of kaolinite, mica and vermiculite.
Diagnostics: Ochric epipedon, calcic horizon; the Ap horizon is either not dark enough or not deep enough to meet the requirements of a mollic epipedon. The calcic horizon includes calcium carbonate nodules (up to 2 cm in diameter) and soft powdery forms and pendants underneath pebbles. Occasionally the Ap and/or AC horizons extend into the calcic horizon.
Soil classification: USDA (1975), Calcixerollic Xerochrepts.
FAO/Unesco (1988): Haplic Calcisols.
Bordering units: 2El, 2I/E and 2Ic.
Remarks: see soil profile P6 (Plate 3A) in Appendix A.1.

Unit 1Ip; (sandy) clayloam soils, having a shallow petrocalcic horizon.

Extent: 33.6 ha, 1.9% of the area, 22.1% of the tops.
R.4
Pedon code: A----- Ioxp
A23
Parent material: Pleistocene, calcareous, (sandy) clayey deposits.
Relief: Flat or almost flat (slope 0-2%).
Erosion: Slight sheet erosion.

Stoniness: High surface stoniness with large fragments of broken petrocalcic horizon (where ploughed with heavy machinery at the surface.

Land use: Fallow or wheat with extremely low productivity.

Soils, general: Well to excessively drained, very shallow soils with an A(p)-Cmk horizon sequence and fragments of petrocalcic horizon as surface stoniness. The petrocalcic horizon (Cmk) occurs deeper than 30-50 cm;

colour: dark yellowish brown to yellowish brown (10YR 4/4-4/6 to 5/4);

texture: variable, from sandy loam to clayloam;

structure: weak, medium, subangular to angular blocky;

consistence: non to slightly sticky (wet), friable to very friable (moist), slightly hard (dry);

chemical properties: very calcareous; the $CaCO_3$ content exceeds 30% (pH-H_2O is about 8.0). The organic matter content is relatively high in the A(p) horizon but decreases strongly with depth. For more properties see Table 2.5(b).

Diagnostics: Ochric epipedon (A(p)), petrocalcic horizon (Cmk).

Classification: USDA (1975): Petrocalcic Xerochrepts.

FAO/Unesco (1988): Petric Calcisols.

Bordering units: 2Ic, 2I/E and 1I/E.

Remarks: Petrocalcic horizons are not always continuous; in places broken by heavy machinery. The soils are locally called "typhekia".

Table 2.5. Indicative chemical properties of soil units 1Ic3 and 1Ip.

Depth	Ec	OM	N	P	K	Tot.Ca	CEC	Na	Ca	Mg	K
cm	mmho	%	ppm	ppm	%	%	<------ cmol(+)/kg ------->				
a. Unit 1Ic3											
0-20	<3	1.64	1030	11.0	0.8	26.5	24.8	0.35	12.8	13.2	0.2
20-35	<3	0.93	750	2.0	0.9	29.8	28.6	0.25	17.5	7.7	0.2
35-60	<3	0.85	659	2.0	0.5	43.3	24.2	0.25	11.3	8.6	0.2
b. Unit 1Ip											
0-12	<3	2.65	3113	56.0	0.6	31.0	21.5	0.25	14.3	2.9	0.2
12-35	<3	0.60	469	6.5	1.8	32.3	12.1	0.35	6.0	3.4	0.2

(Source: ITC, 1984; sites 835065 (a) and 835063 (b)).

Unit 1El; very shallow, very gravelly soils.

Extent: 27.6 ha, 1.5% of the area, 18.2% of the tops.

003
Pedon code: A------Eoxl
A13

Parent material: Pleistocene, thin gravel deposits with mostly rounded pebbles of variable composition and diameter.

Relief: Nearly level; slopes 0-2%.

Erosion: Slight sheet erosion.

Stoniness: Very gravelly and stony at the surface.

Land use: Fallow-wheat rotation; very low yields.

Soils, general: Excessively drained, very shallow, gravelly soils with a lithic contact (conglomerate) usually deeper than 20 cm (horizon sequence: A(p)-R);

colour: brown surface soil (10YR 4/3); yellowish brown at some depth;

texture: loam or sandy clayloam to sandy loam; for range see unit 1Ic3;

structure: n.d.;

consistence: slightly sticky (wet), friable to very friable (moist), slightly hard (dry) top soil.

Diagnostics: Ochric epipedon, lithic contact.
Classification: USDA (1975): Lithic Xerorthents;
FAO/Unesco (1988): Lithic Leptosols.
Bordering units: 1 I/E, 2I/E, and 2El.
Remarks: Calcium carbonate dissolved from the parent material and reprecipitated as semi-continuous pendants under pebbles. The soils are locally called "asprogies".

Unit 1I/E; association of gravelly sandy (clay)loam soils, having a shallow calcic horizon, and very shallow, very gravelly soils.

Extent: 65.5 ha, 3.6% of the area, 43.1% of the tops.
1/334 004
Pedon codes: B--------Ioxc, A------ Eoxl,
B13 A23
Parent material: See unit 1Ic3.
Relief: Almost flat to gently undulating (slope 1-4%). The unit occurs on interconnected tops (shoulders).
Erosion: Slight to moderate sheet erosion. This unit is severely eroded; erosion slowed down when highly resistant conglomerate layers became exposed at the surface.
Stoniness: Locally very gravelly; stony surface.
Land use: Wheat.
Soils, general: (I): Well drained, medium to finely textured soils with shallow calcic horizon and an horizon sequence as in unit 1Ic3; and (E): excessively drained, very shallow, very gravelly loam soils with a lithic contact deeper than 20 cm;
colour: brown (10YR 4.5/3); yellowish brown at some depth;
texture: (I) loam to clayloam, (E) sandy loam to sandy clayloam;
structure: the deeper soils (I) have a weak to moderate, fine subangular blocky structure in the topsoil and a structureless subsoil (see also unit 1Ic3);
consistence: slightly sticky (wet), friable (moist); slightly hard in the topsoil and soft in the subsoil (dry);
chemical properties: (I): very calcareous with 20-30% calcium carbonate in the topsoil and 30-40% or more in the calcic horizon (see Fig. 2.13a); the pH-H_2O ranges between 7.7 and 8.0. The organic matter content >=1.5% in the topsoil and decreases regularly with depth. (E): calcareous; $CaCO_3$ content is 15-20%. The organic matter content >=2.5% in the topsoil and decreases sharply with depth;
For mineralogy see unit 1Ic3.
Diagnostics: (I): A(p) Ochric epipedon, Ck or A(p) over and AC (see also unit 1Ic3)
(E): Ochric epipedon, lithic contact.
Classification: USDA (1975): Calcixerollic Xerochrepts (I) and Lithic Xerorthents (E), in association.
FAO/Unesco (1988): Association of Haplic Calcisols and Lithic Leptosols.
Bordering units: 1El, 2El, 2I/E and 2Ic.
Remarks: see cross-section D-D' (Fig. 2.11d).

Unit 1Ic4; clay soils, having a shallow calcic horizon.

Extent: 18.8 ha, 1.04% of the area, 12.4% of the tops.
435
Pedon code: B--------Ioxc
A/B23
Parent material: Pleistocene, calcareous, clayey deposits.
Relief: Almost flat to gently undulating (slope 1-4%).
Erosion: Moderate sheet wash; some rill formation.
Stoniness: Absent or almost absent.
Land use: Wheat in rotation with cow pea. Exceptionally cotton or sugar beets.
Soils, general: Well drained soils with a calcic horizon within 40 cm from the surface; an

Ap-Ck horizon sequence, usually with a transitional AC horizon extending from 20 to 30-40 cm depth;
colour: brown topsoil (10YR 4/3) changing to yellowish brown (10YR 5/4) below;
texture: clay throughout, (45-63% clay, 17-27% silt, 16-28% sand);
structure: weak to moderate, fine, subangular blocky;
consistence: Sticky (wet), friable (moist), slightly hard to hard (dry);
chemical properties: calcareous topsoil ($CaCO_3$=12-20%, pH-H_2O>=7.5) over very calcareous subsoil ($CaCO_3$=45-55% in the Ck; pH up to 8.3). The organic matter content of the topsoil is about 1.5%, and decreases regularly with depth.
Diagnostics: Ochric epipedon (Ap), calcic horizon (Ck and occasionally AC or Ap).
Classification: USDA (1975): Calcixerollic Xerochrepts.
FAO/Unesco(1988): Haplic Calcisols.
Bordering units: 2El, 2Ic and 2I/E.

Soils of the slopes

The soils of the slopes occupy 67.0% of the area, or 1,215.3 ha, and are subdivided in 10 mapping units.

Unit 2El; very shallow, extremely gravelly soils.

Extent: 8.0 ha, 0.44% of the area, 0.7% of the slopes.
003
Pedon code: A------Eoxl
E33
Parent material: See Unit 1El.
Relief: Moderately steep to steep convex or straight upper slopes.
Erosion: Moderate sheet erosion.
Stoniness: Very stony.
Land use: Fallow-wheat rotation (extremely poor performance).
Soils general: See unit 1El.
Diagnostics: Ochric epipedon, lithic contact.
Classification: USDA (1975): Lithic Xerorthents; FAO (1988): Lithic Leptosols.
Bordering units: Upper limit: 1El; Lower limit: 2I/E, 2Ic and 2Id.
Remarks: This unit has a general southeastern orientation. See also remark for unit 1El.

Unit 2Ic3; very shallow, gravelly, sandy (clay)loam soils, having a calcic horizon within 40 cm from the surface.

Extent: 177.9 ha, 9.8% of the area, 14.6% of the slopes.
1/334
Pedon code: A/B---------Ioxc
C/D23
Parent material: Same as in unit 1Ic3.
Relief: Rolling; higher slopes steep and convex (grade 6-12%).
Erosion: Moderate sheet and slight rill erosion. High erodibility due to surface crusting.
Stoniness: Moderate and locally high surface stoniness.
Land use: Wheat and cow pea in rotation. Very rarely cotton with supplementary irrigation.
Soils general: Well to excessively drained, very shallow, very calcareous gravelly soils with a calcic horizon shallower than 40 cm. Horizon sequence as in 1Ic3, normally with a transitional AC horizon. Rooting depth typically less than 50 cm;
colour: dark yellowish brown (10YR 4/3-4/4) topsoil over yellowish to light yellowish brown (10YR 5/4-6/6) below;
texture: sandy loam to sandy clayloam (for range see unit 1Ic3); estimated gravel content 10-15% (by volume);
structure: mod. fine to medium, subangular blocky A(p) over structureless Ck horizon;

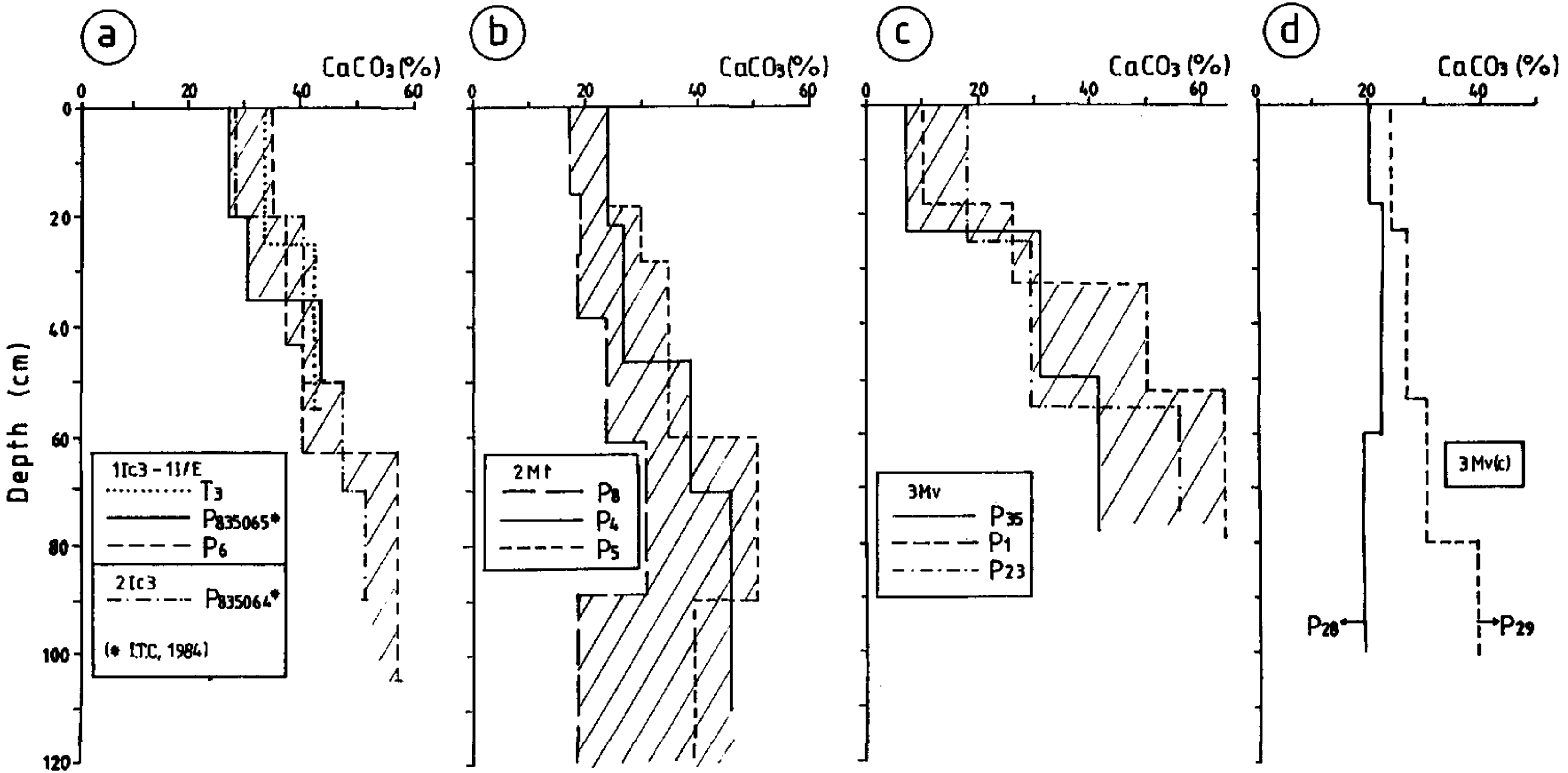


Fig. 2.13. The distribution of calcium carbonate in some Nikea soils: (a) sandy (clay)loamy Calcixerollic Xerochrepts, (b) Typic Calcixerolls, (c) Vertic Calcixerolls, and (d) Vertic-Cumulic Calcixerolls.

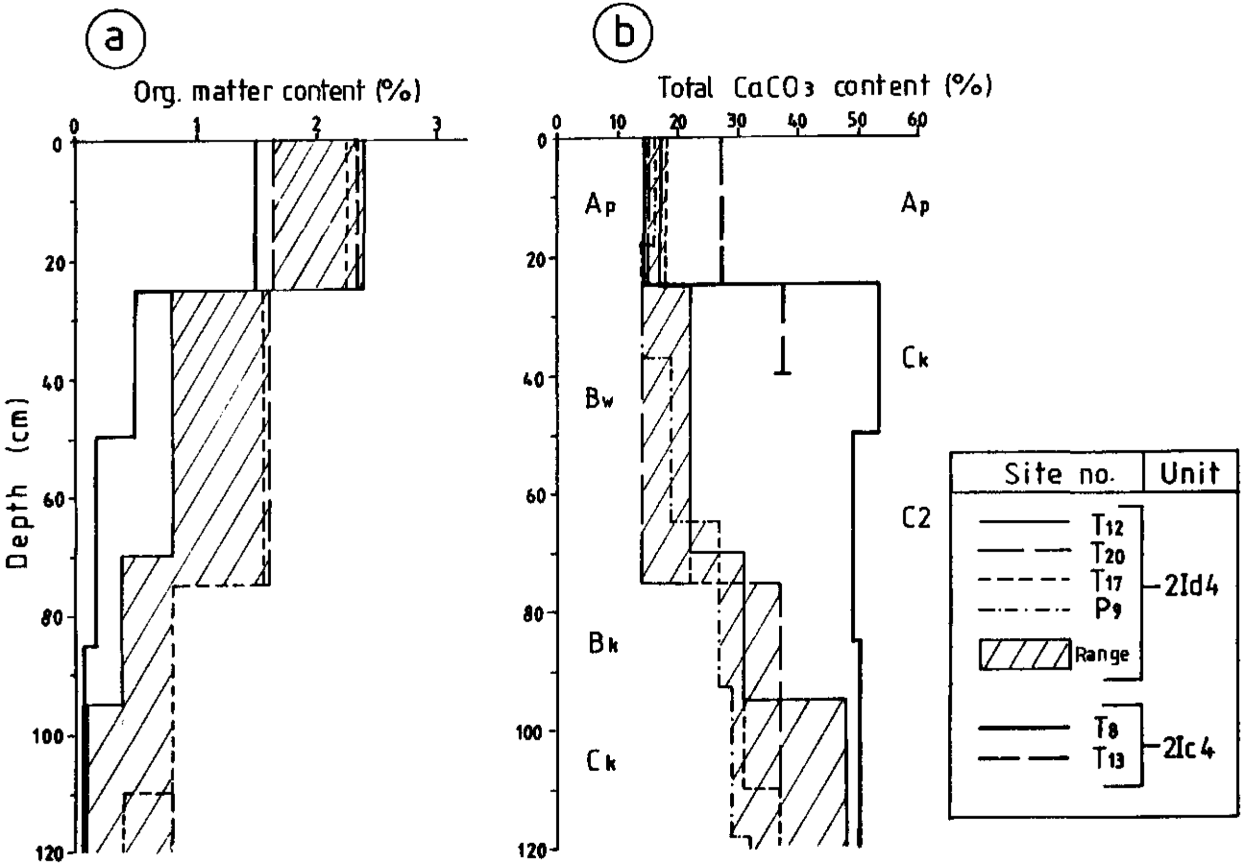


Fig. 2.14. Percentage of organic matter (a), and calcium carbonate (b) as functions of depth in finely textured Calcixerollic Xerochrepts of the Nikea slopes (2Ic4, i.e. shallow counterparts on the upper slopes, and 2Id4, i.e. deeper soils on the lower slopes).

consistence: as in unit 1Ic3;
chemical properties: very calcareous soil with a calcium carbonate content around 30% in the A(p) horizon which increases rapidly with depth to 45% or more in the Ck horizon ($pH-H_2O=8.1-8.4$). The organic matter content is about 1.6% and decreases regularly with depth. For more chemical properties see Table 2.6;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, and 11-25% each one of kaolinite, mica and vermiculite.
Diagnostics: Ochric epipedon, calcic horizon. Unlike in unit 1Ic3, the Ap horizon is part of the calcic horizon, as soft powdery calcium carbonate occurs at the soil surface. Moreover, the Ap is lighter in colour than in unit 1Ic3.
Classification: USDA (1975): Calcixerollic Xerochrepts;
FAO (1988): Haplic Calcisols.
Bordering units: Upper boundary: 1Ic, 1Ip, 1I/E, 2El, and 2I/E.
Lower boundary: 2Mt and 2Id.
Remarks: The soils of this unit are conditioned by severe erosion and surface crusting.

Unit 2Ic4; very shallow, clay soils, having a calcic horizon within 40 cm from the surface.

Extent: 131.0 ha, 7.2% of the area, 10.8% of the slopes.
435
Pedon code: B---------Ioxc
B/C13
Parent material: Pleistocene, calcareous, clayey deposits.
Relief: Undulating; convex and straight upper slopes.
Erosion: Some sheet erosion.
Stoniness: Low surface stoniness.
Land use: Wheat; occasionally cotton.
Soils general: Well drained, shallow, very calcareous, finely textured soils with an Ap (0-25 cm)-Ck horizon sequence; maximum rooting depth is 50 cm;
colour: normally dark yellowish brown (10YR 4/3) in the Ap horizon, over yellowish brown (10YR 5/4) in the upper parts of the Ck horizon;
texture: clay throughout; silt 21-27%, clay 40-63%;
structure: moderate, medium, subangular blocky topsoil;
consistence: the Ap horizon is slightly hard (dry), friable (moist), sticky (wet); the Ck horizon is soft (dry), friable to very friable (moist), and slightly sticky (wet);
chemical properties: very calcareous; $CaCO_3$ is 14-27% or more in the Ap horizon and increases sharply with depth to more than 35% in the Ck horizon (often up to 50%). The organic matter content is 1.5% in the Ap horizon and decreases with depth (see also Fig. 2.14);
Diagnostics: Ochric epipedon (Ap), calcic horizon (Ck).
Classification: USDA (1975): Calcixerollic Xerochrepts;
FAO/Unesco (1988): Haplic Calcisols.
Bordering units: Upper boundary: 2Ic3 and 1Ip. Lower boundary: 2Mt and 2Id4.

Table 2.6. Indicative chemical properties of soil unit 2Ic3.

Depth	Ec	OM	N	P	K	Tot.Ca	CEC	Na	Ca	Mg	K
cm	mmho	%	ppm	ppm	%	%	<------	cmol(+)/kg			------->
0-20	<3	1.84	1064	7.5	0.9	28.8	26.9	0.20	17.5	7.1	0.2
20-50	<3	0.94	336	8.5	0.6	39.5	28.6	0.20	21.1	2.3	0.2
50-70	<3	0.54	347	6.5	0.3	47.0	17.6	0.25	11.0	3.5	0.2
70-85	<3	0.20	313	4.5	0.2	51.2	-	0.20	6.9	4.6	0.2

(Source: ITC, 1984; site 835064).

Unit 2I/E; association of gravelly soils having a shallow calcic horizon, and very shallow, very gravelly soils.

Extent: 256.2 ha, 14.2% of the area, 21.1% of the slopes.
1/334 003
Pedon codes: A ------- Ioxc, A ------ Eoxl
D23 D23
Parent material: See unit 1Ic3.
Relief: Rolling to moderately steep with convex and straight slopes, and in some places gently sloping with concave slopes (cross-section A-A').
Erosion: Moderate sheet and slight rill erosion. Evidence of surface crusting.
Stoniness: Moderate to high surface stoniness, variable over short distances.
Land use: Wheat, in places rotated with cow pea.
Soils, general: (I): Shallow, well to excessively drained, very calcareous clayloam soils with calcic horizon within 40 cm from the surface and an Ap(k)-Ck horizon sequence; and (E): excessively drained, very shallow, gravelly loamy soils with a conglomerate layer at shallow depth;
colour: brown (10YR 4-4.5/3);
texture: (I) loam to clayloam, (E) sandy loam to sandy clayloam;
structure: (I): weak to moderate, fine, subangular blocky structure in the topsoil and structureless at some depth;
consistence: slightly sticky (wet), friable (moist); topsoil is slightly hard (dry) and soft at some depth.
Diagnostics: (I) Ochric epipedon, calcic horizon;
(E) Ochric epipedon, lithic contact.
Classification: USDA (1975): (I) Calcixerollic Xerochrepts; (E) Lithic Xerorthents;
FAO/Unesco (1988): (I) Haplic Calcisols; (E) Lithic Leptosols.
Bordering units: Upper boundary: 1EI, 1I/E, and 2EI.
Lower boundary: 2Ic and 2Id.
Remarks: See cross-sections A-A' and C-C' (Figs. 2.11a&c).

Unit 2Id3; somewhat gravelly, moderately deep and fine-textured soils.

Extent: 40.4 ha, 2.2% of the area, 3.3% of the slopes.
334
Pedon code: B-------- Ioxc
B/C23
Parent material: See Unit 1Ic3.
Relief: Undulating, straight middle and lower slopes (grade 2-8%).
Erosion: Moderate sheet wash and some rill erosion. Evidence of crusting.
Stoniness: Moderate surface stoniness.
Land use: Wheat; exceptionally irrigated cotton.
Soils general: Well drained, moderately deep, calcareous, medium to fine-textured soils. No profile description available;
colour: dark yellowish brown (10YR 4/3) in the surface soil to yellowish brown (10YR 5/4-5/6) at some depth;
texture: homogeneous clayloam or sandy clayloam (field test). The gravel content may reach 10% (by volume);
structure: moderate to strong, fine to coarse, subangular blocky;
consistence: slightly hard (dry), friable (moist), slightly sticky (wet).
Diagnostics: Ochric epipedon, calcic horizon, and (possibly) a cambic horizon (Bw).
Classification: USDA (1975): Calcixerollic Xerochrepts;
FAO (1988): Haplic Calcisols.
Bordering units: Upper boundary: 2Ic and 2I/E.
Lower boundary: 2Iv, 2Mt, 3Iv,3Vt and 3Mv.

Unit 2Id4; moderately deep, fine-textured soils.

Extent: 346.1 ha, 19.1% of the area, 28.5% of the slopes.
434/5
Pedon code: B---------Ioxc
B/C 13
Parent material: Pleistocene, calcareous, finely textured deposits.
Relief: Undulating, straight to concave middle and lower slopes (2-6%).
Erosion: Some sheet wash.
Stoniness: Low to moderate surface stoniness.
Land use: Wheat and exceptionally irrigated cotton or potatoes.
Soils general: Well drained, relatively deep, slightly gravelly, fine-textured soils with a calcic horizon deeper than 40 cm. Horizon sequence is A-B-Ck; horizon A is the plow layer (Ap, 0-18/30 cm) or in some cases an Ap (0 to 18-25 cm) over an Ah horizon (down to 30-40 cm); the relatively thick, structural B horizon may extend down to 100 cm. A transitional B/C horizon may be present. Very fine and fine interstitial pores (few in the topsoil); roots were detected down to 118 cm from the surface;
colour: dark yellowish brown (10YR 3.5/3-4) A horizon over dark brown to strong brown (7.5YR 4/5-6) subsoil;
texture: clayloam to light clay in the topsoil (Ap: 32-38% clay, 24-35% silt, 32-38% sand) over a relatively homogeneous light clayey subsoil; 42-53% clay, 22-27% silt, 24-36% sand. The gravel content is usually less than 5% in the upper soil compartment, increasing towards the Ck horizon to 8% (by volume);
structure: A-horizon: weak to moderate, medium, subangular blocky Ap horizon over moderate, medium to fine, subangular blocky Ah horizon (if present); the B horizon has moderate, medium to coarse prisms breaking down to moderate, medium, subangular blocky elements; the C horizon is massive;
consistence: hard to very hard (dry), friable to firm (moist), sticky (wet) in the Ap horizon; B horizon is hard, firm and sticky; BC and Ck horizons are slightly hard, friable and sticky;
chemical properties (see also Fig. 2.14): the soils are calcareous throughout with a $CaCO_3$ content of 15-19% in the Ap horizon, which increases slightly in the upper part of B horizon and sharply deeper down to reach values of 30-47% (pH-H_2O=7.7-8.5). The organic matter content of the topsoil lies normally between 1.6 and 2.4% and decreases with depth but having values around 1% at a depth of 80 cm from the surface;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, 11-25% kaolinite, 11-25% chlorite and 1-10% mica.
Diagnostics: Ochric epipedon (A-horizon); calcic horizon (Bk horizon: lower part of B, BC, and Ck horizons, usually below 65-85 cm from the surface) with large nodules of calcium carbonate (>=2 cm in diameter) and pockets of soft powdery lime; a cambic horizon lies between the ochric epipedon and the calcic horizon (Bw: upper part of B horizon).
Classification: USDA (1975): Calcixerollic Xerochrepts; FAO (1988): Haplic Calcisols.
Bordering units: Upper boundary: 2I/E and 2Ic.
Lower boundary: 2Mt, 2Iv, 2flp, 2fI/E, 3Mv and 3Iv.
Remarks: Comparing the depth of the calcic horizon of this unit and of the unit 2Ic4 shows that probably the upper 70 cm of the original soils on the higher slopes have been eroded away. Erosion must have accelerated in recent times resulting in accumulating materials rich in organic matter in lower places (unit 2Ic4, Fig. 2.14a).

Unit 2Iv; moderately deep, clay soils having vertic properties.

Extent: 141.9 ha, 7.8% of the area, 11.7% of the slopes.
435
Pedon code: B------Ioxc
B13

Parent material: Pleistocene, calcareous, clayey deposits.
Relief: Undulating, straight middle and lower slopes.
Erosion: Some sheet wash.
Stoniness: Very low, some cobbles transported from higher places by gravity.
Land use: Wheat and cow pea in rotation; occasionally potatoes.
Soils, general: Well drained, cracking clayey soils with an Ap-(B)-Ck horizon sequence. The B horizon extends from the base of the plow layer (usually 30 cm from the surface) to a depth of 50-60 cm. Common very fine and few fine pores throughout; deep rooting is possible;
colour: dark yellowish brown to brown (10YR 4/2.5-3) topsoil over a yellowish brown subsoil;
texture: light clay throughout (37-45% clay, 25-35% silt, 22-28% sand);
structure: weak medium subangular blocky in the Ap horizon changes to moderate medium angular blocky in the B horizon; the Ck horizon is massive;
consistence: slightly hard to hard (dry), friable (moist), sticky (wet);
chemical properties: see Unit 3Iv;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, 11-25% kaolinite, 11-25% chlorite and 1-10% mica.
Diagnostics: Ochric epipedon (Ap), cambic horizon (Bw) in places, calcic horizon (Ck). The dry soils have cracks 1 cm or more wide, extending deeper than 50 cm from the soil surface.
Classification: USDA (1975): Vertic Xerochrepts;
FAO (1988): Haplic Calcisols.
Bordering units: Upper boundary: 2Id4.
Lower boundary: 2fI/E, 3Mv and 3Vt.

Unit 2Mt; moderately deep, dark, clay soils.

Extent: 80.4 ha, 4.4% of the area, 6.6% of the slopes.
435
Pedon code: B---------Mxct
B/C13
Parent material: Pleistocene, calcareous, finely textured colluvium.
Relief: Undulating; concave and straight lower slopes.
Erosion: Some sheet wash.
Stoniness: Locally fairly gravelly surface, with cobbles up to 7 cm in diameter transported from higher places by gravity.
Land use: Wheat and occasionally irrigated cotton, sugar beets, potatoes, etc.
Soils, general: Well drained, somewhat gravelly, finely textured soils, usually with an Ap-Ah-Bw-Bk-Ck horizon sequence. The A horizon extends down to 30-45 cm, and the B horizon to 85-110 cm from the soil surface. Common very fine and few fine pores throughout the soil, fine roots were detected down to 60-80 cm from the surface;
colour: A horizon: very dark greyish brown to dark brown (10YR 3/2-10YR 3/3)); B horizon: brown to brownish yellow (7.5YR 4-5/4-10YR 6/4); Ck horizon: brownish yellow (10YR 6/5) to olive grey (5YR 4/2) and occasionally white;
texture: clay to clayloam (40-48% clay, 20-24% silt, 30-39% sand) in the Ap horizon, clay in the Ah and B horizons (46-56% clay, 20-30% silt, 16-30% sand); and clay to occasionally SiCL, SC or SCL in the Ck horizon. The gravel content is 0-4% (by volume); an extremely gravelly 2Ck horizon may occur below the Ck or Bk horizon;
structure: weak to moderate, medium (rarely fine) subangular blocky in the A horizon; the B horizon consists of moderate, medium to coarse, subangular blocky elements;
consistence: A and B-horizons: slightly hard to hard (dry), friable to firm (moist), slightly sticky (wet); Ck horizon: soft to slightly hard, very friable to firm, slightly sticky to sticky;
chemical properties: calcareous throughout. The total $CaCO_3$ content is 18-25% in the topsoil and increases with depth to values around 40% or higher (see Fig. 2.13b); (pH-H_2O=8.1-8.5). The organic matter content 1.6% or more in the A-horizon and

decreases regularly with depth. The CEC lies between 27 and 35 cmol(+)/kg;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, 11-25% kaolinite, 11-25% chlorite and 1-10% mica.
Diagnostics: A mollic epipedon includes the Ap or the Ap and part or all of the Ah horizon. Bw is a cambic horizon. Bk, Ck or Bk+Ck confine to a calcic horizon with secondary lime nodules (up to 2 cm in diameter) and pockets of soft powdery lime.
Classification: USDA (1975): Typic Calcixerolls;
FAO (1988): Calcic Chernozems or Calcic Kastanozems, depending on the chroma of the mollic epipedon.
Bordering units: Upper boundary: 2Id and 2Ic.
Lower boundary: 3Mv.
Remarks: For a representative profile see Profile P5 (Plate 3C) in Appendix A.1.

Unit 2flp; shallow, fine-textured soils, having a petrocalcic horizon.

Extent: 8.9 ha, 0.5% of the area, 0.7% of the slopes.
R.5
Pedon code: B--------Ioxp
A/B13
Parent material: Pleistocene, calcareous, finely textured colluvial material.
Relief: Flat to gently undulating; straight lower slopes (grade 1-4%).
Erosion: Slight to moderate, sheet erosion.
Stoniness: Large fragments of broken petrocalcic horizon abundant at the surface.
Land use: Wheat.
Soils, general: Well drained, very calcareous, shallow soils with an Ap-Cmk horizon sequence and fragments of the petrocalcic horizon as surface stoniness. The petrocalcic horizon (Cmk) occurs deeper than 30-50 cm from the surface;
colour: dark yellowish brown (10YR 4/3) topsoil;
texture: clay or clayloam;
structure: weak, medium subangular blocky to crumb;
consistence: slightly hard (dry), friable (moist);
Diagnostics: Ochric epipedon, petrocalcic horizon.
Classification: USDA (1975): Petrocalcic Xerochrepts;
FAO/Unesco (1988): Petric Calcisols.
Bordering units: Upper boundary: 2Id4.
Lower boundary: 2I/E.

Unit 2fI/E; association of clay soils having a calcic horizon, and shallow, very gravelly, clayloamy soils.

Extent: 24.5 ha, 1.4% of the area, 2.0% of the slopes.
434/5 004
Pedon codes: C ------- Ioxc, A----- Eoxl
B03 B03
Parent material: Calcareous clay and gravel layers of Pleistocene or younger age. Strong vertical and horizontal variation.
Relief: Gently undulating, straight lower slopes (grade 2-4%).
Erosion: Nil.
Stoniness: Locally high, particles up to 10 cm in diameter or larger.
Land use: Wheat in rotation with cow pea.
Soils, general: As in Unit 2I/E; the calcic horizon is usually below 40 cm in the Inceptisols.
Diagnostics: See unit 2I/E.
Classification: USDA (1975): (I): Calcixerollic Xerochrepts; (E): Lithic Xerorthents;
FAO (1988): (I): Haplic Calcisols; (E): Lithic Leptosols.
Bordering units: Upper boundary: 2Id, 2Iv, and 2flp.
Lower boundary: 3Vt.

Soils of the valley bottoms

The soils of the valley bottoms cover 21.75% of the area, or 394.7 ha, and are subdivided in 5 mapping units:

Unit 3Vt; strongly swelling clay soils.

Extent: 161.9 ha, 8.9% of the area, 41.0% of the valley bottoms.

Pedon code: $\mathrm{C}\overset{435}{\underset{\mathrm{A02}}{\text{------}}}\mathrm{Vxct}$

Parent material: Recent, calcareous, finely textured colluvium. The materials were carried down from geographically higher positions in the landscape by mass flow.

Relief: Flat (slope < =1%) to maximally 2% toward the footslopes.

Erosion: Nil.

Stoniness: Toward the footslopes the surface is occasionally fairly gravelly, with rounded gravel of variable composition and a diameter of less than 5 cm.

Land use: Wheat or irrigated cotton, maize, sugar beets, potatoes.

Soils, general: Deep, moderately well drained, calcareous, strongly swelling soils. A degraded deep dark A horizon is present (eroded mollic epipedons). Horizon sequence is Ap-Ah-AC-C(k); Ah extends from the base of the plow layer (20-35 cm) down to 75-95 cm and occasionally deeper than 100 cm of the soil surface, and overlies a C(k) or a transitional AC horizon. Plenty very fine to fine pores and roots are normally found 80-100 cm below the soil surface;

colour: very dark greyish brown and dark brown (10YR 3/2-3/3) in the Ap horizon; ditto in the upper parts to brown (10YR 4/4) in the lower parts of the Ah horizon; AC or C horizons are brown to strong brown (10YR 3/3 - 10YR 4/6);

texture is clay throughout; textural range in the Ap horizon is 44-50% clay (and occasionally up to 60%), 21-32% silt and 19-34% sand; the clay content of the subsurface horizons might be as much as 8 percent less than in the topsoil. The texture varies only slightly with depth: 51-61% clay, 10-28% silt, 18-35% sand;

structure: moderate or weak, medium, subangular blocky to moderate, medium to coarse, angular blocky in the Ap horizon; Ah horizon is moderate, medium, subangular to angular blocky (in the upper part), to moderate to strong, medium to coarse, angular blocky and occasionally strong, medium, prismatic (in the lower part); the C(k) horizon is massive. Slickensides commonly occur between 35 and 80-100 cm from the soil surface;

consistence: generally firm to very firm and occasionally friable (moist), sticky to very sticky and plastic (wet) and hard (dry). The Ap horizon is hard to very hard when dry;

chemical properties: the soils are calcareous throughout but have lower carbonate content than the soils of most other units; the $CaCO_3$ content ranges between 3 and 13% in the Ap horizon and increases with depth to values of 16-23% in the AC or C(k) horizons of the soils in the main valley or values as high as 30% in the soils in the valley to the northwest (see Fig. 2.15b). The pH=7.4-7.9 in the Ap horizon and as high as 8.4 in the AC and C(k) horizons. The organic matter content of the Ap horizon ranges from 1.7 to 3.3 and remains above 1.5% in the upper parts of the Ah horizon (50 cm from the surface); values of 1% might occur at 100 cm depth (Fig. 2.15a). For more properties see Table 2.7.

Diagnostics: Ochric or mollic epipedon, occasionally soft calcic horizon; carbonate nodules were found but they were probably not formed *in situ*. The ochric epipedon (if any) meets all but the structure requirements of a mollic epipedon. Vertic properties, slickensides.

Classification: USDA (1975): Typic Chromoxererts;
FAO/Unesco (1988): Eutric Vertisols.

Bordering units: 2Id, 2Iv, 2fI/E, 3Iv and 3Mv.

Remarks: Profiles 2 and 3 (Plate 3D) in Appendix A.1 represent this unit.

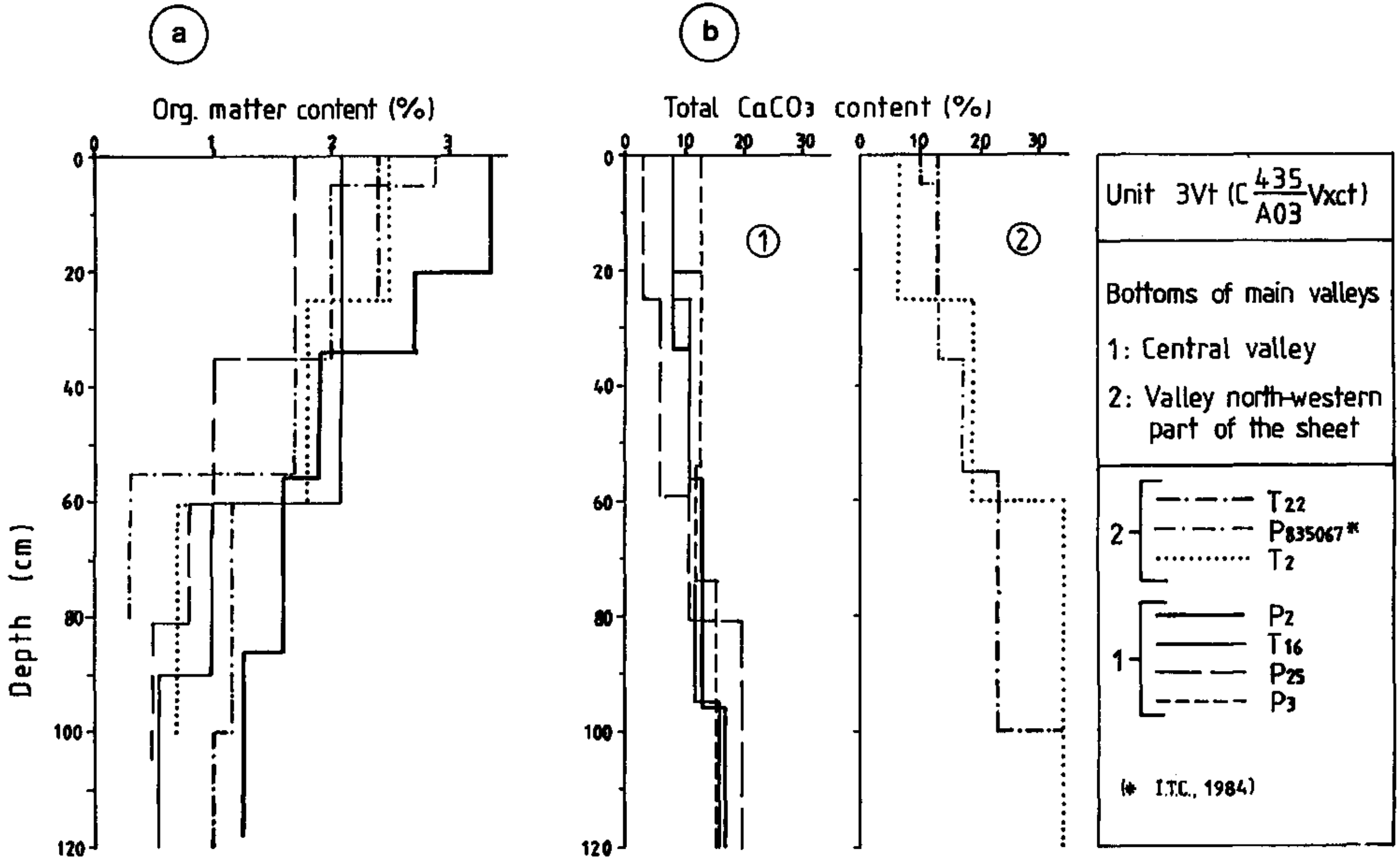


Fig. 2.15. Percentage of organic matter (a), and calcium carbonate (b) as functions of depth in Typic Chromoxererts of the Nikea area.

Table 2.7. Indicative chemical data of soil unit 3Vt

Depth cm	Ec mmho	OM %	N ppm	P ppm	K %	Tot.Ca %	CEC	Na	Ca	Mg	K
							<-------	cmol(+)/kg			------>
0- 5	<3	2.88	1179	18.0	0.8	9.7	34.1	0.25	23.4	10.2	0.2
5-35	<3	1.98	996	5.0	3.6	12.6	35.6	0.25	13.3	21.8	0.2
35-55	<3	1.70	672	1.0	0.9	17.4	34.2	0.25	10.9	23.4	0.2
55-80	<3	0.28	560	1.0	0.8	23.1	27.7	0.25	18.6	8.6	0.2

(Source: ITC, 1984; site 835067).

Unit 3Mv; moderately deep, dark, clay soils having vertic properties.

Extent: 112.4 ha, 6.2% of the area, 28.5% of the valley bottoms.

$$\text{Pedon code: B/C}\ \frac{435}{\text{A03}}\ \text{Mxcv}$$

Parent material: Calcareous clay colluvium.
Relief: Level to nearly level higher parts of main valley bottoms (slope= <2%).
Erosion: Nil.
Stoniness: Normally absent; in places somewhat gravelly at the surface.
Land use: Wheat; if irrigated: cotton, maize, sugar beets etc.
Soils, general: Well to moderately well drained, moderately deep to deep, calcareous, finely textured soils with an Ap-Bk-Ck horizon sequence. The Ap horizon extends down to a depth of 18-25 cm, and the Bk horizon down to 50-60 cm; normally a transitional BC horizon extends between 50-60 cm and 85-95 cm from the surface. Very fine and fine interstitial pores are common; some tubular pores can be found to a depth of 50 cm. Fine roots were detected down to the depth of the Ck horizon;
colour: the Ap horizon is dark brown to black (10YR 3/3-10YR 2/1); the Bk horizon is brown to strong brown (7.5YR 4/4-7.5YR 4/6) and dark brown (7.5YR 3/3); the B/C and Ck horizons are strong brown to reddish yellow (7.5 YR 4/6 - 7.5YR 6/6) and brown (7.5YR 4/4);
texture: clay in Ap and Bk horizons (clay 45-55%, silt around 20%) over clay, sandy clay, clayloam or silty clayloam in BC and Ck horizons;
structure: moderate to strong, medium, subangular blocky and occasionally weak to moderate, fine, granular in the Ap horizon; the Bk horizon is moderate to strong, subangular or angular blocky structured; the AC horizon consists of weak, medium, angular blocky to strong, coarse, prismatic elements; the Ck horizon is massive;
consistence: the Ap horizon is hard (dry), friable (moist), sticky (wet); the Bk horizon is hard, friable to firm, sticky; the AC and Ck horizons are hard, friable to firm, and slightly sticky to sticky;
chemical properties: calcareous with $CaCO_3$ content increasing from 8-16% in the Ap to 40-60% in the Ck horizon (Fig. 2.13c). The pH-H_2O is 7.7-7.9 in the topsoil to 8.5 in the Ck horizon. The organic matter content is around 2.5% and decreases regularly with depth. CEC amounts to 22-26 cmol(+)/kg in the surface soil;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, 11-25% kaolinite, 11-25% chlorite and 1-10% mica.
Diagnostics: Mollic epipedon (18-25 cm) over a cambic horizon (upper part of Bk); a nodular calcic horizon includes the lower part of the Bk horizon and extends down to the Ck horizon. The soils exhibit vertic properties with cracks of 1 cm extending down to the depth of the calcic horizon.
Classification: USDA (1975): Vertic Calcixerolls;
FAO/Unesco (1988): Calcic Chernozems or Haplic Calcisols (depending on the depth of calcic horizon).
Bordering units: Upper boundary: 2Id4, 2Mt. Lower boundary: 3Vt.
Remarks: See profile P1 in Appendix A.1.

Unit 3Mv/c; deep, dark, cracking clay soils.

Extent: 55.1 ha, 3.0% of the area, 14.0% of the valley bottoms.

435
Pedon code: B/C ----- Mxcv/c
A03

Parent material: Calcareous, clayey, humus-rich materials transported down by mass flow from geographically higher locations (colluvium).
Relief: Level to nearly level bottoms of some secondary valleys (slope= <2%).
Erosion: Nil.
Stoniness: Fairly gravelly at the surface.
Land use: Wheat and exceptionally irrigated cotton.
Soils, general: Moderately well to well drained, deep, calcareous, finely textured soils with an Ap-Ah-ACk-Ck horizon sequence. The thick dark A horizon is characteristic of this unit; the Ah horizon under the plow layer (Ap, 0-18/25 cm) extends down to 80-100 cm or more; a transitional AC horizon is normally present; the Ck horizon might be deeper than 140 cm of the soil surface. Many very fine and common fine pores even at great depth. No rooting restrictions;
colour: black (10YR 2/1) to dark brown (10YR 3/3) in the Ap and Ah, over very dark greyish brown (10YR 3/2) to dark yellowish brown (10YR 4/4) in the AC horizon;
texture: clay throughout (clay 45-55%, silt 17-25%, sand 21-34%); in places the clay content of the Ap horizon may be 10 percent higher. The gravel content is between 0 and 3% throughout;
structure: moderate, medium, subangular blocky to coarse granular in the Ap horizon; the structure of the Ah horizon is weak to moderate, medium to fine, subangular blocky (upper part) changing to strong, medium, prismatic or coarse angular blocky deeper than 45 cm from the surface; the AC horizon consists of weak to moderate, medium prismatic to weak, medium, subangular blocky elements;
consistence: hard (dry), firm to very firm (moist), very sticky (wet), throughout;
chemical properties: calcareous throughout with a relatively constant $CaCO_3$ content in the A-horizon (range: 15-25%) increasing up to 39% in the AC or Ck horizon (see Fig. 2.13d). The pH-H_2O ranges between 7.9 and 8.4. The CEC amounts to 22-30 cmol(+)/kg;
mineralogy: the relative amount of clay minerals present is 41-55% smectite, 11-25% kaolinite, 11-25% chlorite and 1-10% mica.
Diagnostics: Mollic epipedon over a calcic horizon; if the soils are dry, cracks wider than 1 cm extend deeper than 50 cm from the surface.
Classification: USDA (1975): Vertic/Cumulic Calcixerolls;
FAO/Unesco (1988): Calcic Chernozems or Haplic Calcisols (depending on the depth of calcic horizon).
Bordering units: Upper boundary: 2Id4, 2Mt.
Lower boundary: 3Vt.
Remarks: See profile P7 in Appendix A.1.

Unit 3Iv; cracking clay soils.

Extent: 55.8 ha, 3.1% of the area, 14.1% of the valley bottoms.

435
Pedon code: B/C ------- Ioxv
A/B03

Parent material: Calcareous clayey colluvial deposits.
Relief: Level, very gently undulating near the footslopes (slope 0-3%).
Erosion: Nil.
Stoniness: Somewhat gravelly surface in places.
Land use: Wheat and rarely irrigated cotton.
Soils, general: moderately well to well drained, homogeneous clay soils with vertic properties and an Ap (0 to 18-25 cm)-Ck horizon sequence. Very fine to fine pores

are normally found at a depth of 100 cm; common fine roots down to 55-60 cm from the soil surface;

colour: dark yellowish brown (10YR 4/4) topsoil (Ap) over dark yellowish brown (7.5YR 4/4) to strong brown (7.5YR 6/6) subsoil;

texture: clay throughout; range: clay 45-52%, silt 18-24%, sand 24-30%;

structure: weak to moderate, medium, angular or subangular blocky Ap horizon, over massive to weak, medium, angular or subangular blocky Ck horizon;

consistence: sticky (wet), friable (moist), slightly hard to hard (wet);

chemical properties: the soils are calcareous with a CaCO$_3$ content of 15-25% in the Ap horizon increasing with depth to 32-55% in the Ck horizon (pH around 8.0 throughout). The organic matter content is about 1.6% in the Ap and decreases regularly with depth.

Diagnostics: Ochric epipedon (Ap), calcic horizon (Ck); the soils exhibit vertic properties (cracks of 1 cm or more wide extend deeper than 50 cm from the surface).

Classification: USDA (1975): Vertic Calcixerollic Xerochrepts;
FAO/Unesco (1988): Haplic Calcisols.

Bordering units: Upper boundary: 2Ic, 2Id.
Lower boundary: 3Mv, 3Vt

Unit 3E/M; association of dark, very shallow and gravelly soils, and dark, deeper, gravelly clay soils.

Extent: 9.5 ha, 0.52% of the area, 2.4% of the valley bottoms.

005 405 435
Pedon codes: A----- Eoxl/Mxhl, A----- Mxht, B----- Mxct
A03 A03 A03

Parent material: Calcareous (gravelly) and clayey strata of Pleistocene age or younger.

Relief: Flat to almost flat (slope < =2%).

Erosion: Nil.

Stoniness: Locally very high surface stoniness; pebbles of various composition and diameter.

Land use: Wheat-fallow in rotation.

Soils general: Shallow to very shallow, well to excessively drained, dark clayey, skeletal soils with a lithic contact (conglomerate) within the control section;

colour: brownish black (10YR 3/2) to dark brown (10YR 3/3);

texture: clay throughout; the solum is very gravelly;

consistence: sticky (wet), friable (moist), (slightly) hard (dry).

Diagnostics: Mollic epipedon or ochric epipedon (too shallow for mollic epipedon); in places calcic horizon; lithic contact in places shallower than 50 cm from the soil surface.

Classification: USDA (1975): Lithic Xerorthents (lithic contact < =25 cm from the surface), Lithic Haploxerolls (lithic contact deeper than 25 cm), Typic Haploxerolls (mollic epipedon, CaCO$_3$ leached to great depth in the skeletal soil), Typic Calcixerolls (mollic epipedon, calcic horizon, reduced amount of gravel).
FAO/Unesco (1988): Lithic Leptosols (lithic contact < =30 cm from the surface), Haplic Kastanozems (Haplic Chernozems if chroma of the mollic epipedon < =2), Calcic Kastanozems (Calcic Chernozems).

Bordering units: 3Mv, 3Iv.

Remarks: The gravel layer might be the top of a Plio-Pleistocene hard conglomerate deposit. Cross section D-D' (Fig. 2.11d) illustrates the distribution of the soils.

Some physical properties

Bulk density

Data on bulk density are presented in Table 2.8 for a number of representative soils of the Nikea area. Apparently there is a negative correlation between bulk density and clay content, which is schematically presented in Fig. 2.16. Against expectations, soil depth and organic matter do not significantly affect bulk density.

Table 2.8. Bulk density and soil moisture characteristics for representative soils of the Nikea area.

Unit (Profile number)	Depth cm	Texture code	Clay %	pF-values								AWC % vol	BD kg/lt
				0	1.0	1.5	2.0	2.3	2.7	3.5	4.2		
1Ic3 (P6a)	15	L	20	46.0	44.0	36.0	29.0	24.0	19.5	14.5	10.6	18.4	1.43
	45	L	20	44.5	41.0	35.0	29.0	26.4	23.0	17.8	11.4	17.6	1.47
1Ic4 (835065)	10	CL	n.a.	45.6	44.4	42.4	37.5	35.2	32.4	27.7	25.7	11.8	1.29
	30	SCL	n.a.	50.1	45.8	38.0	31.3	28.9	26.7	22.4	21.3	10.0	1.43
	80	SC	n.a.	47.9	44.9	39.2	32.3	29.7	26.6	18.2	15.9	16.4	1.36
1Ip (835063)	10	SL	n.a.	47.8	39.6	32.4	26.3	23.9	21.2	17.7	17.0	9.3	1.34
2Ic3 (835064)	15	SiC	n.a.	48.4	46.2	45.2	42.1	40.0	37.5	31.2	29.8	12.3	1.48
	40	L	n.a.	48.2	44.5	37.9	31.8	29.3	26.8	22.1	19.1	12.7	1.34
	70	SC	n.a.	49.4	45.3	37.9	32.1	29.4	26.4	22.8	18.6	13.5	1.34
2Mt (835069)	10	C	76	51.4	51.4	50.0	46.5	45.0	42.0	37.2	32.8	13.7	1.18
	30	C	76	52.7	52.4	50.3	48.6	47.7	45.4	40.2	35.2	13.4	1.20
	50	C	73	56.2	55.9	54.6	53.8	53.4	51.7	40.6	35.3	18.5	1.17
	90	C	71	49.2	48.7	47.5	46.3	45.4	43.5	40.9	36.2	10.1	1.27
2Mt (P5a)	15	CL	37	45.5	44.3	42.5	39.5	37.5	35.0	29.0	22.2	17.3	1.44
	45	C	42	50.1	45.2	42.0	39.5	38.0	35.0	30.0	22.0	17.5	1.32
2Iv (Pcl)	15	C	41	50.0	47.3	46.0	43.0	40.0	35.0	23.5	20.1	22.9	1.33
	45	C	49	46.0	45.0	41.0	38.0	34.5	32.0	25.5	21.8	16.2	1.43
3Mc/v (835066)	15	C	n.a.	46.9	45.6	42.5	37.8	35.6	32.5	26.6	25.3	12.5	1.34
	45	C	n.a.	51.4	46.7	39.7	34.5	32.5	30.1	26.5	24.4	10.1	1.20
	65	C	n.a.	49.1	48.1	44.7	41.1	39.3	36.6	31.8	28.8	12.3	1.32
	90	C	n.a.	51.5	46.0	38.0	30.2	27.3	24.6	19.7	18.3	11.9	1.12
3Vt (835067)	20	C	60	49.1	48.1	44.7	41.1	39.3	36.6	31.2	28.8	12.3	1.32
	45	C	60	55.4	53.3	46.9	41.3	38.9	35.5	29.9	26.0	15.3	1.23
	65	C	60	44.9	42.2	36.7	33.0	31.5	29.3	27.2	23.9	9.1	1.31
	80	C	60	46.4	42.0	36.2	31.9	30.4	28.4	27.0	22.5	9.4	1.35

Soil moisture characteristics

Table 2.8 presents the soil moisture characteristics for the same soils. The soil moisture content at 16 bar correlates with the clay content:

$$\text{SMPWP} = 4.5 + 0.39 * \text{Clay} \quad \text{(see Fig. 2.17)}, \qquad (2.1)$$

where SMPWP is the moisture content at 16 bar (%, v/v), and Clay is the clay content (%).

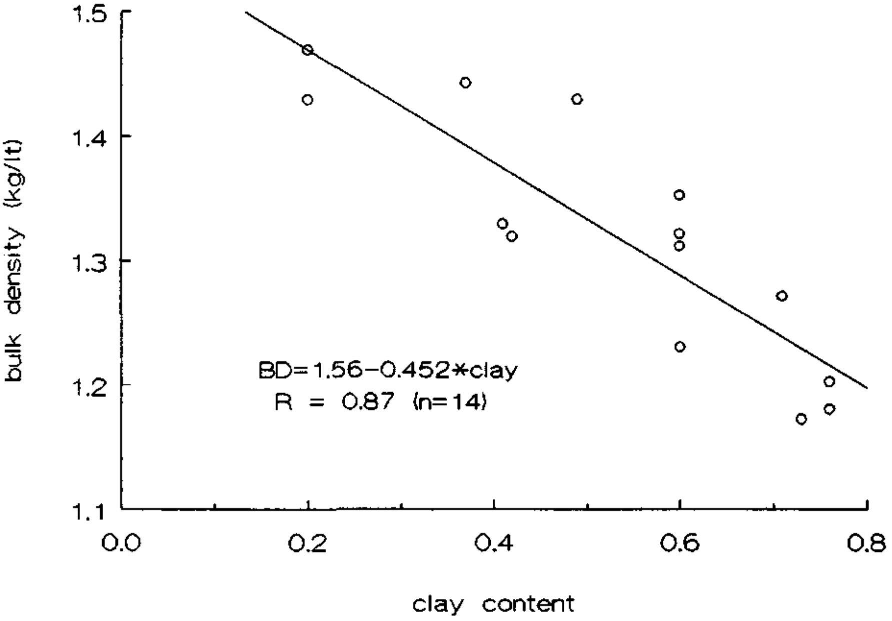


Fig. 2.16. Relation between bulk density and clay content in soils of the Nikea area.

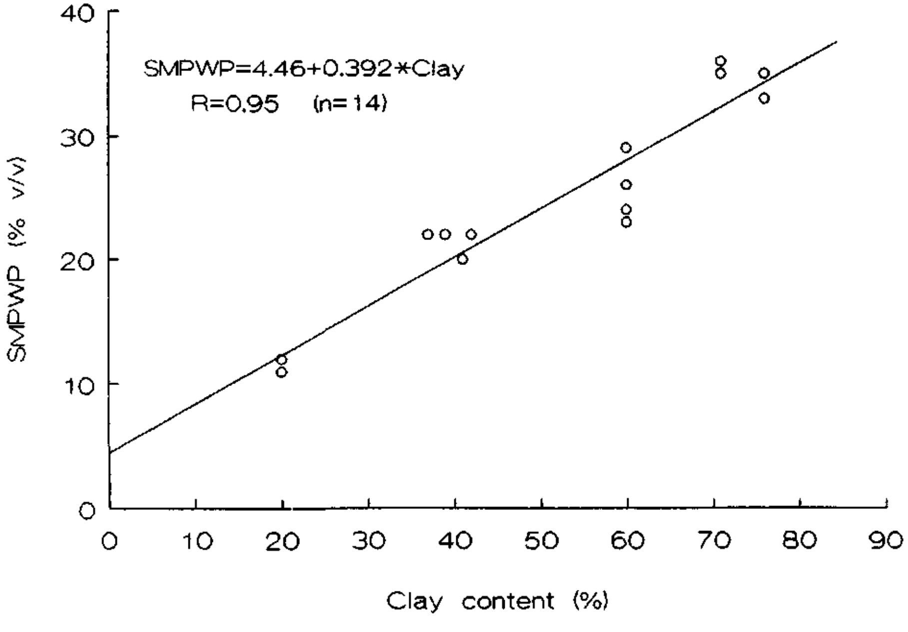


Fig. 2.17. Relation between clay content and moisture content at 16 bar of the studied soils.

Some 95 percent of the variation in moisture content is accounted for (Fig. 2.17). The equation can be used to approximate the moisture content at 16 bar from the texture of the soil material.

The quantity of water retained at low matric suction (between 0 and 1 bar of suction) is strongly affected by soil structure. The values of the soil moisture content at saturation and at 1/3 bar correlate less satisfactorily with the soil texture (see Fig. 2.16).

The available water capacity (AWC, in % v/v) is calculated by subtracting the moisture content at wilting point from that at field capacity (pF=2) and is included in Table 2.8.

All soils of Table 2.8 for which soil moisture characteristics and clay content are known could be described by a logarithmic relation between soil moisture content and soil potential and clay content, in the range of pF=2 to pF=4.2:

$$SM = SMO \exp [(b0+b1*clay)*\ln(PSI)\hat{}2] \qquad (2.2)$$

where

SM is the soil moisture content (cm^3cm^{-3})
SMO is the saturated soil moisture content (cm^3cm^{-3})
clay is the clay content (%)
PSI is the soil suction (cm),
b0 and b1 are coefficients.

This equation may be written as:

$$\ln (SM/SMO) = (b0 + b1*clay) * \ln (PSI)\hat{}2, \text{ or} \qquad (2.3)$$

$$\ln (SM/SMO) = [b0 * \ln (PSI)\hat{}2] + [b1 * clay * \ln (PSI)\hat{}2] \qquad (2.4)$$

$$Y \quad = \quad X1 \quad + \quad X2$$

Assuming that Y=ln (SM/SMO) is the dependent variable and that X1 and X2 are the independent variables:

$$\ln (SM/SMO) = BO + B1 * \ln (PSI)\hat{}2 + B2 * clay * \ln (PSI)\hat{}2 \qquad (2.5)$$

It appears that the SM-SMPSI relation for Nikea soils can be satisfactorily simulated with the relation:

$$SM = SMO \exp [\ln(PSI)\hat{}2 * (0.0001865*clay-0.01824)] \qquad (2.6)$$
$(r^2=0.94, df=68)$

This is demonstrated by Fig. 2.18, where measured and simulated values are compared for two soils of the Nikea area.

The above equation (2.6) is identical with the one used by Driessen (1986) who uses a texture-specific coefficient, gama:

$$gama = 0.01824 - 0.0001865 * clay \qquad (2.7)$$

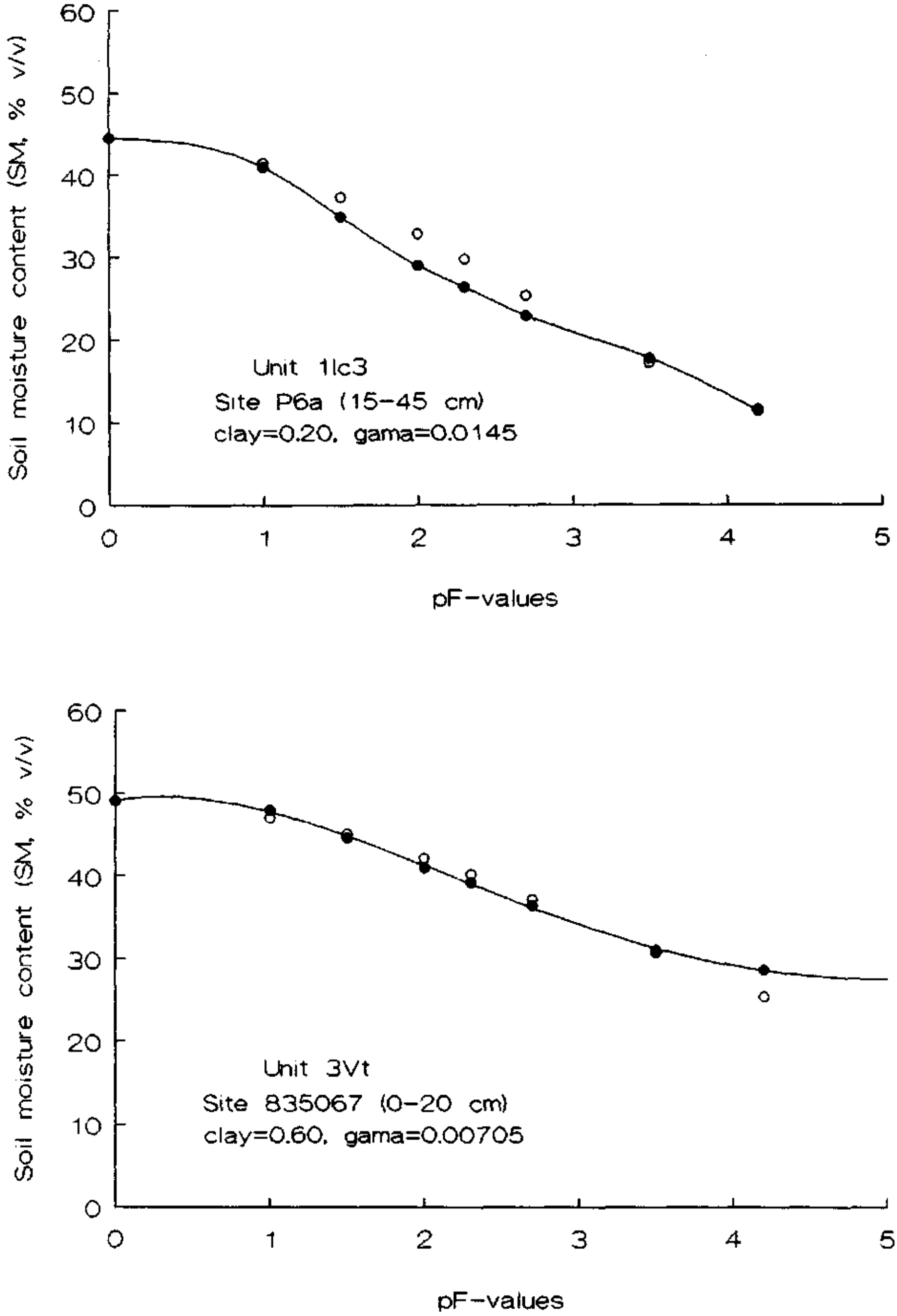


Fig. 2.18. Measured (●—●) and approximated (o) soil moisture characteristics for a loamy soil (above), and a clay soil (below) of the Nikea area. For the equation used for the approximation, see text.

Infiltration parameters

The initial infiltration rate is conditioned by the sorptivity (S) of the soil (material), which depends on the soil texture and the moisture content of the surface layer. Upon prolonged infiltration, the infiltration rate is determined by the permeability (A), which also reflects the hydraulic properties of the porous medium.

The infiltration capacity of the soils and the roles of the parameters S and A will be discussed in detail in Section 3.3, where is also explained how, with a few well executed experiments, the above parameters can be established under field conditions. The estimated standard sorptivity (SO) and permeability values of representative soil units of the Nikea area are summarized in Table 2.9.

Table 2.9. Indicative infiltration parameter values of Nikea soils.

Soil Unit	SO (cm $min^{-1/2}$)	A (cm min^{-1})
2Mt, 3Mv, 3Mv/c	1.43*	0.010-0.020
1Ic4, 2Ic4, 2Id4	0.80	0.001-0.003
2Iv, 3Iv	0.80*	0.001-0.005
3Vt	1.10*	0.003-0.004
2Ic3, 2Id3	1.06	0.010-0.020
1Ic3	0.85	0.013

The momentary sorptivity (S) can be calculated from its standard value (SO) and the momentary soil moisture content. Note that for swelling soils (with asterisk in Table 2.9) the linear S-SMO relation applies; the parabolic model can be used for other soils, as explained in Section 3.3.

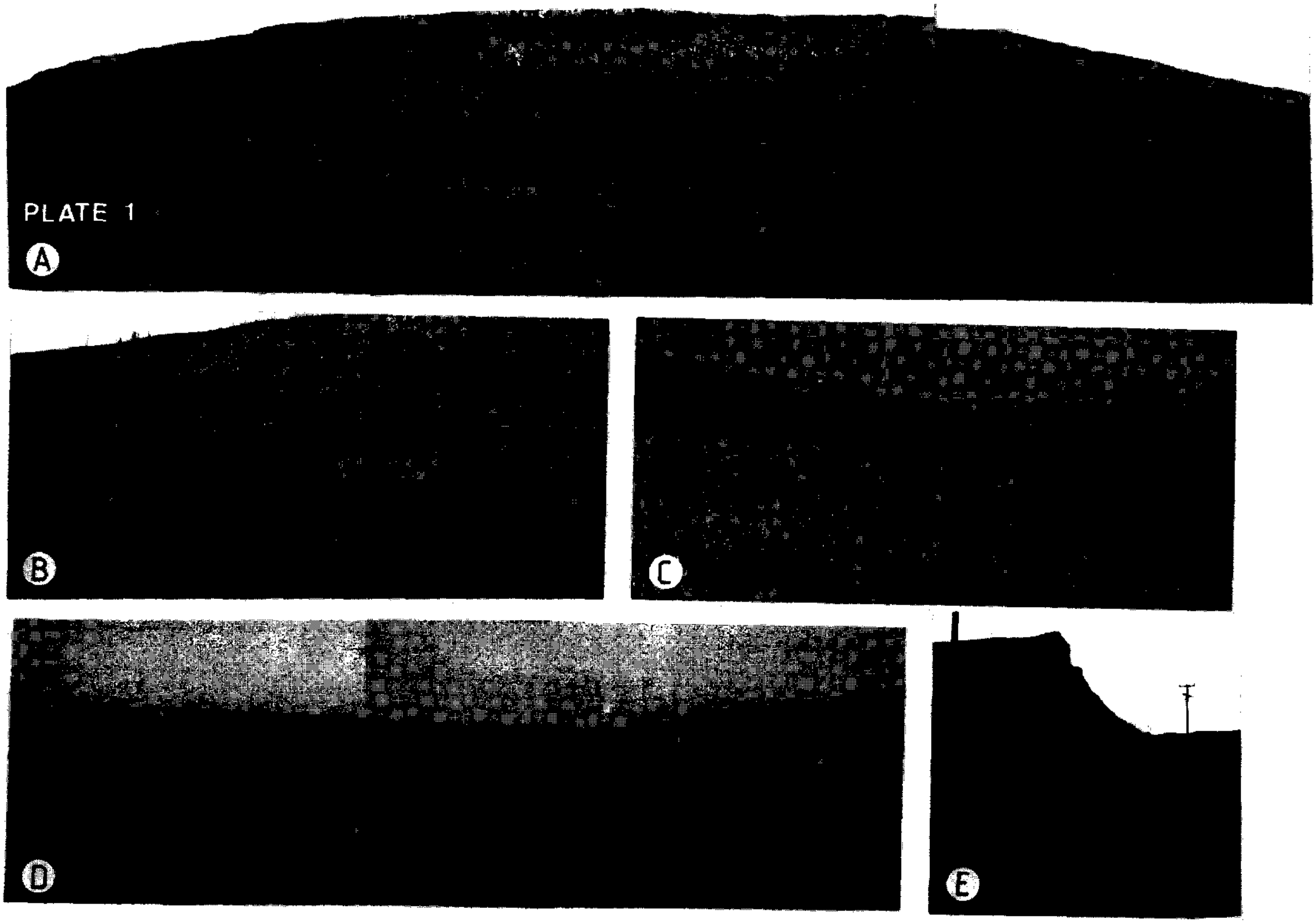


PLATE 1

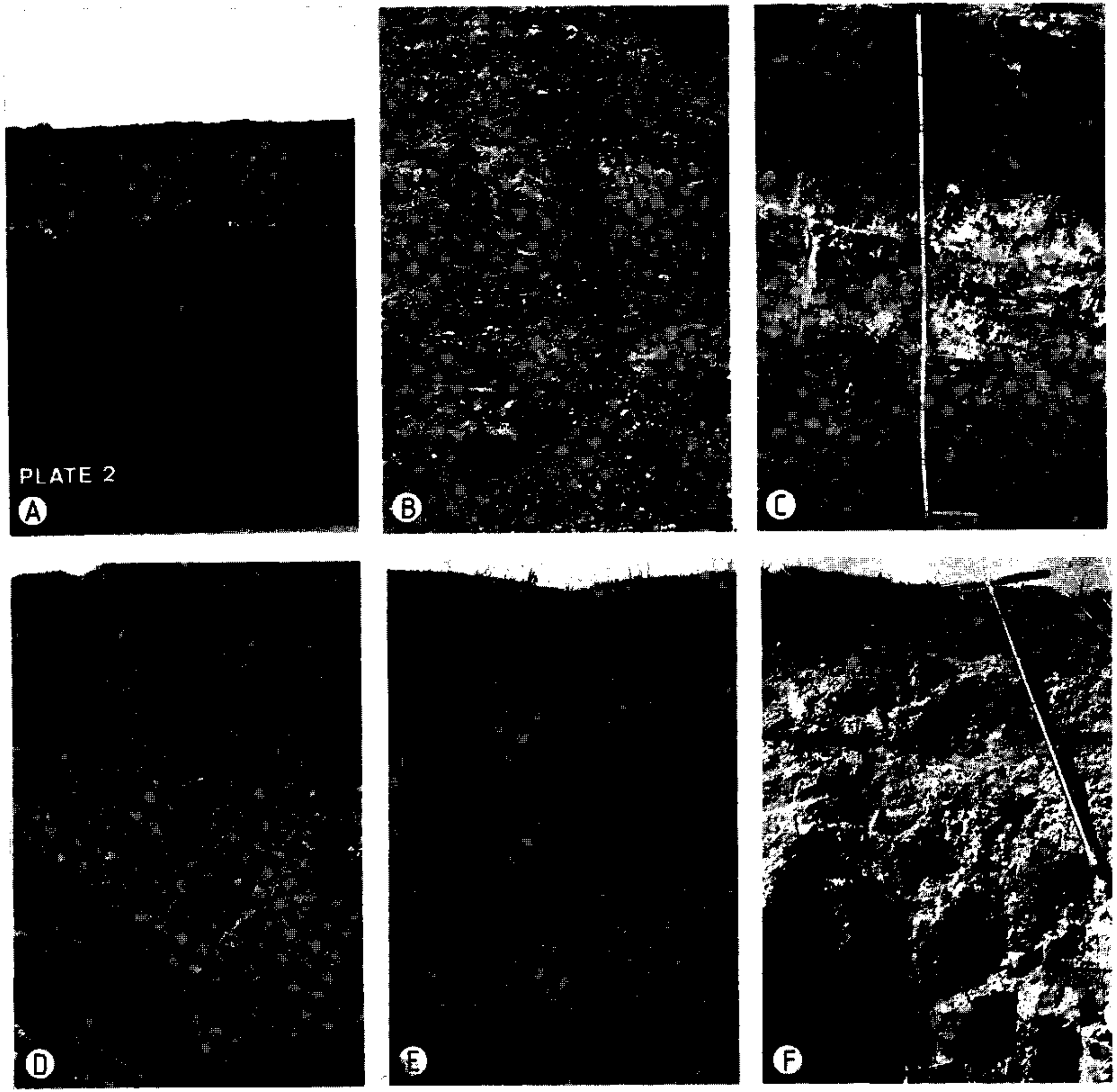


PLATE 2

Plate 1. Fluvio-terrestrial deposits in the Nikea area.

Plate 1A- A south facing quarry, 1.5 km west of Nikea. Clay, sandy clayey and gravelly deposits can be seen. A fault is also visible with a horizontal layer displacement of about 1.5 m, belonging to the subsiding Larissa (Karla) basin.

Plate 1B- (facing north) the same sediments; the sandy layers appear as empty pockets.

Plate 1C- Homogeneous clayloamy sediment, characteristic of many slopes in the northern part of the Nikea area.

Plate 1D- Hard conglomerate sediment about 1.5 km south of Nikea, on the fringe of the studied pilot area. Folding caused strata to dip under an angle of 5 degrees (9%) as is visible in the right part of the photo.

Plate 1E- Deposit of alternating gravel and sandy clayey layers, occurring 1.5 km south of Nikea, west of the road to Farsala. In the lower gravel layers, large quantities of semi-rounded chert were found.

Plate 2. Parent materials in the Nikea area.

Plate 2A- A three-meters thick, calcareous clayey layer between two very calcareous, gravel layers.

Plate 2B- Deposit of alternating very calcareous gravel and sandy clayey layers.

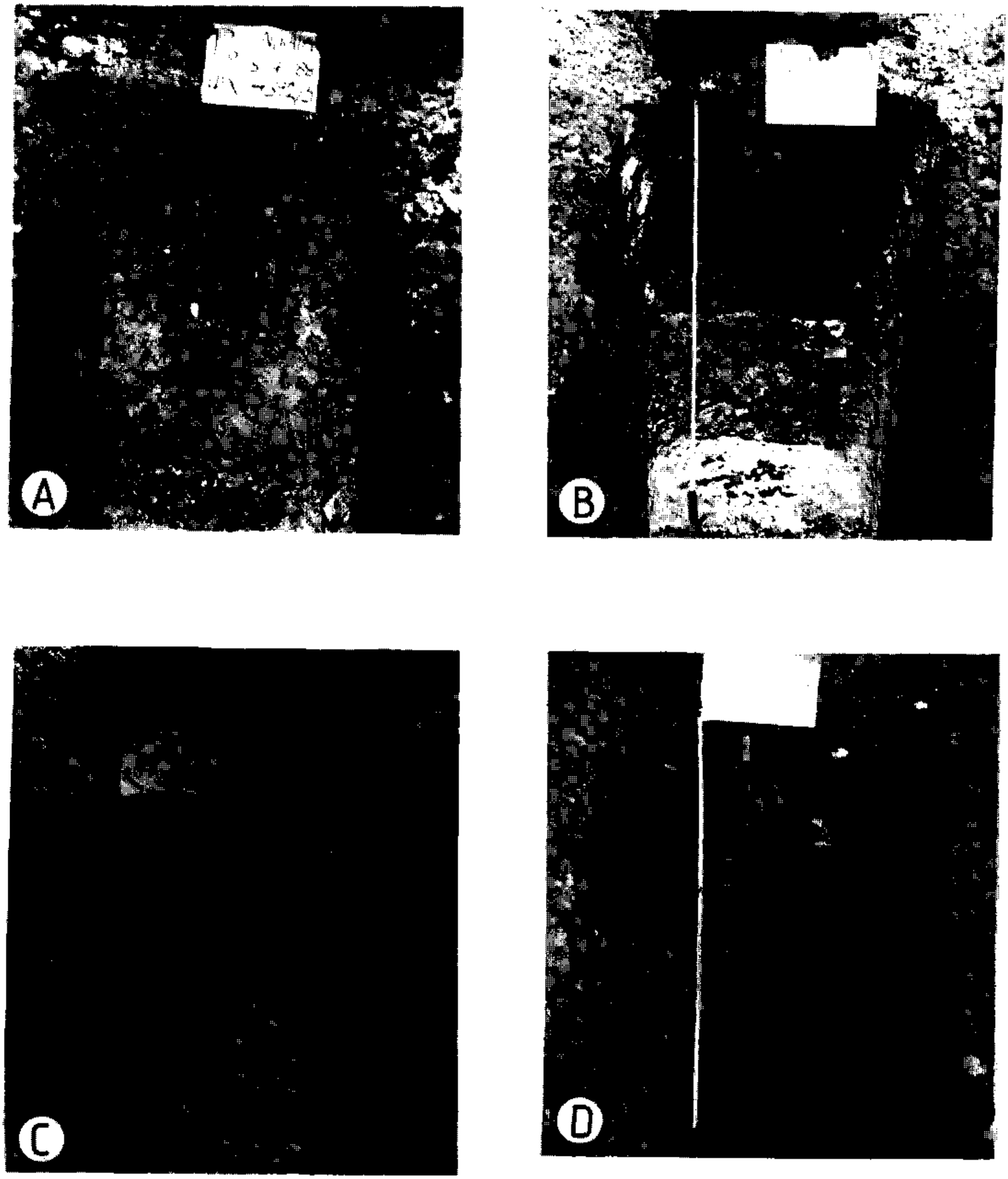
Plate 2C- Thin calcareous clayey deposit over very calcareous sand and gravel.

Plate 2D- A very thick petrocalcic horizon is formed in calcareous gravel material (Petrocalcic Palexeroll) probably by subsurface throughflow of $CaCO_3$-rich water, thickening the petrocalcic horizon from above rather than from below.

Plate 2E- A two-meters thick, calcareous, sandy clay layer over a thick gravel deposit.

Plate 2F- Homogeneous clayloamy sediment.

Plate 3. Major soils of the Nikea area. *Plate 3A*.-Shallow Calcixerollic Xerochrept (unit 1Ic3). *Plate 3B*.-Moderately deep Calcixerollic Xerochrept; note that the topsoil is not dark enough to qualify as a mollic epipedon (unit 2Id4). *Plate 3C*.-Typic Calcixeroll (unit 2Mt). *Plate 3D*.-Typic Chromoxerert (unit 3Vt).



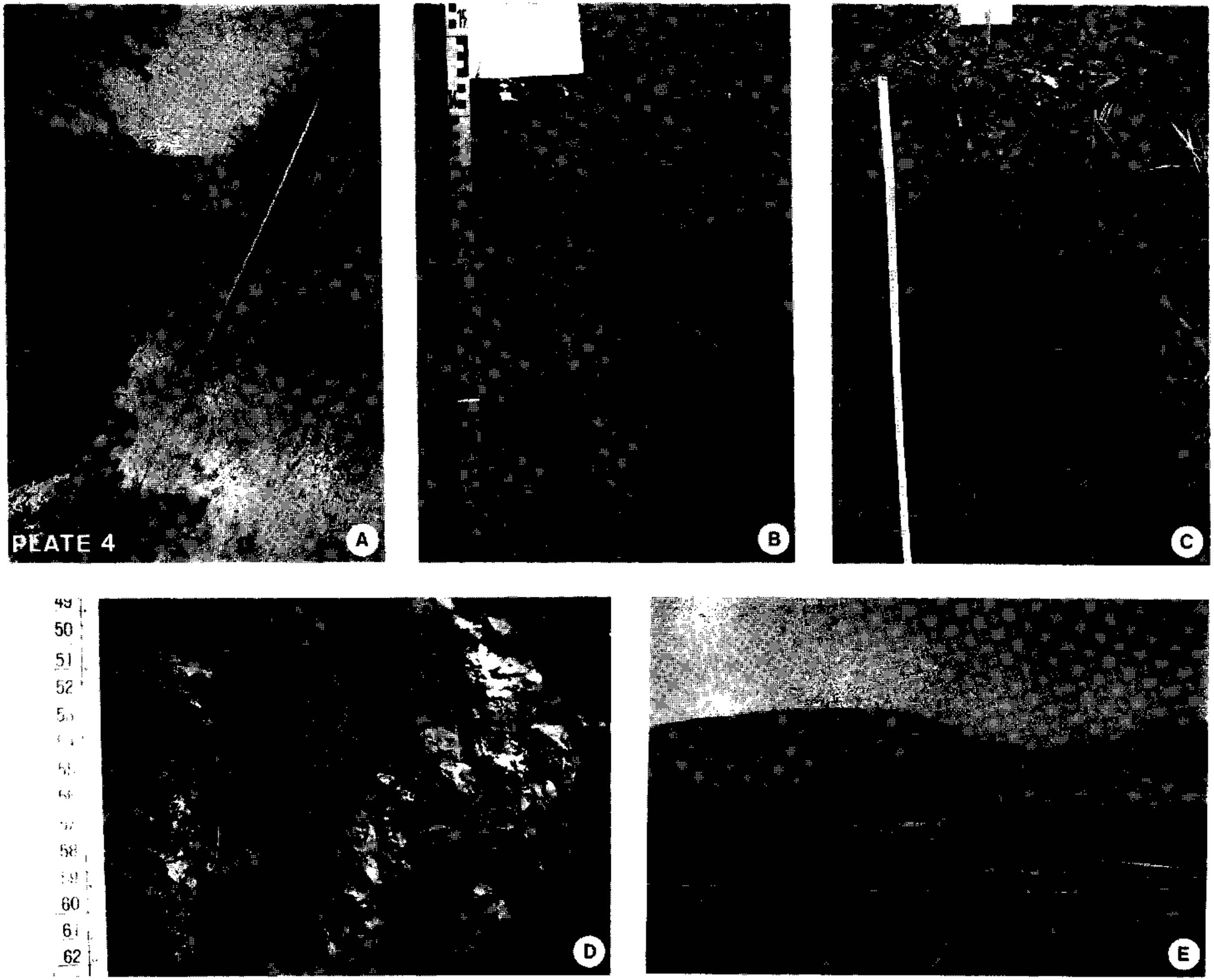


PLATE 4
A
B
C
49
50
51
52
58
60
62
D
E

Plate 4. Major soils of the Holocene terraces and the Peneios river flood plain.

Plate 4A- (facing southwest) Brown argillic horizon with thin clay films and strong blocky structure over a nodular (semi-hard nodules, 1/2 cm in diameter) calcic horizon, occurring on a Peneios river bank, 3 km southwest of Platanoulia. This "Girtoni" alluvium is buried 60 cm below a stratified, calcareous sediment of the Peneios river. Mount Ambari is visible in the background.

Plate 4B- The upper part of a Typic Xerofluvent (soil unit AE1) formed in stratified, calcareous, coarse-textured sediment of the Peneios river (see Pedon P4 in App. A.2).

*Plates 4C and D-*Typic Haploxeralf (soil unit HAh) formed in early Holocene, non calcareous colluvium deposited near the edge of the Holocene terrace bordering on the "Niederterrasse". The argillic horizon is moderately thick with distinct clay skins and has a strong coarse angular blocky structure (Plate 4D; see also Pedon P1 in App. A.2).

Plate 4E- (facing WSW) Holocene terrace in the southern Platanoulia area seen from the edge of the Pleistocene terrace. Mount Ambari and the "Kalamakiou narrows" are visible in the background. The village in the footslopes is Amygdalea.

Plate 5. Major soils of the Pleistocene terrace.

Plate 5A- Typic Palexeralf of the upper Pleistocene terrace level (F1) formed in calcareous alluvium of the Xerias river (soil unit F1Ap1w; see Pedon P6 in App. A.2).

Plate 5B- Shallow Calcixerollic Xerochrept of the undulating F1-F2 transition zone. The soil is formed after the surface E horizon and the greater part of the argillic Bt horizon have eroded away; the calcic Ck horizon has come close to the surface (soil unit F1Ic; see Pedon P5 in App. A.2).

Plate 5C- Calcic Haploxeralf (soil unit F1Ah2m) formed in Pleistocene calcareous alluvium of the Peneios river. The eluvial E horizon has eroded away, and the argillic horizon has come close to the surface (see Pedon P3 in App. A.2).

Plate 5D- Pondian to Pleistocene marl deposits exposed near the northwest margins of the Platanoulia area. The Pleistocene terrace in the background (facing south-southwest).

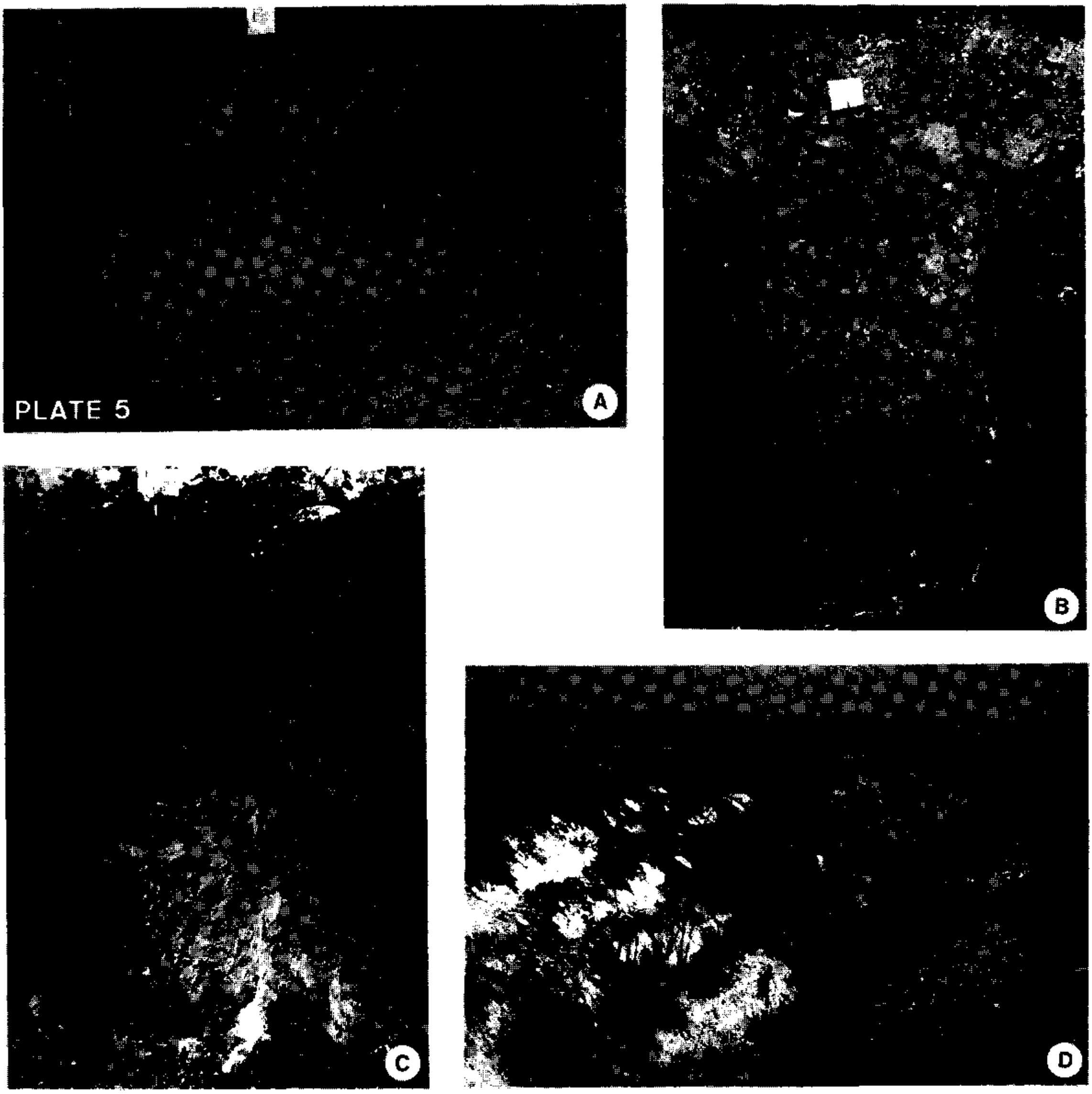


PLATE 5

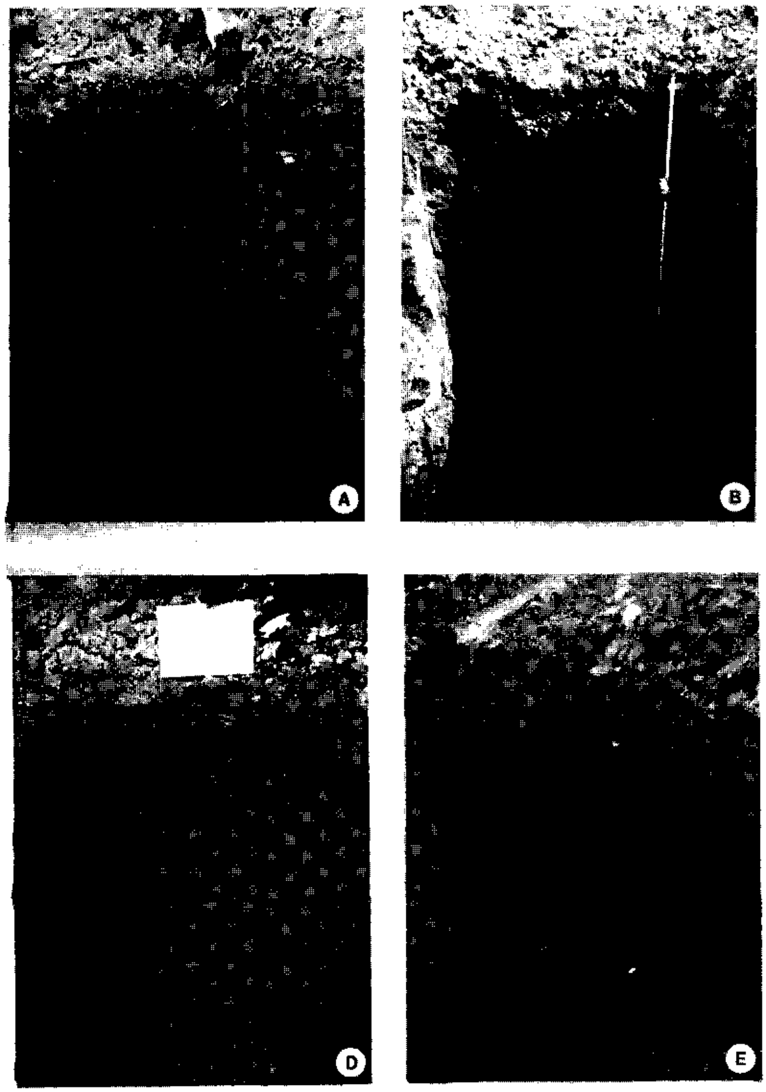


Plate 6. Major soils of the Peneios delta area. *Plate 6A.*-Typic Xerofluvent; a cambic horizon is buried below a 70 cm thick, stratified, calcareous sediment of the Peneios river (Pedon P2, App.A.3). *Plates 6B and 6C.*-Aquic Xerofluvents (Pedons P5 and P6, App.A.3). *Plate 6D.*-Vertic Xerochrept (Pedon P3, App. A.3). *Plate 6E.*-Vertic Haplaquept (Pedon P4, App.A.3).

2.3 The Platanoulia pilot area

2.3.1 Introduction

The Platanoulia area is the second area studied in detail (see Fig. 2.19 and Fig. 2.21). It is situated at a distance of 11 km west-northwest of the city of Larissa, in the western Larissa plain, and is defined by the Peneios river in the south, the 110 m contour (footslopes of the Ambari mount) in the west and by the drainage channel of Agia Sophia village in the north and east. A narrow strip of the area extends as far as the Xerias (Titaresios) river in the northwest. The pilot area lies between 39°39’ and 39°43’43’’ North and 22°16’24’’ and 22°19’15’’ East; it is situated between 74 and 110 m ASL and covers approximately 2,000 ha. The Platanoulia area includes soils on the Pleistocene terrace, on the Holocene terraces and in the flood plain.

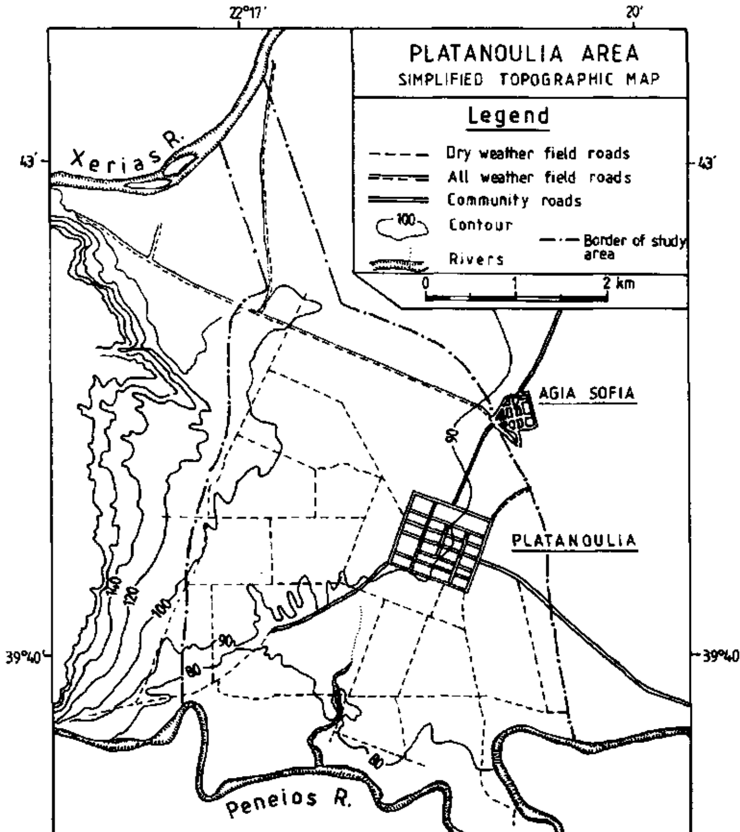


Fig. 2.19. The Platanoulia pilot area

2.3.2 Geogenesis

Geology

Late Pleistocene to young Holocene alluvial deposits cover the pilot area (Fig. 2.20) and also the lowland north of Larissa. The Holocene deposits are less than 3 meters thick and consist of calcareous fluvial gravel, sands, silts and clays.

The fluvial late Pleistocene fill consists of well-sorted calcareous gravels, sands, silts and clays. A thickness of 6.5 m was recorded in a river bank exposure some 2 km from where the Peneios river exits the Kalamakiou Narrows.

The greatest part of the post-Neogene fill consists of Pliocene to Miocene lacustrine marls, especially in the areas around Larissa and west of it. More to the north, in the area around Tyrnavos, conglomerates of Pleistocene age reach a thickness of 100 m or more (Institute of Geology and Mineral Exploration, I.G.M.E., 1985). They are exposed near the margins of the plain, and can also be seen in the west part of the Platanoulia area.

Pre-Neogene bedrock occurs at various depths below the surface of the plain. It is exposed at the margins of the plain, viz. the marbles of the Mount Ambari, west of the pilot area. The depth to the bedrock increases towards the centre of the plain and reaches 500 m in the vicinity of Larissa.

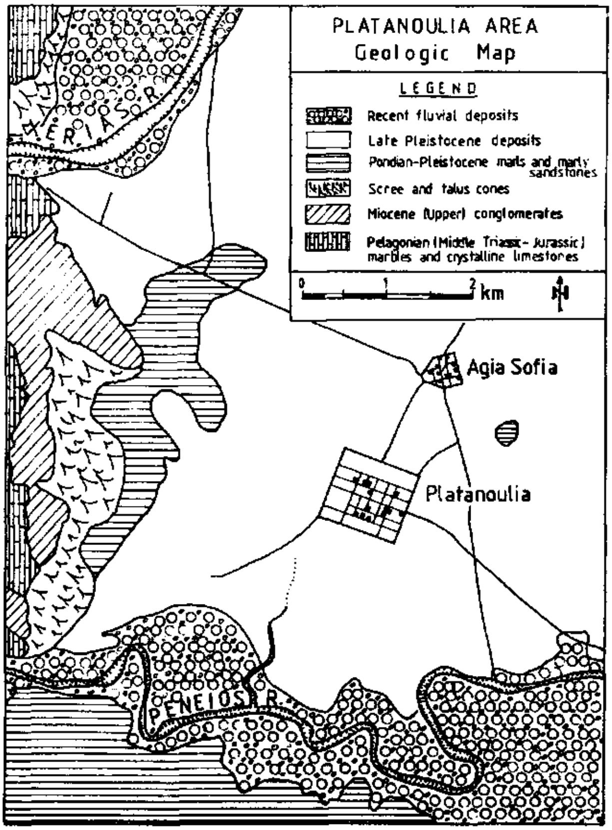


Fig. 2.20. The geology of the study area (after I.G.M.E., 1985; Sheet: Larissa).

Geomorphology-Geogenesis

The landforms of the Larissa region were outlined in Section 2.1 (see Fig. 2.3). Fig. 2.21 presents a more detailed view of the plain north of Larissa. The following landforms are distinguished in the Platanoulia pilot area (i.e. the south-western part in Fig. 2.21):

F	Pleistocene terrace,
H	Holocene terraces, and
A	Meandering (flood) plain.

Landform F represents the extensive, very gently sloping paleo-flood plain of the Peneios river and its tributaries (mainly the Xerias river). This landform is well-preserved at an elevation of 5-15 meters above the present flood plain level. The Xerias river dominated the formation of this landform as testified by (photo-geologic evidence of) now abandoned Xerias paleo-channels on the Pleistocene surface. Some of these channels were active until recent times (Papoutsopoulos & Svorikyn, 1936).

A long history of soil formation produced soils with well developed argillic horizons over a nodular calcic horizon. Dissection resulted in at least 2 levels of different height and age, coded F1, F2 (and F3). The original base level is probably the level of land unit F1 (higher terrace). Land unit F2 represents the mid-level terrace that is very gently undulating; the land unit F3 is the lower terrace level or a low part of the F2 level that is flat to nearly flat. The latter unit (F3) is absent from the pilot area. Landform F covers about 14,000 ha or 50% of the lowland north of Larissa (Fig. 2.3), and 1,841 ha in the pilot area (Fig. 2.19 and soil map).

Landform H consists of the Holocene terraces of the Peneios river, situated along the margins of the Pleistocene surface. This landform occupies 117,3 ha in the pilot area; it makes up about 1 percent (1,465 ha) of the area on the ITC Physiographic Map. In the pilot area, the terraces are level to nearly level; they border on Landform F in the north, where slopes are about 12%. The terrace soils are partly decalcified and contain a cambic horizon.

Landform A represents the present flood plain of the Peneios river and its tributaries (mainly the Xerias river). The deposits are highly variable in texture and gravel content and rest on a (truncated) late Pleistocene or early Holocene surface. The deposits of the Xerias are generally coarser than those of the Peneios river; the Xerias is a braided river with seasonally high discharges and bed loads. The Peneios river traverses the west Thessaly plain before entering the Larissa plain. It has a low bed load and (usually) clear water. Its meanders and oxbow lakes (Fig. 2.21) reflect its more steady discharge rate.

The Pleistocene terrace was first considered to be a Peneios paleo-flood plain or "Niederterrasse" by Schneider (1968). According to Demitrack (1986), the Niederterrasse aggraded between 42,000 and 27,000 years BP and comprises the oldest now-exposed alluvium in the Larissa plain. Stability prevailed since 27,000 years BP.

The climatic shift from the late-Glacial to the warmer, moister post-Glacial had a significant effect on the landscape around Larissa (Bottema, 1979; Van Zeist and Bottema, 1982). The long period of stability of the Niederterrasse ended between 14,000 and 10,000 years BP, when erosion and dissection occurred, followed by resumed deposition at a lower level. The floodplain aggraded again in the Middle Neolithic period, viz. 7,000-6,000 years BP, when the "Girtoni alluvium" was deposited (Demitrack, 1986). This deposition took place about 1,000 years after the introduction of agriculture to Thessaly, and is probably a result of land clearance by Man.

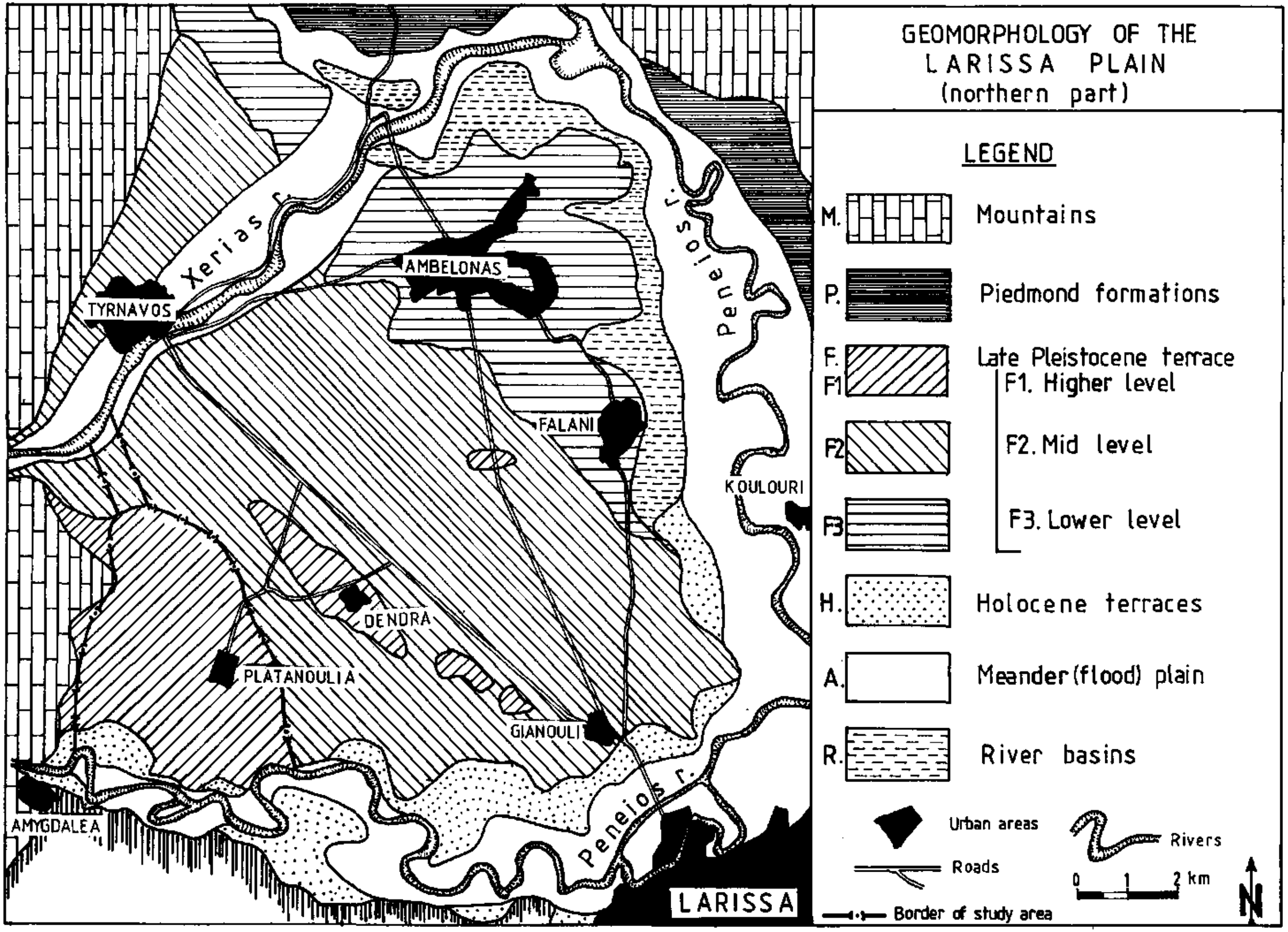


Fig. 2.21. The geomorphology of the plain north of Larissa (after I.T.C., 1984).

Sometime after 6,500 years BP, the Peneios river lowered its base by 5-15 m; the Pleistocene floodplain was abandoned. The formation of river terraces must have occurred in this period. Soil formation continued on a stable Neolithic surface (Girtoni alluvium) and produced soils with an argillic horizon over a calcic horizon. This "Girtoni" soil is exposed only between Larissa and the Kallamakiou Narrows. In the pilot area, buried Girtoni soil was found at 60 cm below the present flood plain on a Peneios river bank (Plate 4A). The 2.5 m thick Girtoni alluvium remained in place for prolonged times; deposition has resumed only in modern times.

The variation in the depth to bedrock in the Larissa plain (see Section 2.2) could reflect the original topography and/or be caused by differential subsidence of the Larissa depression, with higher rates towards the centre of the plain. A subsidence rate of 1.5 m/1000 years has been mentioned (paragraph 2.2.2). Though earthquakes and tremors prove that the tectonic activity in the area continues until the present day, the rate of subsidence seems to have slowed down since the late Pleistocene; the deposits of this age would have been deeply buried otherwise. The fact that the Peneios abandoned the Niederterrasse is probably caused by a decrease in the subsidence rate of the Larissa basin and increased erosion of the Rodia Narrows, where the Peneios exits the Larissa plain. This is in accordance with the increased precipitation in Thessaly in the post-Glacial period (Van Zeist and Bottema, 1982). A possible result of rapid subsidence near Larissa is the extending of Peneios' elbow as far as the city before the river turns abruptly northwards.

It should be mentioned that Van der Meeren and Shrestha (1984) consider the Pleistocene terrace to be a Xerias fan surrounded by Peneios deposits whereby the river has been pushed away by the building fan. Although this theory is not adopted here, the domination of Xerias deposits on the Pleistocene surface is evident.

2.3.3 Vegetation and land use

Cultivation and fires have eradicated the natural plant cover (a deciduous forest). Remnants of the original vegetation can still be found, with *Quercus coccifera* (Kermes oak; Gr. pournari), *Pirus amygdaliformis* (wild pear; Gr. agriogortsia), *Rubus* sp. (Bramble; Gr. vata) and *Paliurus* sp. (Garland; Gr. paliouros).

The main cultivated crops are the following:
- annuals: wheat, cotton, maize and vegetables;
- perennials: pear, almond, grape, apple, peach.

Land use by the Platanoulia-Agia Sophia-Dendra Community (890 families) is as follows Table 2.10):

Table 2.10. Land uses in Platanoulia (Nat. Serv. of Stat., 1989).

Crop	Area (ha)
Wheat durum	1,350
Wheat soft	266
Cotton	730
Water melon	200
Pear	250
Rest	484

Total	3,280

The average holding amounts to 3,280/890=3.7 ha/family

The durum wheat species "Mexicali" is sown in November and harvested in (mid) June. The crop is normally rainfed; it receives 120-150 kg N/ha and 60-80 kg P/ha and yields 2.5-3.0 t/ha. Soft varieties may yield up to 4 t/ha.

Irrigated cotton is the second important crop. Cultivars of Acala are sown between April and middle May and harvested in autumn. Cotton yields are lower in this area than in other parts of the Larissa plain, viz. 1.5-2.5 t/ha. The area grown to cotton decreased in the last years. The same happened to maize that produces less than 11 tons grain per hectare. In the few remaining maize fields, the hybrids Pioneer 3183, DeKalb (usually for late sowing) and ARIS (a Greek hybrid) are grown.

Vegetables including onion, cauliflower, melon and watermelon are grown in small parcels on the Holocene terraces. Water melon is also grown on the Pleistocene soils, where yields are about 50 t/ha and water melon tends to replace other irrigated crops.

Pears are the most important fruit trees in the area. Varieties tolerant to calcium carbonate like "Krystalli" and "Passa krassana" gradually replace the older "Williams". Grapes are not very common in the pilot area, but they grow extensively elsewhere on the Pleistocene terrace, e.g. in the vicinity of Tyrnavos and in the area between Tyrnavos and Ambelonas. The yields are around 80 t/ha. Almond is another important crop, yielding about 3 kg clean fruit per tree (about 1.5 t/ha). Peaches and apples are grown in smaller numbers. It is typical of the Pleistocene terrace that the trees (except for almonds) are cultivated in "palmetes" (i.e. in parallel rows to allow the use of tractors) and receive drip irrigation.

All crops are fully fertilized. Ammonium phosphate or calcium-ammonium phosphate (20-10-0) is commonly used as a basic dressing of annual crops, and ammonium nitrate (33.5-0-0) is used as a top-dressing. Fruit trees receive potassium sulphate, not seldom in (too large) quantities of 2 t/ha per year (Kariotis, 1988).

Irrigation water is pumped up from deeper strata (80-100 m) below the Pleistocene terrace. In the Platanoulia-Agia Sophia-Dendra area (3,500 ha), 42 public deep-water pumps (Gr. "pomones") lift 8,820 cubic meters per hour.

The water is applied to the annual crops with traditional hand-moved (aluminum) laterals as well as stationery large sprinklers and travelling guns. The latter tend to replace all other systems. However, as explained in Chapter 6, their extensive use leads to lower maize and cotton yields. Drip irrigation is applied to the perennial crops.

An additional discharge of 24.5 million m^3 may be made available to the Platanoulia- and its surrounding areas from the springs of "Agia Anna" and "Amygdalea" (Pagonis, 1987).

2.3.4 Methods

Desk studies

Topographical and geological maps, reports and other literature about the plain north of Larissa were collected and studied prior to the field work. The Platanoulia area is well documented; topographical maps could be obtained from the Greek Army Geographical Service (G.Y.S.) at scales 1:5,000 (sheets 4380/2 and 4380/4), 1:20,000 (sheet: Tyrnavos) and 1:50,000 (sheet: Larissa).

The 1:50,000 geological map of Larissa (1985) includes the Platanoulia area; it was kindly supplied by the Greek Institute of Geology and Mineral Exploration (I.G.M.E.).

The 1:100,000 Physiographic Soil Map of the Larissa Area (van der Meeren and Shrestha, 1984) was consulted, as well as the old 1:100,000 Soil Map of Larissa Area (Papoutsopoulos and Svorikyn, 1936); the more recent Soil Map of the Tyrnavos Area (Giolas *et al.*, 1971), at a scale 1:20,000, was available from the Institute of Soil Mapping and Classification, Larissa.

(Old) descriptions of 6 soil profiles and chemical and physical data of 56 auger points in the general area were supplied by the Greek Soil Classification and Cartography Division. All these data were reviewed and gave useful preliminary information about the Pleistocene and Holocene terraces and the present flood plain.

Six black and white air-photos of the study area (coded 80617, 80618, 80619, 80620, 80624 and 80625, year 1975), at a scale 1:20,000, were obtained from the Army Geographical Service. The smaller scale of the available air-photos if compared with the scale of the base maps (1:5,000) and the nearly flat topography of the study area, limited the use of the air-photos; they served as a supplemental tool for better orientation and for drawing the field map.

Field methods and map compilation.

A number of exploratory trips were made to the area north of Larissa. The Platanoulia area was then chosen as a pilot area to represent soils of the Pleistocene terrace, the Holocene terraces and the present flood plain.

A detailed soil survey of the area was carried out in the summer of 1987. A number of cross-sections were made through the main physiographic units to study the geomorphology of the pilot area and its soils. The complexity and variability of the soils in the area made it necessary to do an intensive field survey, during which some 150 sites were described.

The taxonomic (soil) units distinguished in the area are documented by full descriptions of representative soil profiles. These descriptions were made on freshly dug pits and follow the "FAO Guidelines for Soil Descriptions". They are presented in Appendix A.2.

A final soil map with a descriptive legend was compiled at a publication scale 1:20,000.

Laboratory methods

Soil samples from the selected soil profiles were analyzed for soil texture, pH, organic matter-, calcium carbonate- and potassium contents, extractable phosphorus, C.E.C. and exchangeable sodium at the Institute of Soil Mapping and Classification (ISMC), Larissa. The procedures are outlined in Subsection 2.2.4.

A total of 42 undisturbed soil samples from seven sites were transported to Wageningen where the moisture retention characteristics (pF) were determined at the Laboratory of ISRIC. An additional number of retention curves of representative soils (sites 835047, 835048, 835061, 835068, 835070 and 835080) from the vicinity of Platanoulia were analyzed at ISRIC as part of the ITC research and are included in Van der Meeren and Shrestha (1984). Thirteen infiltration experiments were carried out at representative sites in the pilot area.

Mineralogical analyses for two sites in the Platanoulia area are available by Kariotis (1988).

2.3.5 Soils

Aspects of genesis and classification

The landscape surfaces in this pilot area (and the soils in them) vary greatly in age, viz. from a few years old on the present floodplain to some 27,000 years old on the Pleistocene terrace. Consequently, time is the dominant factor which conditioned the development of the soils of the area.

As elsewhere, certain soil properties are well correlated with the age of the soils in the Larissa area. As soils age, their colour reddens, textures become finer, soil structure develops and clay films thicken on ped faces, in pores and around single grains. In calcareous soils, calcium carbonate migrates to deeper soil layers and accumulates in successive morphological stages e.g. soft powdery lime, concretions and nodules.

On the nearly level Pleistocene terrace, decalcification and subsequent clay illuviation resulted in a soil with a deep argillic horizon over a thick calcic horizon (Plate 5A). The calcic horizon occurs normally below 100 cm and contains large lime nodules that are normally 1-2 cm in diameter and occasionally up to 10 cm. The argillic horizon is thick with pervasive, thick clay films in pores and on peds, and a strong blocky structure. It is reddened with colour hues of 5 to 7.5 YR as a consequence of the transformation of ferrihydrite to hematite under conditions of good aeration. A bleached eluvial horizon of loamy texture lies abruptly over the argillic horizon. Such a soil classifies as a Calcic Palexeralf (USDA, 1975) or as an Eutric Planosol (FAO, 1988). The (slight) differentiation in the texture of these soils is attributed to the origin of the parent material: the deposits of the Xerias river are less finely grained and more gravelly than those of the Peneios river.

Subsequent erosion and dissection has shaped the Pleistocene terrace and affected most soils formed in it. Palexeralfs which are the oldest soils of the Larissa plain, occupy the greater part of the stable high terrace. (Geological) erosion of the Pleistocene terrace seems to have begun before farming was introduced to the plain because many early and middle Neolithic settlement sites are on top of truncated Palexeralfs (Halstead, 1984). Erosion accelerated after the natural cover was cleared by Man.

Man settled on the Pleistocene terrace and began farming as early as 8,000 years BP (Theocharis, 1973). More than 350 pre-historic settlement sites are known in the Larissa lowland; they date back to the period from 8,000 years BP to 3,000 years BP when the area was a major cultural centre. The close relation between the introduction of farming and the renewed deposition of the Girtoni alluvium (see Subsection 2.3.2) suggests that early cultivation has accelerated erosion and aggradation of the floodplain. A new equilibrium was apparently reached in pre-modern times. Near the margins of the Pleistocene terrace, the Girtoni soil developed a nodular calcic horizon overlain by an argillic horizon with a brownish colour, a strong blocky structure and thin clay films. In contrast with the Palexeralfs, the calcic horizon of this soil contains small, semi-hard nodules with a diameter of 1/2 cm. Demitrack (1986) claims that formation of large and hard pedogenic lime nodules takes at least 11,000 to 15,000 years under the circumstances prevailing in the Larissa area; Girtoni soil, which is less than 6,500 years old, is the youngest soil in the plain possessing a nodular calcic horizon.

Erosion accelerated in pre-modern and modern times and removed part or all of the surface horizons of many Palexeralfs. Deep ploughing has become common practice over the last decades, and mixed the topsoil with the upper part of the argillic horizon. Such soils have a clayey or clayloamy upper layer and lack the abrupt textural change to the subsoil, characteristic of untouched Palexeralfs. These soils are classified as Calcic Haploxeralfs (USDA, 1975) or Calcic Luvisols (FAO, 1988). In the undulating transition areas between the Pleistocene terrace and the Holocene terraces or the flood plain, severe erosion has removed the argillic horizon completely; the soils are stripped to their calcic horizons, and are classified as Calcixerollic Xerochrepts (USDA, 1975; Calcisols, FAO, 1988) (Plate 5B).

Some soils have a finely textured argillic horizon close to or at the surface; upon drying, they develop cracks down to a depth of 50 cm or more. Apparently, these cracks are partly filled with surface materials and, upon wetting, the developed shear stress causes the formation of slickensides. These soils are classified as Palexerollic Chromoxererts (USDA, 1988) or Calcic Vertisols (FAO, 1988).

Most soils on the Holocene terraces are considerably younger than all soils mentioned so far. They have developed in young calcareous Peneios deposits on top of the Girtoni soil. Pedogenesis produced a cambic horizon overlying a calcic (Ck) horizon with soft powdery lime. The soils are classified as Calcixerollic Xerochrepts. However, their properties differ greatly from those of the Calcixerollic Xerochrepts on the Pleistocene terrace, which are eroded Alfisols.

On a Holocene terrace (Plate 4E) and particularly close to the transition to the Pleistocene terrace, soils with a well developed argillic Bt horizon but lacking a calcic horizon were found. They were classified as Typic Haploxeralfs (USDA, 1975) or Haplic Luvisols (FAO, 1988). The Bt horizon is brown, moderately thick and has thick clay skins (Plates 4C&D). The soils appear to be older than the Girtoni soil but younger than the Palexeralfs or their eroded counterparts (Haploxeralfs) on the Pleistocene terrace. The parent material is non calcareous and is believed to be erosion material from the adjacent Pleistocene terrace, which eroded away at times when the Holocene terraces were formed. According to this hypothesis, these Typic Haploxeralfs are older than the Girtoni soil but younger than the Palexeralfs.

The soils of the present flood plain are recent and show no diagnostic horizons. They are all calcareous, stratified and exhibit a high lateral variability in texture. They are classified as Typic Xerofluvents (USDA, 1975) or Calcaric Fluvisols (FAO, 1988) (Plate 4B).

Palexeralfs are the oldest soils in the Larissa plain and much older than the soils on the Tertiary hills. It is clear that soil age corresponds with the age of the land surface rather than with the age of the (deposition of the) parent materials; the age of the land surface is strongly connected with the topography of the Larissa area. In contrast with the Tertiary slopes, soils on the Pleistocene and Holocene terraces have probably never had a mollic epipedon, because the natural vegetation was cleared for cultivation, and the crop residues were burned since ancient times. The very low organic matter contents are typical of these soils.

Systematics and nomenclature

The official Greek pedon code was used during field work (see Fig. 2.12). This code is not employed in the final compilation of the Platanoulia soil map. The legend of the soil map distinguishes between physiographic positions, viz. (F) soils of the Pleistocene terrace and particularly of the higher level (F1) and the middle level (F2), (H) soils of the Holocene terraces, and (A) soils of the flood plain. The strong relation which exists between the physiography of the land and soil formation makes that many symbols can be omitted; slope grade, erosion class, calcium carbonate pattern, and texture of the topsoil are rather uniform within a particular physiographic landform. For example, Haploxeralfs on the Pleistocene terrace have a combination of a clay loamy topsoil (class 4), slight erosion (class 1), calcium carbonate within 120 cm (class 1), and they are nearly level (slope class A-B) (see Fig. 2.12).

To ensure that the map can be consulted for correlation purposes, etc., further subdivision at lower levels is based on taxonomic classification. In line with the Greek system, the Soil Taxonomy (USDA, 1975) has been used. The physiographic units comprise one or more mapping units whose codes reflect the Taxonomic Soil Order: A for Alfisols, I for Inceptisols, V for Vertisols and E for Entisols. At the Subgroup level, the following units were found in the study area: Typic and Calcic Palexeralfs (coded F1Ap), Calcic Haploxeralfs (coded F1Ah and F2Ah, respectively), Typic Haploxeralfs (coded HAh), Calcixerollic Xerochrepts (coded F1Ic if occurring on the Pleistocene terrace and HIc on the Holocene terraces), Fluventic Xerochrepts (coded F2If), Palexerollic Chromoxererts (coded F1Vp) and Typic Xerofluvents (coded AE). In the case of the Alfisols, two series are distinguished: (1) somewhat gravelly clay loamy soils (Xerias series), and (2) clay soils (Peneios series); they are further subdivided in well drained (w) and in moderate well drained (m) soils. Likewise, Vertisols are divided in well to moderately well drained (w) and in imperfectly drained (m) soils. In the case of Entisols, 3 series are distinguished: (1) coarse soils, (2) medium-textured soils, and (3) moderately fine-textured soils.

The soil legend for the Platanoulia area (key to the soil map)

1. Soils of the Pleistocene terrace

a. higher level (soils with reddish Bt horizon)

F1Ap1w	Deep, well drained soils, having a loamy surface over a thick, clayloamy Bt horizon.
F1Ah1w	Moderately deep, well drained, clayloam soils having an argillic horizon.
F1Ap1m	Deep, moderately well drained soils having a loamy surface over a thick, clayloamy Bt horizon.
F1Ap2w	Deep, well drained soils having a loamy surface over a thick, clayey Bt horizon.
F1Ah2w	Moderately deep, well drained, clay soils having an argillic horizon.
F1Ah2m	Moderately deep, moderately well drained, clay soils having an argillic horizon.
F1Ap2m	Deep, moderately well drained soils, having a loamy surface over a thick clayey Bt horizon.
F1Vpw	Deep, well to moderately well drained, cracking clay soils having an argillic horizon.
F1Vpm	Deep, moderately well to imperfectly drained, cracking clay soils having an argillic horizon.
F1Ic	Shallow, well to excessively drained, fine-textured soils having a shallow calcic horizon.

b. middle level (brown soils)

F2Ah	Deep, well drained, clayloam soils having an argillic horizon.
F2If	Deep, well drained, medium-textured soils having a cambic horizon.

2. Soils of the Holocene terraces

HAh	Deep, well drained, clayloam soils having an argillic horizon.
HIc	Moderately deep, well drained, moderately fine-textured soils having a calcic horizon.

3. Soils of the flood plain

AE1	Moderately deep, excessively drained, calcareous, coarse-textured soils.
AE2	Moderately deep, well drained, calcareous, medium-textured soils.
AE3	Moderately deep, well drained, calcareous, moderately fine-textured soils.

Soils of the Pleistocene terrace

Unit F1Ap1w; deep, well drained soils, having a loamy surface over a thick, clayloamy Bt horizon.

Extent: 487 ha, 23.2% of the area, 26.5% of the Pleistocene terrace.
                    4 3 3
Pedon code: B-------Axpc/t
                    A 0 1
Parent material: Pleistocene alluvium of the Xerias river consisting of slightly calcareous, slightly gravelly, medium to moderately fine-textured materials.
Relief: Flat to very gently undulating (slope 0-3%).
Erosion: None; soils are very susceptible to sealing.
Stoniness: Nil.
Land use: Rainfed wheat is the main crop followed by irrigated cotton, pear, apple, grape and almond orchards. The perennial crops are irrigated with dripping systems.
Soils, general: Deep, well drained soils; the remaining few undisturbed soils have an A-E-Bt-Ck horizon sequence. The eluvial E horizon extends down to a depth of 30-40 cm. Deep ploughing has mixed the surface horizons so that an Ap horizon normally overlies the Bt horizon. The latter is characterized by thick, continuous clay cutans and extends down to 110-130 cm. Normally a transitional B/C is present between 110-130 and 150+ cm. Fine pores occur throughout the solum. In the cropped soils, common roots are still found 80 cm below the surface or deeper;
  colour: the Ap horizon is brown (7.5 YR 5/3-4 if dry and one colour value less if moist). Surface horizons of undisturbed soils (A and/or E) may be pinkish grey to light brown (7.5 YR 7/3). The hue becomes redder with increasing depth. The Bt horizon is dark reddish brown if moist and reddish brown (5 YR 3-4/3-4) to occasionally brown (7.5 YR 4/4) if dry;
  texture: loam to silty loam in the Ap, A and/or E horizons. In some cropped soils, deep ploughing has mixed the topsoil and the subsoil and the texture class is loam to clayloam. The Bt-horizon is typically a clayloam with a clay content of less than or equal to 41%. The normal range in cropped soils is: Ap: 15-25% clay, 27-43% silt and 25-42% sand; Bt: 32-41% clay, 29-40% silt and 22-37% sand. The gravel content ranges between 2 and 4% in the Ap, 2 and 11% in the Bt, and is highly variable in the subsoil, occasionally exceeding 30%;
  structure: the Ap horizon has a massive to weak subangular blocky structure; the Bt horizon is characterized by strong angular blocky or prismatic elements, usually coarse and occasionally medium in size. In the transitional B/C horizon, the structure is moderate to strong, medium to coarse angular blocky;
  consistence: slightly sticky and plastic (wet), friable (moist), hard to very hard (dry) topsoil, over a sticky to very sticky and plastic (wet), firm to very firm (moist), hard to very hard (dry) Bt horizon;
  chemical properties: calcium carbonate has moved down and is absent in the Ap and Bt horizons. It is present in the B/C and C horizons, also in secondary forms (nodules 1-2 cm in diameter or larger). The pH ranges between 5.2 and 7.0 in the Ap horizon and between 6.2 and 7.2 in the Bt horizon, and increases to values up to 8.2 deeper down. The soils are very poor in organic matter, that is normally below 1.5% in the topsoil and decreases sharply with depth. The CEC is usually less than 8 cmol(+)/kg soil but increases to 20 cmol(+)/kg in the clayloamy Bt horizon. The base saturation ranges from 70-85% in the Ap and Bt horizons to 100% in the sub-soil, with Ca^{2+} dominating the exchange complex.
Diagnostics: Ochric epipedon, Eluvial E horizon, Argillic (Argic, FAO, 1988) horizon, abrupt textural change, normally a calcic horizon.
Soil classification: USDA (1975), Calcic Palexeralfs (Typic if the calcic horizon is deeper than 150 cm from the soil surface).
  FAO/Unesco (1988): Eutric Planosols.
Bordering units: F1Ap2w, F1Ap2m, F1Ap1m, F1Ah1w, F1Ah2m, F1Vpm, F1Ic.
Remarks: Pedon P6 (Plate 5A) in Appendix A.2 may represent this mapping unit.

Unit F1Ah1w; moderately deep, well drained, clayloam soils having an argillic horizon.

Extent: 82 ha, 3.9% of the area, 4.5% of the Pleistocene terrace.
4 3 4 4 3 4 4 3 4
Pedon codes: B------- Axhc B-------- Axhc B-------- Axhc
A 1 1 A 2 1 B 2 1
Parent material: Pleistocene alluvium of the Xerias river consisting of slightly calcareous, slightly gravelly, medium to moderately fine-textured materials.
Relief: Nearly flat to very gently undulating (slope 1-6%) transition area between higher and middle Pleistocene terrace level (F1-F2).
Erosion: Slight to moderate; soils are susceptible to sealing.
Stoniness: Nil.
Land use: Rainfed wheat is the main crop followed by irrigated cotton, pears, apples and grapes.
Soils, general: Well drained, slightly gravelly clayloamy soils with an Ap-Bt-Ck horizon sequence. The soils resemble those of unit FAp1w but are shallower with the calcic horizon at a depth of 70-90 cm. The original A horizon has eroded away and the Bt horizon is near or at the surface. The Ap horizon is therefore typically clayloamy. Normally, a transitional B/C horizon with clay skins and secondary lime in pores and ped faces occurs between the Bt and Ck horizons. Very fine interstitial pores are common throughout the control section. Roots are common in the upper 80 cm of the soils. For more properties see unit FAp1w.
Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon, Calcic horizon.
Soil classification: USDA (1975), Calcic Haploxeralfs.
FAO/Unesco (1988): Calcic Luvisols.
Bordering units: F1Ap1w, F1Ap1m, F1Ic.

Unit F1Ap1m; deep, moderately well drained soils having a loamy surface soil over a thick, clayloamy Bt horizon.

Extent: 95.2 ha, 4.5% of the area, 5.2% of the Pleistocene terrace.
4 3 3
Pedon code: C-------Axpc
A 0 1
Parent material: Pleistocene alluvium of the Xerias river consisting of slightly calcareous sandy clay materials.
Relief: Flat (slope 0-1%).
Erosion: None; the soils are very susceptible to sealing.
Stoniness: Nil.
Land use: Rainfed wheat and irrigated cotton and grapes.
Soils, general: Very deep, moderately well drained and finely textured soils. The few undisturbed occurrences have an A-E-Bt-Ck horizon sequence. Deep ploughing has mixed the surface horizons so that the sequence is often: Ap (0-30 cm)-A/B (30-50 cm)-Bt (50-110/120 cm)-B/C and/or Ck (110/120-150 cm+). The Bt horizon is characterized by thick, continuous clay cutans and iron and manganese concretions. Concretions are also observed in the B/C horizon but they are less abundant. Very fine and fine pores are present throughout the solum. Roots extend to the base of the argillic horizon;
colour: the Ap horizon is usually brown (7.5 YR 5/3-4 if dry and one colour value less if moist). The surface horizons of the undisturbed soils (A and/or E) may be pinkish gray to light brown (7.5 YR 7/3). With increasing depth, the hue becomes redder, viz. dark reddish brown (moist) to reddish brown (dry) Bt horizon (5 YR 3-4/2-4);
texture: the Ap horizon consists of loam to silty loam; usual range: 10-21% clay, 40-43% silt, 39-47% sand. The Bt horizon is clayloam with 31-37% clay, 24-28% silt and 36-41% sand. Gravel makes up 2-6% of the soil volume and consists largely of quartz fragments, 2-5 cm in diameter;

structure: same as in unit FAp1w;

consistence: slightly sticky and plastic (wet), friable (moist), hard to very hard (dry) in the Ap, changes to sticky to very sticky and plastic (wet), very firm (moist), very hard (dry) in the Bt;

chemical properties: calcium carbonate is present below the argillic horizon e.g. in the transitional B/C horizon, also in secondary forms (large nodules). The pH ranges between 4.9 and 5.9 in the topsoil and increases to around 6.5 in the Bt horizon and 7.5 below it. The organic matter content is less than 1% in the surface soil and decreases sharply with depth. For more chemical properties see unit FAp1w.

Diagnostics: Ochric epipedon, Eluvial E horizon, Argillic (Argic horizon; FAO, 1988), abrupt textural change, calcic horizon.

Soil classification: USDA (1975), Calcic Palexeralfs (Typic, if secondary lime is accumulated below the solum).

FAO/Unesco (1988): Eutric Planosols.

Bordering units: F1Ap1w, F1Ap2w, F1Ah1w, F1Ic.

Remarks: For a representative profile, see Pedon P7 in Appendix A.2.

Unit F1Ap2w; deep, well drained soils having a loamy surface over a thick, clayey Bt horizon.

Extent: 387.4 ha, 18.4% of the area, 21.04% of the Pleistocene terrace.

4 3 3
Pedon code: B-------Axpc
A 0 1

Parent material: Pleistocene alluvium of the Peneios river consisting of calcareous, fine textured materials.

Relief: Flat to very gently undulating (slope 0-3%).

Erosion: None; the soils are very susceptible to sealing.

Stoniness: Nil.

Land use: Rainfed wheat followed by irrigated cotton, pears, apples, grapes and occasionally almonds, water melon and rarely maize.

Soils, general: The horizon sequence is the same as that of the Palexeralfs of unit FAp1w. However, the Bt horizon is finer textured (see below). The adequate drainage is attributed to sandy or gravelly aquifers in the subsoil. Very fine and fine pores are present throughout the solum. In the cropped soils, roots extend to the base of the argillic horizon or deeper;

colour: generally less reddish than the Alfisols of the previous units: the Ap horizon is brown or yellowish to dark yellowish brown (10 YR 4-5/3-4); the Bt horizon is dark brown (7.5 YR 4/3-4);

texture: Ap, or A and E horizons: loam; range: 21-27% clay, 35-42% silt, 31-44% sand. The clay content in the Bt horizon exceeds 40%; normal range: 42-46% clay, 25-37% silt, 20-33% sand. The B/C or C horizons (110-150 cm) are clayey to clayloamy (30-44% clay, 23-38% silt, 25-40% sand). Note that the texture class is clay at least to a depth of 120 cm and usually down to 150 cm. The gravel content ranges from 2 to 5% in the Ap and Bt horizons, and from 3 to 9% but occasionally up to 15% in the horizons below;

structure: massive to weak subangular blocky in the Ap horizon; the Bt horizon is characterized by strong angular blocky or prismatic elements, usually coarse and occasionally medium-sized. In the transitional B/C horizon, the structure is moderate to strong, medium to coarse angular blocky;

consistence: slightly sticky and plastic (wet), friable (moist), hard to very hard (dry) in the topsoil, and sticky-very sticky and plastic (wet), firm to very firm (moist), hard to very hard (dry) in the Bt horizon;

chemical properties: calcium carbonate has leached down and is present in the Ck or/and B/C horizons, also as secondary nodules 1-2 cm in diameter. The total $CaCO_3$ content ranges from 15 to 30%. The pH ranges from 4.9 to 7.0 in the Ap horizon and from 6.1 to 7.0 in the upper parts of the Bt horizon to a depth of at least 70-80 cm and occasionally 110 cm. Below, the pH increases to values higher than 7.4, with a maximum of 8.5. The organic matter content is lower than 1.5% in the Ap horizon and decreases with depth to very low values. The CEC of the surface horizon lies in the same range as in the soils of the previous groups (< =8 cmol(+)/kg soil). It increases in the Bt horizon, ranging from 25 to 30 cmol(+)/kg soil. The base saturation ranges from 70-85% in the Ap and Bt horizons to 100% in the sub-soil, with Ca dominant at the exchange complex.

Diagnostics: Ochric epipedon, Eluvial E horizon, Argillic (Argic, FAO, 1988) horizon, abrupt textural change, calcic horizon.

Soil classification: USDA (1975), Calcic Palexeralfs.
FAO/Unesco (1988): Eutric Planosols.

Bordering units: F1Ap1w, F1Ap1m, F1Ap2m, F1Ah1w, F1Ah2w, F1Ah2m, F1Ic, F1Vpw, HIc.

Unit F1Ah2w; moderately deep, well drained, clay soils having an argillic horizon.

Extent: 63.2 ha, 3.0% of the area, 3.4% of the Pleistocene terrace.

            4 3 4   4 3 4   4 3 4   4 3 4
Pedon codes: B------ Axhc B-------- Axhc B-------- Axhc B--------- Axhc
            A 1 1   A 2 1   B 1 1   B 2 1

Parent material: Pleistocene alluvium of the Peneios river consisting of calcareous, fine textured materials.

Relief: Nearly flat to very gently undulating (slope 2-6%).

Erosion: Slight to moderate sheet wash; the soils are susceptible to sealing.

Stoniness: Nil.

Land use: Rainfed wheat and irrigated cotton; also some pears (varieties tolerant to $CaCO_3$).

Soils, general: Moderately deep, well drained, fine-textured soils with an Ap-Bt-B/C-Ck horizon sequence. Due to surface erosion, the clayey Bt horizon has come near or at the soil surface. A calcic horizon occurs at a depth of 70-90 cm from the surface and contains carbonate nodules 1-2 cm in diameter or larger. The good drainage is attributed to sandy or gravelly material below the solum. Very fine interstitial pores are common throughout the control section. Common roots are found to a depth of 90 cm;

colour: the Ap horizon is yellowish brown (10 YR 5/4 dry); the Bt horizon is normally dark brown to brown (7.5 YR 3-4/4);

texture: the Ap horizon is clayloam to (occasionally) loam (25-33% clay, 26-29% silt and 41-46% sand). The Bt horizon resembles that of the unit FAp2w (range: 47-51% clay,16-18% silt, 33-35% sand). The Ck horizon consists of clay to sandy clayloam;

structure: the Ap horizon has a weak subangular blocky or weak medium to coarse granular blocky structure. In the lower part of Ap horizon or the upper part of the Bt horizon, the structure is strong medium to coarse subangular blocky. The Bt horizon is characterized by strong coarse angular blocky or prismatic elements, changing to weak coarse subangular blocky in the Ck horizon below;

consistence: sticky (wet), friable (moist), hard (dry) in the topsoil, changing to very sticky and plastic (wet), firm to very firm (moist), very hard (dry) in the Bt horizon;

chemical properties: calcium carbonate has leached down and is absent from the Ap and Bt horizons. It is present in the Ck horizon (also in secondary forms), whereas the total content lies normally between 15 and 30%. The pH is slightly above 7.0 in the upper soil and increases toward the calcic horizon (to 8.3). The organic matter content is less than 1.5% in the Ap horizon and decreases gradually with depth. The CEC is between 10 and 15 cmol(+)/kg in the topsoil and increases to 20-25 cmol(+)/kg in the Bt horizon.

Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon, calcic horizon.

Soil classification: USDA (1975), Calcic Haploxeralfs.
FAO/Unesco (1988): Calcic Luvisols.

Bordering units: F1Ap2w, F1Ap2m, F1Ah1w, F1Ic, F1Vpw, HAh, HIc.

Unit F1Ah2m; moderately deep, moderately well drained, clay soils having an argillic horizon.

Extent: 84 ha, 4.0% of the area, 4.6% of the Pleistocene terrace.
4 3 4
Pedon code: C------ Axhc
A 1 1
Parent material: Pleistocene alluvium of the Peneios river consisting of calcareous, fine textured materials.
Relief: Nearly flat to very gently undulating (slope 2-3%).
Erosion: Moderate sheet wash; the soils are susceptible to sealing.
Stoniness: Nil.
Land use: Irrigated cotton and pears (varieties tolerant to $CaCO_3$).
Soils, general: Moderately deep, moderately well drained, fine-textured soils with an Ap-Bt-B/C-Ck horizon sequence. Due to surface erosion, the clayey Bt horizon has come at the soil surface. A calcic horizon occurs at a depth of 70-90 cm from the surface and contains carbonate nodules 1-2 cm in diameter or larger. The soils greatly resemble those of the previous unit except for their less adequate drainage.
Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon, calcic horizon.
Soil classification: USDA (1975), Calcic Haploxeralfs.
FAO/Unesco (1988): Calcic Luvisols.
Bordering units: F1Ap2w, F1Ap2m, F1Vpw, F1Ap1w.
Remarks: Pedon P3 (Plate 5C) in Appendix A.2 may represent the Calcic Haploxeralfs (Peneios series).

Unit F1Ap2m; deep, moderately well drained soils, having a loamy surface over a thick clayey Bt horizon.

Extent: 93.6 ha, 4.5% of the area, 5.1% of the Pleistocene terrace.
4 3 3
Pedon code: C-------Axpc
A 0 1
Parent material: Pleistocene alluvium of the Peneios river consisting of calcareous, fine textured materials.
Relief: Nearly flat to very gently undulating (slope 1-3%).
Erosion: None; the soils are very susceptible to sealing.
Stoniness: Nil.
Land use: Rainfed wheat and irrigated cotton. Some almonds trees and water melons.
Soils, general: The soils are very similar to those of unit FAp2w except for their moderately well drainage.
Soil classification: USDA (1975), Calcic Palexeralfs; FAO/Unesco (1988): Eutric Planosols.
Bordering units: F1Ap2w, F1Ap1w, F1Vpw, F1Ah2m.

Unit F1Vpw; deep, well to moderately well drained, cracking clay soils having an argillic horizon.

Extent: 118 ha, 5.6% of the area, 6.4% of the Pleistocene terrace.
4 3 5 4 3 5 4 3 4
Pedon codes: B/C-------- Vxcp B/C -------- Vxcp B/C ------- Vxcp
A 2 1 A 2 2 A 1 1
Parent material: Pleistocene alluvium consisting of calcareous, fine-textured materials.
Relief: Flat to very gently undulating (slope 0-3%).
Erosion: Slight and occasionally moderate sheet wash. Often the topsoil has eroded away and the clayey Bt horizon is exposed at the surface.
Stoniness: Nil.
Land use: Rainfed wheat, irrigated water melon, maize and cotton.

Soils, general: Deep, moderately well drained, fine-textured soils with an Ap-Bt-C(k) horizon sequence. The argillic Bt horizon is characterized by broken, thin to thick clay skins on ped faces; it may extend down to 100-120 cm. The Bt horizon has come near or at the surface due to erosion. A concretional calcic horizon exists at some depth below 110 cm and may extend to a depth of 160 cm. If the soils are dry, cracks wider than 1 cm extend deeper than 50 cm of the soil surface, whereas in the lower part of the Bt horizon, slickensides of various sizes are common. Few, small (0.1 cm in diameter) spherical Mn nodules are present throughout the soil profile. Common, very fine to fine interstitial and ellipsoidal pores in the upper soil, become few, and very fine at greater depth. Roots are abundant in the Ap horizon and common in the upper parts of the Bt horizon; few roots are found down to 100 cm;

colour: varies from brown or dark yellowish brown (10 YR 4/3-4) to dark brown to strong brown (7 YR 3/3-6) or, in some cases, even redder. The calcic horizons, if present in the lower part of the profile, are lighter, viz. yellowish brown to yellow (10YR 5-7/4-6);

texture: the surface soil (Ap) has a clay to occasionally clayloam texture. The subsoil and substratum are clayey. Range: Ap: 25-48% clay, 24-43% silt, 21-36% sand; Bt: 44-48% clay, 26-31% silt, 23-30% sand in the upper part and 45-47% clay, 24-34% silt, 18-30% sand; Ck: 39-51% clay, 26-35% silt, 21-35% sand;

structure: the Ap horizon has a weak medium to coarse subangular blocky structure; the Bt horizon has medium to strong coarse angular blocky or medium prismatic elements, and grades into the structureless parent material below;

consistence: the topsoil is sticky to very sticky and plastic to very plastic (wet), friable to firm (moist) and hard to very hard (dry). The Bt horizon is sticky to very sticky and plastic to very plastic (wet), firm to very firm (moist) and hard to very hard (dry). The calcic horizon, if present, is slightly sticky to sticky (wet), very friable (moist) and soft to slightly hard (dry);

chemical properties: calcium carbonate has leached down and is absent from the Ap and Bt horizons; it is normally present below 100 cm, in the concretionary Ck horizon. The total $CaCO_3$ content varies between 7 and 25%. The pH ranges between 6 and 7.3 in the Ap, 7-7.5 in the Bt and increases with depth, reaching a value up to 8.5 in the Ck-horizon. The organic matter content is low (1-1.6%) in the Ap horizon and decreases gradually with depth. The CEC is proportional to the clay content. Thus in the Bt horizon, the CEC assumes a value between 25 and 30 cmol(+)/kg soil due to the high clay content. In the clayloamy Ap horizon, the CEC may be only 15 cmol(+)/kg.

Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon, vertic properties, slickensides. Occasionally the Ck horizon is a true calcic horizon (when the $CaCO_3$ content exceeds 15%).

Soil classification: USDA (1975), Palexerollic Chromoxererts.
FAO/Unesco (1988): Calcic Vertisols.

Bordering units: F1Ap1w, F1Ap2w, F1Ap2m, F1Ah2w, F1Vpm, F1Ic.

Remarks: For a representative profile see Pedon 2 in Appendix A.2.

Unit F1Vpm; deep, moderately well to imperfectly drained, cracking clay soils having an argillic horizon.

Extent: 28.2 ha, 1.3% of the area, 1.5% of the Pleistocene terrace.

4 3 5
Pedon code: C/D-------Vxcp
A 2 1

Parent material: Pleistocene, calcareous, fine-textured alluvium.

Relief: Flat to very gently undulating (slope < 1%).

Erosion: Slight to moderate sheet wash. The topsoil has eroded away and the clayey Bt horizon is exposed at the surface.

Stoniness: Nil.

Land use: Irrigated summer crops, e.g. water melon, maize and cotton.

Soils, general: The soils resemble those of unit F1Vpw except for their moderate to imperfect drainage. This is due to the lower position of this unit in the landscape. The groundwater level rises in winter (perched), and the crops (winter cereals, orchards, etc.) may suffer from excess moisture.
Soil classification: USDA (1975), Palexerollic Chromoxererts.
FAO/Unesco (1988): Calcic Vertisols.
Bordering units: F1Ap2m, F1Ah2m, F1Vpw.

Unit F1Ic; shallow, well to excessively drained, fine-textured soils having a shallow calcic horizon.

Extent: 234.8 ha, 11.2% of the area, 12.7% of the Pleistocene terrace.
4 3 5 4 3 4 4 3 4
Pedon codes: A/B------- Ioxc A/B-------- Ioxc A/B------- Ioxc
B 3 3 B 4 2 C 4 3
Parent material: Pleistocene alluvium consisting of slightly calcareous sandy clay materials.
Relief: Undulating (slope 3-12%).
Erosion: Severe sheet wash and moderate rill erosion; the soils are very susceptible to sealing.
Stoniness: Large carbonate nodules (gravel size) on 2-4% of the surface.
Land use: Rainfed wheat and low yielding irrigated cotton.
Soils, general: Shallow soils formed after the Ap horizon and all or the greater part of the argillic horizon have eroded away. The calcic horizon came very close to the soil surface or is exposed. The horizon sequence is Ap-C(k). The soils are well to excessively drained. Rooting is shallow;
colour: brown (10 YR 4/3) in the Ap horizon changing to yellowish brown in the subsoil (10 YR 5-6/4);
texture: clayloam to clay throughout;
structure: moderate medium to coarse subangular blocky to a depth of 50 cm, weakening with depth;
consistence: very sticky (wet), firm (moist), hard to very hard (dry) in the Ap horizon, and sticky (wet), friable (moist), very hard (dry) deeper down;
chemical properties: the soils are very calcareous. $CaCO_3$ makes up 30-40% of the Ap horizon. Abundant secondary lime in soft powdery forms, concretions and large nodules (1-2 cm or more in diameter). The pH lies between 7.8 and 8.2 throughout the control section. The organic matter content is about 1.6%; the CEC lies between 15 and 20 cmol(+)/kg soil (base saturation is 100%).
Diagnostics: Ochric epipedon, calcic horizon.
Soil classification: USDA (1975), Calcixerollic Xerochrepts.
FAO/Unesco (1988): Haplic Calcisols.
Bordering units: F1Ap1w, F1Ap1m, F1Ap2w, F1Ap2m, F1Ah1w, F1Ah2w, F1Vpw, F2If, HIc, HAh, AE1, AE2.
Remarks: For a representative profile, see Pedon P5 (Plate 5B) in Appendix A.2.

Unit F2Ah; deep, well drained, clayloam soils having an argillic horizon.

Extent: 92.8 ha, 4.4% of the area, 5.0% of the Pleistocene terrace.
4 3 3
Pedon code: B-------Axhc
A 0 1
Parent material: Late Pleistocene to early Holocene, calcareous, moderately fine-textured alluvium of the Xerias river.
Relief: Level to nearly level (slope <2%).
Erosion: None;
Stoniness: Nil.
Land use: Pears, apples and grapes are grown in "palmetes" and irrigated with dripping

systems; they produce high yields.

Soils, general: Deep, well drained soils with an Ap-Bt-Ck horizon sequence. The Ap horizon is 20-30 cm thick. The Bt horizon is characterized by moderately thick, continuous clay cutans and extends to a depth of some 70-80 cm. Normally a transitional B/C horizon exists. Very fine pores are present throughout the solum. Restrictions to rooting do not exist;

colour: brown in the topsoil (10 YR 5/3) and slightly darker in the Bt horizon below (10YR 4/3). The Ck horizon is yellowish brown (10 YR 5/4);

texture: loam in the Ap horizon; clayloam in the subsoil (Bt and Ck horizons): 30-37% sand, 33-40% silt, 30-36% clay;

structure: the weak medium subangular blocky structure of the Ap horizon changes to moderate medium to coarse subangular blocky in the Bt horizon. The Ck-horizon is structureless;

consistence: sticky (wet), friable (moist), hard (dry), throughout;

chemical properties: calcium carbonate is absent from the surface soil, down to the base of the Bt. It is present in the B/C and may reach 25% or more in the Ck-horizon below. Nodular secondary lime is common in the Ck horizon. The pH ranges from 7.5 to 8.1. The organic matter content is about 1.5 in the Ap and decreases gradually with depth. The CEC ranges from about 10 cmol(+)/kg soil in the Ap to 13-20 cmol(+)/kg in the horizons below.

Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon, Calcic horizon (Ck).

Soil classification: USDA (1975), Calcic Haploxeralfs; FAO/Unesco (1988): Haplic Luvisols.

Bordering units: F2If.

Remarks: For a representative profile, see Pedon P8 in Appendix A.2.

Unit F2If; deep, well drained, medium-textured soils having a cambic horizon.

Extent: 75.4 ha, 3.6% of the area, 4.1% of the Pleistocene terrace.

4 2 3
Pedon code: B-------Ioxf
A 0 2

Parent material: Holocene, calcareous alluvium of the Xerias river.

Relief: Level to nearly level (slope <2%).

Erosion: None;

Stoniness: Few surface gravels and stones.

Land use: Mostly pears and grapes producing high yields. Drip irrigation is applied.

Soils, general: Deep, well drained soils with an Ap-Bw-Ck horizon sequence. The Ap horizon is 20-30 cm thick. The Bw horizon extends down to 70-80 cm. Normally a transitional B/C exists. Very fine and fine pores are present throughout the solum. Restrictions to rooting do not exist;

colour: typically brown in the topsoil (10 YR 5/3) and slightly darker in the underlying Bt horizon (10YR 4/3). The Ck horizon is usually yellowish brown (10 YR 5/4);

texture: loam in the Ap; clayloam in the Bw changes to loam or sandy loam below;

structure: the weak medium subangular blocky structure of the Ap horizon changes to a moderate medium to coarse subangular blocky structure in the Bw horizon. The Ck horizon is structureless;

consistence: sticky (wet), friable (moist), hard (dry), throughout;

chemical properties: the $CaCO_3$ content varies with the depth from 0 to 10% as a result of original stratification. Lime is present in the Ck horizon also in secondary forms (soft powdery lime and concretions). The pH ranges from 7.5 to 8.0. The organic matter content is about 1.6 in the Ap horizon and decreases irregularly with depth. The CEC ranges from about 7 to 15 cmol(+)/kg soil (base saturation=100%).

Diagnostics: Ochric epipedon, Cambic horizon (Bw).

Soil classification: USDA (1975), Fluventic Xerochrepts;
FAO/Unesco (1988): Calcaric Cambisols.

Bordering units: F2Ah, AE2.

Remarks: For a representative profile, see Pedon P9 in Appendix A.2.

Soils of the Holocene terraces

Unit HAh; deep, well drained, sandy clayloam soils having an argillic horizon.
Extent: 32.8 ha, 1.6% of the area, 28.0% of the Holocene terraces.

4 3 4
Pedon code: B-------Axht
A 0 0

Parent material: Early Holocene, non-calcareous colluvial deposits confining probably to the eroded upper parts of neighbouring soils on the Pleistocene terrace.
Relief: Level to nearly level (slope 0-3%).
Erosion: None; soils are very susceptible to sealing.
Stoniness: Nil.
Land use: Pears, apples and grapes are grown in "palmetes", irrigated with drip irrigation and producing high yields.
Soils, general: Deep, well drained soils with an Ap-Bt-C horizon sequence. The Ap horizon is 20-30 cm thick. The underlying Bt horizon is characterized by thick, continuous clay cutans and extends to a depth of about 120 cm. Very fine pores are present throughout the solum. Restrictions to rooting do not exist;
colour: dark yellowish brown to yellowish brown (10 YR 4-5/4-5) in the topsoil and substratum (Ap and C horizons). The Bt horizon is dark brown to brown (7.5 YR 3-4/3);
texture: sandy clayloam throughout: 27-32% clay, 16-18% silt and 52-55% sand;
structure: weak coarse subangular blocky elements in the Ap horizon over strong coarse angular blocky elements in the Bt horizon;
consistence: slightly sticky (wet), friable (moist), loose to slightly hard (dry) in the topsoil changes to sticky, firm (moist), hard to very hard in the Bt horizon below;
chemical properties: Calcium carbonate is absent but the soil has an alkaline reaction with pH values between 7.5 and 7.9. Unlike the Pleistocene Alfisols, their organic matter content is reasonably high in the Ap horizon (3%), but decreases rapidly with depth. The CEC ranges from 16 to 20 cmol(+)/kg soil. The base saturation is 100% with Ca dominant on the exchange complex.
Diagnostics: Ochric epipedon, Argillic (Argic, FAO, 1988) horizon.
Soil classification: USDA (1975), Typic Haploxeralfs.
FAO/Unesco (1988): Haplic Luvisols.
Bordering units: F1lc, F1Ah2w, Hlc, AE2, AE3.
Remarks: For a representative profile, see Pedon P1 (Plates 4C and 4D) in Appendix A.2.

Unit HIc; moderately deep, well drained, moderately fine-textured soils having a calcic horizon.

Extent: 84.4 ha, 4.0% of the area, 72.0% of the Holocene terraces.

3 3 4
Pedon code: B--------- Ioxc
A 0 1/2

Parent material: Holocene, calcareous, moderately fine-textured alluvium. Relief: Nearly level (slope 0-2%).
Erosion: None.
Stoniness: Gravel < =2% on the surface.
Land use: Irrigated perennials, vegetables, alfalfa and occasionally maize.
Soils, general: Well drained, moderately fine-textured soils with an Ap-Bw-Ck horizon sequence. The Bw horizon extends from 25 to 90 cm from the soil surface. The Ck horizon below is characterized by secondary lime filaments and concretions. Very fine and fine pores are common in the upper 100 cm of the soil. No restrictions for rooting exist;
colour: the Ap horizon is dark brown to brown (10 YR 3-4/2-3) if moist over a dark yellowish brown to yellowish brown (10 YR 4-5/3-6) Bw horizon and light yellowish brown (10 YR 6/4) subsoil;

texture: clayloam and occasionally sandy clayloam. Usual range: 24-37% clay, 34-45% silt, 34-45% sand;
structure: the Ap horizon is fine to medium granular; the Bw horizon is moderate medium to coarse subangular blocky; and the Ck horizon is structureless to weak medium to coarse subangular blocky;
consistence: normally sticky and plastic (wet) and firm (moist) except for the Ck horizon which is friable (moist);
chemical properties: calcium carbonate is present in small quantities in the upper parts of the soil (Ap and Bw horizons); its content increases abruptly to 18-30% in the Ck horizon. The pH is 7-7.5 in the upper parts of the soils increasing towards the Ck-horizon to values up to 8.5. The organic matter content is 1.5% in the Ap horizon and decreases regularly with depth.
Diagnostics: Ochric epipedon, cambic horizon, calcic horizon.
Soil classification: USDA (1975), Calcixerollic Xerochrepts.
FAO/Unesco (1988): Haplic Calcisols.
Bordering units: F1Ap2w, F1Ah1w, F1Ah2w, F1Ic, HAh, AE1, AE2.

Soils of the flood plain

Unit AE1; moderately deep, excessively drained, calcareous, coarse-textured soils.

Extent: 21.6 ha, 1.0% of the area, 15.1% of the flood plain.
1 1 2
Pedon code: A------- Efxt
A 0 3
Parent material: Recent calcareous, coarse-textured alluvium.
Relief: Level (slope 0-2%).
Erosion: None.
Stoniness: Slight gravelly and stony surface (≤2%).
Land use: Mainly vegetables, onions, cauliflower, irrigated with small sprinklers.
Soils, general: Excessively drained, undeveloped soils with an Ap-C horizon sequence. The soils are porous with common very fine and few fine interstitial pores throughout a depth of 120+ cm. Rooting is not restricted in any way;
colour: brown (10 YR 4/3) to dark yellowish brown (10 YR 4/4) if moist, light yellowish brown (10 YR 5/3-4) if dry;
texture: slightly gravelly sandy loam throughout but with variable sand content in the subsurface soil. Range: 61-75% sand, 10-32% silt, 6-15% clay). Very few to occasionally few gravel;
structure: weak structure to structureless;
consistence: loose to soft (dry), loose to friable (moist), not sticky and not plastic (wet);
chemical properties: the soils are calcareous having a CaCO$_3$ content of 3-10%; the pH ranges from 7.5 to 8.5. The organic matter content is low (1-1.5%) in the Ap horizon and decreases irregularly with depth. The CEC is usually below 10 cmol(+)/kg soil.
Diagnostics: Ochric epipedon.
Soil classification: USDA (1975), Typic Xerofluvents.
FAO/Unesco (1988): Calcaric Fluvisols.
Bordering units: F1Ic, HIc, AE2, AE3.
Remarks: For a representative profile see Pedon P4 (Plate 4B) in Appendix A.2.

Unit AE2; moderately deep, well drained, calcareous, medium-textured soils.

Extent: 110.4 ha, 5.3% of the area, 77.3% of the flood plain.
2 1 2 2 1 3
Pedon codes: B------- Efxt B ------- Efxt
A 0 3 A 0 3

Parent material: Recent calcareous alluvium.
Relief: Level (slope 0-2%).
Erosion: None.
Stoniness: Fairly gravelly and stony surface (≤2%).
Land use: Vegetables (onions, cauliflower, etc).
Soils, general: Well drained, undeveloped soils with an Ap-C horizon sequence. The soils are porous with common very fine and few fine interstitial pores to a depth of 120+ cm. There is no restriction for rooting;
colour: see unit AE1;
texture: slightly gravelly sandy loamy to loamy topsoil (10-22% clay, 38-50% silt, 34-52% sand), over a loamy subsoil (9-22% clay, 29-50% silt, 30-51% sand). Few gravel throughout (5-15% by volume);
structure: weak structure to structureless;
consistence: the Ap horizon is loose to slightly hard (dry), loose to friable (moist), non to slightly sticky (wet). The C horizon is slightly hard, friable to firm, slightly sticky;
chemical properties: the soils are calcareous with a $CaCO_3$ content of 3-15%; the pH ranges from 7.5 to 8.5. The organic matter content is low (≤1.5%) in the Ap horizon and decreases irregularly with depth.
Diagnostics: Ochric epipedon.
Soil classification: USDA (1975), Typic Xerofluvents.
FAO/Unesco (1988): Calcaric Fluvisols.
Bordering units: F1Ic, F2If, HIc, AE1, AE3.

Unit AE3; moderately deep, well drained, calcareous, moderately fine-textured soils.

Extent: 10.8 ha, 0.5% of the area, 7.6% of the flood plain.
Pedon codes: $B\frac{3\,3\,3}{A\,0\,3/2}Efxt$ $B\frac{3\,3\,4}{A\,0\,3/2}Efxt$
Parent material: Recent calcareous alluvium.
Relief: Level (slope 0-2%).
Erosion: None.
Stoniness: Nil.
Land use: Vegetables (onion, cauliflower, etc.).
Soils, general: Well drained, undeveloped soils with an Ap-C horizon sequence. The soils are porous with common very fine and few fine interstitial pores to a depth of 120+ cm. There is no restriction for rooting;
colour: as in unit AE1;
texture: loamy, clayloamy or sandy clayloamy surface soil over a clayloamy or sandy clayloamy subsoil, occasionally interlayered with loamy material;
structure: weak to moderate, coarse to medium subangular blocky in the upper soil layers;
consistence: slightly hard to hard (dry), firm (moist), sticky (wet);
chemical properties: the soils are calcareous with a $CaCO_3$ content of 1-5% in the upper layers and 3-15% in the lower layers; the pH ranges from 7.5 to 8.5. The organic matter content is low (≤1.5%) in the Ap horizon and decreases irregularly with depth.
Diagnostics: Ochric epipedon.
Soil classification: USDA (1975), Typic Xerofluvents.
FAO/Unesco (1988): Calcaric Fluvisols.
Bordering units: HAh, AE1, AE2.

Some physical properties

Porosity-bulk density

Figure 2.22 presents the relation between the porosity and the clay content for a number of Entisols and Inceptisols (Fig. 2.22a) and some Alfisols (Fig. 2.22b) in the study area. It appears that the porosity is positively related to the clay content in all soils. The relation is linear in the case of Entisols and Inceptisols and described by the equation:

$$SMO = 22.9 + 0.528 * C \qquad (2.8)$$

where SMO is the total pore fraction (%, v/v) and C is the clay content (%). In the case of soils having an argillic horizon, the relation can be described by a 2nd degree polynomial equation:

$$SMO = 22.7 + 0.185 * C + 0.0096 * C^2 \qquad (2.9)$$

The intercept of both curves with the y-axis is almost identical; the curves cross each other at a clay content of about 35% (Fig. 2.22). The shape of the two curves cannot be compared in this clay range because there are only few Entisols and Inceptisols with a clay content >35% (Fig. 2.22a). The porosity of Alfisols is significantly less than that of younger soils if the clay content is less than 35 percent; this difference is maximum for clay contents between 15 and 25%. Note that this is the range of the loamy Ap horizons of the Alfisols. As explained earlier, these horizons are massive and very hard when dry. Their low pH and organic matter content are largely responsible for this. Moreover, many of these soils are compacted by heavy machinery, whereas heavy equipment is not used in the younger soils of the flood plain and the Holocene terraces where the small parcels are mainly under vegetables.

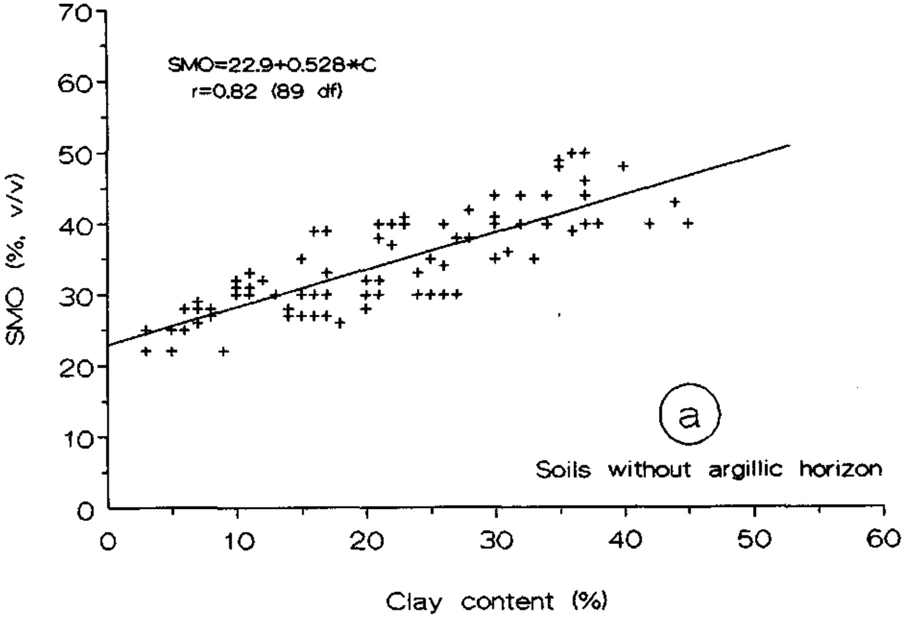
No data on bulk density are available for the soils of Fig. 2.22. However, the bulk density can be approximated with:

$$BD = p_s - (SMO * p_s) \qquad (2.10)$$

where BD is the bulk density (gr/cm^3), p_s is the specific density of the soil particles, having an approximate value of 2.65 gr/cm^3, and SMO is expressed in cm^{3}cm^{-3}.

The calculated relation between bulk density and clay content is shown in Fig. 2.23. The BD-clay content relation for the Nikea soils is included in the same figure for comparison (see Fig. 2.16). The soils on the Nikea slopes and on the Tertiary hills are richer in organic matter, have a higher pH and a much better structure than the soils on the level parts of the Larissa plain. Moreover, they are less compacted by heavy machinery.

The effect of the organic matter content on the bulk density and porosity is evident in the few uncultivated Alfisols of the Platanoulia area. Based on raw data supplied by Kariotis (1988), the interrelationships between the organic matter content, the total clay percentage, the percentage of the fine clay, the silt content and the bulk density in all horizons of 2 uncultivated Alfisols were studied. It appeared that the organic matter content and also the percentage of the fine clay determine the bulk density value (r^2=0.79).



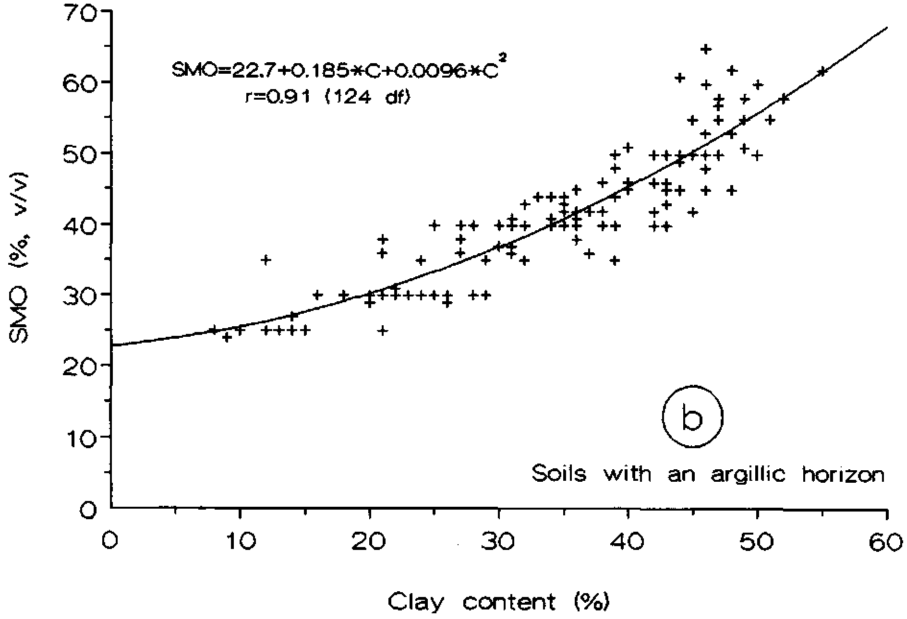


Fig. 2.22. The relation between porosity (SMO) and clay content for Entisols and Inceptisols (a) and for soils having an argillic horizon (b) in the Platanoulia area.

Table 2.11. Bulk density and soil moisture characteristics for a number of soils with argillic horizons in the Platanoulia area.

Site no.	Depth cm	Clay %	pF-values								AWC % vol	BD kg/lt
			0	1.0	1.5	2.0	2.3	2.7	3.5	4.2		
T2	15	51	57.0	54.0	44.0	38.0	35.0	31.0	26.0	22.0	16.0	1.133
	45	43	52.0	48.5	44.0	41.0	39.0	37.0	33.0	28.0	13.0	1.379
T3	15	37	41.0	37.5	33.5	27.0	23.5	20.0	23.5	22.5	4.5	1.525
	45	35	41.0	40.5	38.5	33.0	30.0	27.5	19.5	19.0	14.0	1.572
T4	15	36	43.5	41.5	39.0	33.0	30.0	26.0	22.5	21.0	12.0	1.545
	45	40	44.0	41.0	36.0	30.5	27.0	22.5	16.0	13.5	17.0	1.447
T5	15	32	40.0	38.5	37.5	35.0	33.0	31.0	25.5	21.5	13.5	1.656
	45	32	41.0	40.5	39.5	38.0	37.0	36.0	20.0	16.0	22.0	1.653
T7	15	35	41.0	40.5	37.5	34.5	32.0	28.0	16.0	13.5	21.0	1.560
	45	30	38.0	37.0	34.5	32.5	31.5	28.5	24.7	21.5	11.0	1.672
T8	15	36	42.0	40.0	38.5	36.0	33.0	30.0	19.0	17.5	18.5	1.545
	45	33	42.0	40.0	38.0	35.0	33.0	30.5	23.0	13.0	22.0	1.618
835061	20	30	27.5	26.5	23.2	19.0	16.8	12.9	6.5	5.7	13.3	1.539
	40	31	39.7	38.7	36.0	32.3	30.8	28.4	23.6	23.0	9.3	1.879
	70	25	55.4	53.1	51.1	38.7	25.2	21.8	18.3	17.3	21.4	1.456
	110	21	39.2	35.5	31.9	26.9	24.2	20.4	16.1	12.3	14.6	1.641
835068	15	16	46.8	43.0	38.7	30.3	26.3	21.4	14.7	10.8	17.0	1.432
	35	16	50.5	45.4	37.7	28.7	24.7	20.1	15.5	12.0	16.7	1.343
	65	32	44.0	39.3	34.9	29.3	26.3	21.1	12.2	8.8	20.5	1.574
	120	26	45.2	41.9	36.9	31.4	28.6	24.9	21.1	16.8	14.6	1.408
	180	18	46.6	42.9	38.4	31.4	27.6	23.1	13.9	9.9	21.5	1.415
835070	10	24	35.8	34.9	32.6	28.9	27.2	24.7	17.3	8.2	20.7	1.795
	35	40	47.3	45.5	43.7	39.8	37.8	35.1	29.7	21.6	18.2	1.628
	65	44	43.1	39.2	35.9	30.8	28.0	25.7	19.2	16.2	14.6	1.615
	110	42	38.7	37.3	35.9	33.7	32.6	30.5	27.5	21.6	12.1	1.839

Table 2.12. Bulk density and soil moisture characteristics for a number of Entisols and Inceptisols on the Holocene terraces and in the flood plain.

Site no.	Depth cm	Clay %	pF-values								AWC % vol	BD kg/lt
			0	1.0	1.5	2.0	2.3	2.7	3.5	4.2		
T6	10	30	37.0	35.0	33.5	31.0	29.0	27.0	23.0	20.0	11.0	1.679
	45	34	41.0	40.0	37.0	34.0	31.0	29.0	26.0	21.0	13.0	1.582
835047	10	11	35.9	23.9	7.6	4.9	4.1	3.4	1.8	1.4	3.5	1.714
	40	10	33.3	30.2	14.5	8.3	6.8	7.6	2.9	2.9	5.4	1.7.5
	65	10	30.9	29.3	25.8	18.2	14.9	12.1	6.4	4.8	13.4	1.665
835048	10	16	38.7	35.2	31.7	24.4	20.4	16.5	10.3	7.9	16.5	1.479
	40	18	37.1	35.0	31.6	23.1	18.5	14.6	9.5	6.3	16.8	1.672
	65	28	33.8	32.0	29.6	24.6	21.2	18.3	10.8	8.1	16.5	1.795
835080	5	41	49.7	47.8	42.6	39.9	36.2	32.0	22.9	18.2	21.7	1.284
	20	41	44.4	42.8	41.2	39.3	37.9	35.7	29.6	23.5	15.8	1.461
	45	43	51.7	50.7	47.4	44.5	41.7	39.0	33.9	26.7	17.8	1.366
	95	33	49.0	47.7	45.6	38.6	24.3	19.7	11.5	8.7	29.9	1.295

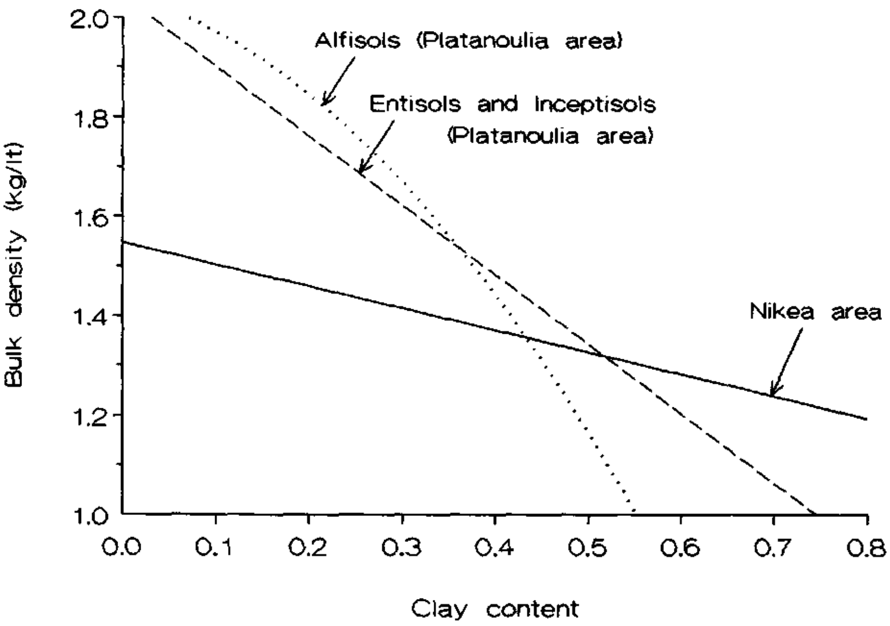


Fig. 2.23. The relation between bulk density and clay content in soils of the Larissa plain.

Soil moisture characteristics

Table 2.11 presents the measured soil moisture characteristics of a number of soils having an argillic horizon in the Platanoulia area. Table 2.12 contains relevant data for Entisols and Inceptisols on the Holocene terraces and in the flood plain (ITC, 1984). No data on clay content were available for the studied soils (Sites T2-T8 in Table 2.11). However, these were approximated using the relation of Fig. 2.22b and the measured value of SM(pF=0).

The exponential model described in Section 2.2.5 (Equation 2.2) was tested with the data of Tables 2.11 and 2.12. It appeared that the SM-PSI relation can be satisfactorily simulated separately for the Entisols and Inceptisols and for the older soils (having an argillic horizon), using the following formulas:

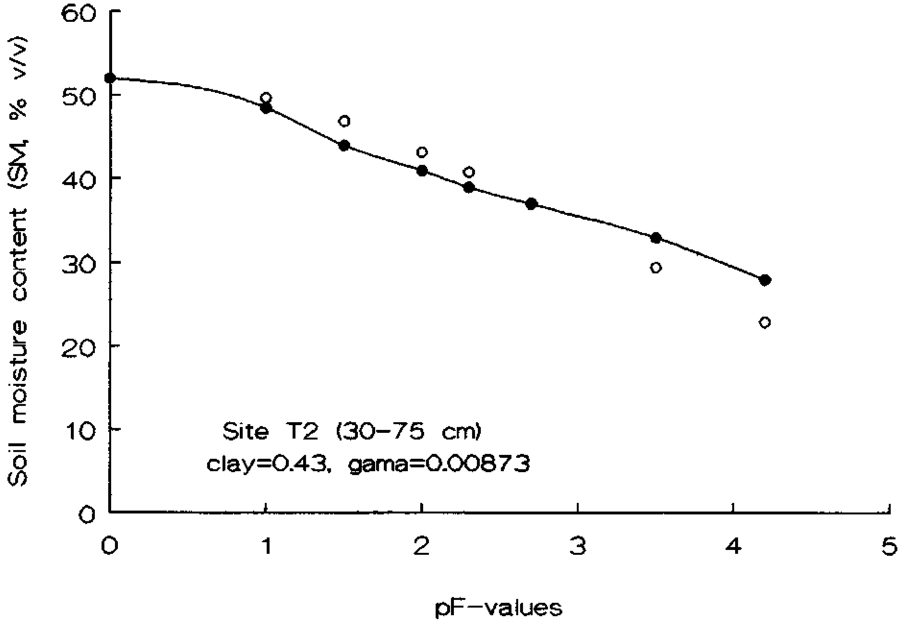
$$SM=SMO*\exp[\ln(PSI)\hat{}2*(0.000686*C-0.03709)] \quad (r^2=0.87) \text{ (Entisols, Inceptisols)} \quad (2.11)$$
$$SM=SMO*\exp[\ln(PSI)\hat{}2*(0.000245*C-0.01925)] \quad (r^2=0.90) \text{ (Alfisols)} \quad (2.12)$$

where SM is the soil moisture content (cm^3cm^{-3}), SMO is the porosity (cm^3cm^{-3}), PSI is the soil matrix suction (cm), and C is the clay content (%).

In line with Eqn. 2.7 (Section 2.2.5), the texture specific gama values are given by:

$$gama=0.03709 - 0.000686*C, \text{ for Entisols and Inceptisols, and} \quad (2.13)$$
$$gama=0.01925 - 0.000245*C, \text{ for soils with an argillic horizon.} \quad (2.14)$$

The match between measured data and those simulated using the exponential model is illustrated by Fig. 2.24; the first 2 soils of Table 2.11 were used as examples.



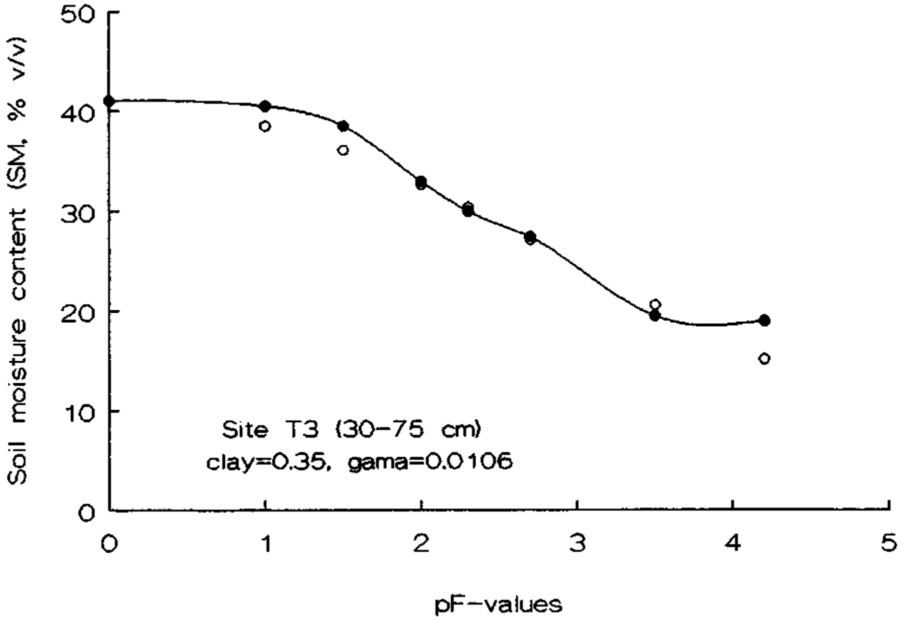


Fig. 2.24. Measured (●—●) and approximated (o) (with Eqn. 2.12) soil moisture characteristics for two Pleistocene soils (sites T2 and T3, see Table 2.11) in the Platanoulia area.

Infiltration parameters

As mentioned in paragraph 2.2.5 and discussed in Section 3.3, infiltration is made up of a sorptivity (S) and a permeability (A) component (Philip, 1957). Sorptivity is greatly influenced by the soil moisture content, so that its value of the dry soil (standard sorptivity, SO), is used as reference. The infiltration capacity of the soils of this pilot area and the methodology to establish the infiltration parameters are also discussed in Section 3.3. To avoid repetition, indicative values of the standard sorptivity and the permeability of soil units in the Platanoulia area are presented in Table 2.13.

The momentary sorptivity can be then calculated from SO and the actual soil moisture content, using the parabolic model described in Section 3.3.

Table 2.13. Indicative infiltration parameter values for Platanoulia soils.

Soil unit	SO (cm $\text{min}^{-1/2}$)	A (cm min^{-1})
F1Ap1m	0.30	0.0001
F1Ap1w, F1Ap2w, F1Ap2m	0.40	0.0006
F1Ah1w, F1Ah1m	0.50	0.0003
F1Ah2w, F1Ah2m	0.50	0.0005
F2Ah, F2If	0.50	0.0022
F1Ic	0.40	0.0006
F1Vpw, F1Vpm	0.83	0.0020
HAh	0.60	0.0043
HIc	0.60	0.0840
AE1	1.01	0.0520
AE2	0.80	0.0300
AE3	0.60	0.0084

2.4 The Peneios delta (pilot) area

2.4.1 Introduction

The third pilot area comprises a large part of the Peneios delta area (see Figs. 2.25 and 2.1), which has a different climate from the rest of the Thessaly plain and soils with a high ground-water table. The study area is bordered by the Aegean sea to the north and east, by the Larissa-Thessaloniki highway to the west and by the Omolio-Stomio road to the south (Fig. 2.25). It is situated between 39°52' and 39°58'20''North and between 22°36'25''and 22°44'20''East; and has an elevation between 0 and 15 meters ASL. The area covers approximately 57 km^2.

2.4.2 Climate

Climatic data are available from the Mikra Meteorological Station (National Meteorological Service, E.M.Y.) and presented in Table 2.14. Despite its considerable distance from Mikra (Thessaloniki), the study area belongs to the Thiessen polygon of this station (CORINE, EEC-Project, in press).

The average temperature of the summer months is 25.6°C and of the winter months 6.1°C. January is the coldest month with 4.9°C; July is the warmest month with 26.6°C. The mean annual temperature is 15.7°C. Its amplitude is 21.7°C.

The annual precipitation sum is 470 mm, of which 25% falls in the period September-November and 32% in the period December-February. Some 27% of the mean annual precipitation falls in spring.

The potential evapotranspiration rate is calculated according to Penman (1943, modified by Frère in 1979); mean monthly values are included in Table 2.14. The approximate water balance of a soil with very deep ground water was calculated with the Thornthwaite-Mather (1955) method, using the data of Table 2.14 and a soil water-storage value of 130 mm. It is shown in Fig. 2.26. It appears that -as in the rest of the Thessaly plain- rainfall lags behind potential evapotranspiration in the period May-September, leading to pronounced drought at the end of the summer. From October till April, precipitation is greater and its surplus is used to fill the assumed soil moisture storage capacity.

The study area has a mediterranean climate with a warm dry summer and a mild winter, and is designated as Csa according to Koeppen (1931). Application of the FAO definition of a "possible growing period" (see paragraph 2.1.3) shows that the growing period length is about 240 days. The 1970 version of Papadakis labels the climate of the study area as Continental Mediterranean (code 6.73) but distinguishes it from that of the Larissa plain due to its cooler summer (viz. av-g, Me versus av-G, Me).

According to Soil Taxonomy (Soil Survey Staff, 1975) and based on the values of average winter soil temperature (8.3°C), average summer soil temperature (25.0°C) and the mean annual soil temperature (16.7°C), the temperature regime of the study soils is "thermic".

Many soils of the study area are saturated with water for prolonged periods and have an aquic moisture regime (Soil Survey Staff, 1975). The soils with a deep ground-water table have a xeric moisture regime (Fig. 2.26), whereas very few soils are permanently saturated with water (wetlands) and have a peraquic moisture regime.

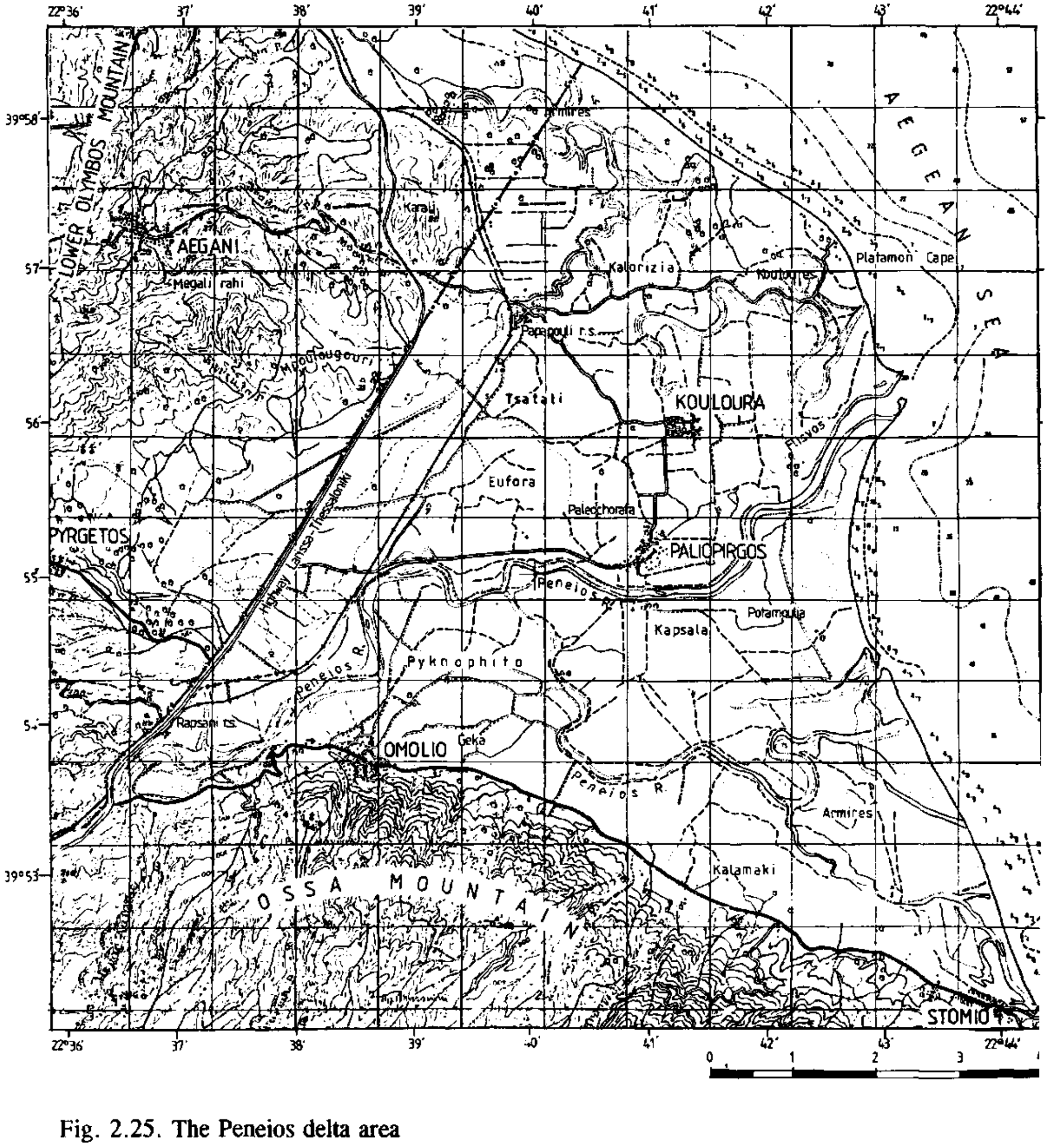


Fig. 2.25. The Peneios delta area

Table 2.14. Climatic record of the Mikra meteorological station (40°31'N, 22°58'E, 4 m. ASL), over the period 1959-1975.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
average daily temperature (°C)	4.9	6.5	9.5	14.3	19.8	24.1	26.6	26.2	21.8	16.0	11.4	6.9	15.7
average max. daily temperature (°C)	9.0	11.1	14.1	19.4	24.8	29.1	31.6	31.6	27.2	21.5	16.3	11.3	20.6
average min. daily temperature (°C)	1.2	1.9	4.2	7.1	11.7	13.7	18.2	17.9	14.7	10.2	6.7	2.8	9.4
average maximum temperature (°C)	16.1	17.7	20.5	25.2	30.8	34.7	36.6	36.0	32.4	27.2	22.2	17.2	26.4
average minimum temperature (°C)	-6.8	-5.0	-1.9	1.2	6.2	10.9	13.3	13.4	9.1	3.1	-2.7	-4.3	3.0
absolute maximum temperature (°C)	19.8	22.2	22.4	30.0	35.8	36.8	42.0	38.2	36.2	30.0	25.4	20.2	42.0
absolute minimum temperature (°C)	-14.0	-10.2	-4.6	-1.2	3.0	9.2	10.0	8.2	5.2	-1.4	-6.2	-8.6	-14.0
average relative humidity (%)	80	76	75	70	65	58	55	56	64	71	79	81	69.0
average precipitation (mm)	47.1	39.6	47.5	31.3	49.8	32.5	25.1	15.7	36.6	37.5	43.9	63.6	470.2
max. precipitation in 24 hours (mm)	35	38	52	39	41	41	35	44	59	56	36	63	63
number of clear days	5.4	5.3	4.4	4.2	4.4	6.7	14.4	14.9	11.0	8.2	4.9	4.7	88.5
number of overcast days	13.2	10.8	13.5	7.9	5.8	3.1	1.1	1.5	3.5	6.8	10.0	12.2	89.2
sunshine duration (hours)	88.5	91.5	146.8	203.4	269.1	280.1	308.9	271.3	221.8	162.5	118.4	105.0	2267.3
average wind speed (m/s)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.5	1.1
potential evapotranspiration (mm)	17.3	20.7	41.2	72.3	115.6	140.1	157.5	158.1	102.0	39.7	18.9	10.9	928.6

(Source: National Meteorological Service, E.M.Y.)

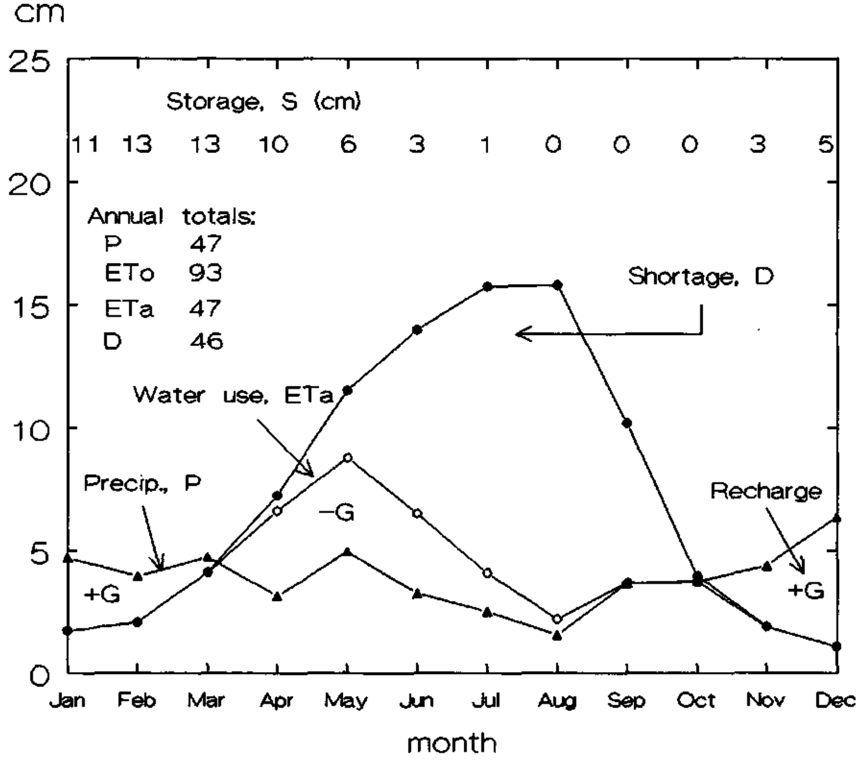


Fig. 2.26. Soil water balance sheet of the Peneios delta area. A deep ground-water table and a maximum water-storage capacity of 130 mm are assumed.

2.4.3 Geomorphology

Fig. 2.27 shows that the Peneios river delta has an arcuate (fan-like) shape with an average radius of 9.5 km. It lies between 0 and 20 m ASL and covers approximately 65 km^2. In the west and south, the delta is bordered by high ridges, viz. the lower Olymbos and Ossa mounts (see also Section 2.1).

In the study area, the following landforms can be distinguished (Fig. 2.27):

- Floodplain (A)
    - Channel belt (Ac)
    - Meander belt (Am)
    - Backswamps (Ab)
- Beach ridges (BR)
- Estuarine plain (E)
- Alluvial fans (F)

Floodplain deposits (Landform A) occupy the greater part of the study area, occurring between 0.5 and 8 meters ASL. The topset beds of deltas are widely thought to be a continuation of the alluvial deposits of the river floodplain. The distribution of the materials follows the general rules of deposition: coarse fractions are laid down along river courses in natural levees, sand bars or splays, and the finer fraction is carried in suspension and settles in depressions between levees (backswamps), or between bars (swales). Features such as the above are associated with inundated floodplains as a result of overbank flooding. Lateral erosion results in scrolls, abandoned channels or oxbow lakes, especially in the northern, north-eastern and south-eastern parts of the study area.

The floodplain deposits are all calcareous. The extreme variations in texture, occurring over short distances and at shallow depths, make it necessary to further subdivide the materials into channel belt deposits (Land subtype Ac), meander belts (Land subtype Am) and backswamps (Land subtype Ab).

Land subtype Ac includes the natural levees, the point bars (formed on the inside of bends or former bends), and the old splays. An extensive old splay can be distinguished on air-photos taken in 1945 (see paragraph 2.3.6); it occurs in the area in which the Peneios branch south of the Paliopirgos village (see Fig. 2.27) meets the beach ridges and deposits its load in a fan-like form or splay. On the air-photos of 1981, the old splay is partly covered by natural vegetation and partly cultivated, and no further deposition takes place since the channel is now active and debouches into the sea. Channel belt deposits appear on the air-photos with light tones mostly parallel to the streams; they indicate both good drainage and coarse-textured soils.

Land subtype Ab includes the depressions or backswamps between levees but also between bars, and generally the areas occupying low positions. They are characterized by overall dark tones on the air-photos, indicative of higher water tables and/or fine-textured soils (not in all cases). The rather poor drainage, especially in the backswamps between the Omolio-Stomio road and the main river channel, is apparent on the air-photos of 1945. At that time, the channel was the only active Peneios branch and often flooded the area (dikes and other flood-control structures did not exist at the time).

Land subtype Am includes the rest of floodplain, notably the areas between channel belt and backswamps. Most of this subtype is characterized by well to imperfectly drained, extensively cultivated soils, which show on the air-photos as a chequered pattern of dark and

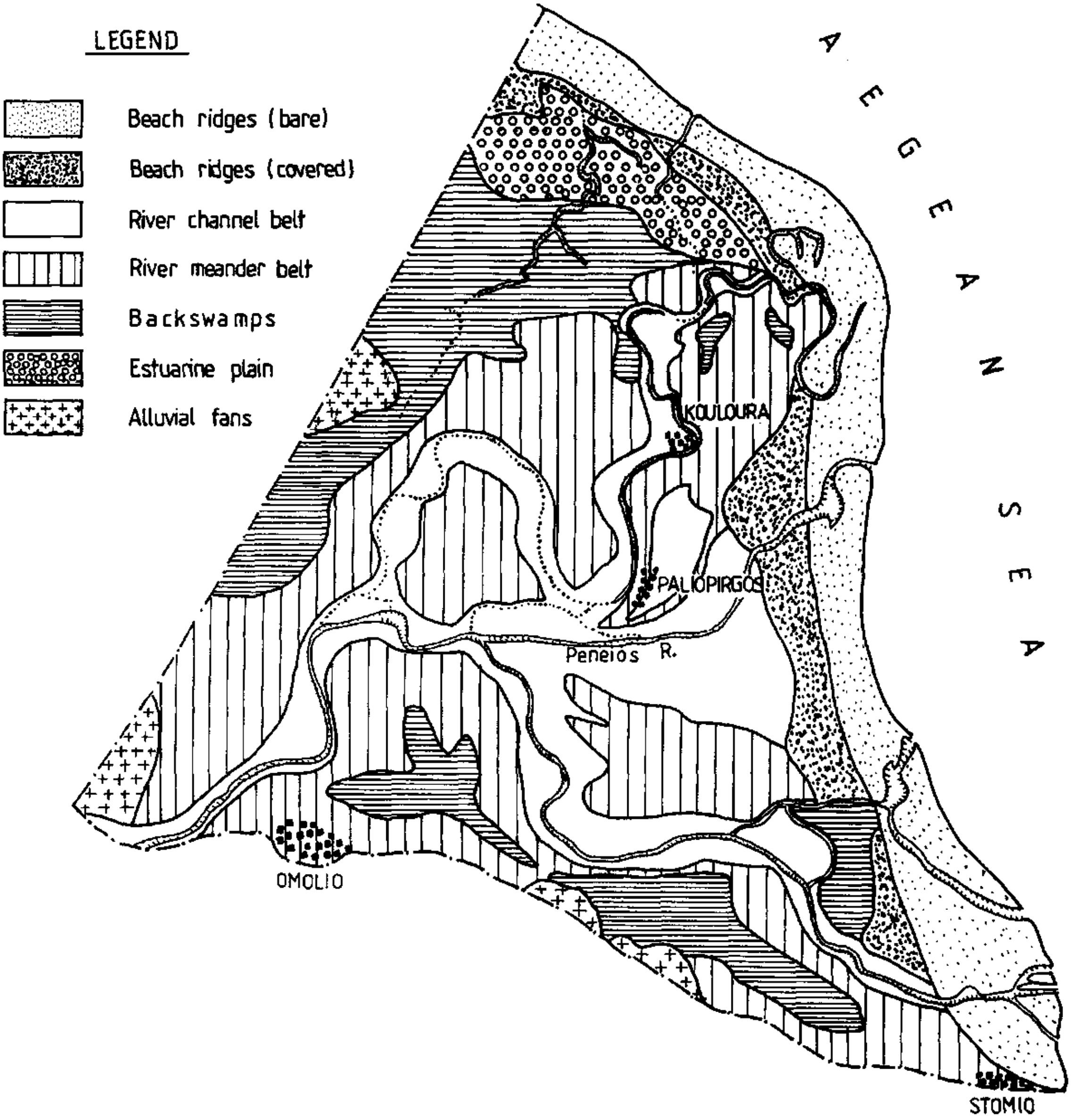


Fig. 2.27. The landforms in the Peneios delta area

light areas. Only in the north-eastern part of the study area do dark colours indicate a high ground-water table. The soil materials of Land subtype Am are all calcareous and highly stratified, which suggests that flooding took place until recent times. Some areas, however, might have been stable for quite some time, and buried cambic horizons may be found.

Beach ridges (BR) are old shoreline deposits of calcareous sands. They occur between 300 and 1,000 meters from the coast and are situated between 0 and 2.5 meters ASL (Fig. 2.27). On the air-photos, they appear in curvilinear and straight patterns.

This landform, comprises both sand dunes and sand flats covered by vegetation. The dunes run parallel to the coast and appear in white tones due to the high albedo of the bare sand. Sand flats occupy areas inbetween the sand dunes and the floodplain (Fig. 2.27). They were under natural vegetation of small shrubs and grasses in 1945, but are now partially cultivated. In the northern and north-eastern parts of the study area, a number of off-shore bars occur near the mouths of the channels.

The coast of the Peneios delta in the study area is approximately 14 km long. Actually, it can serve as an example of coastal modification through river deposition: comparing the air-photos of 1945 with those of 1981, it is evident that the beach aggraded some 400 meters or about 11 ha in the mouth of the distributary flowing through the Paliopirgos village.

The estuarine plain (E) is a level, continuous plain with mud-flats, oxbow lakes and small lagoons, bounded by the beach ridges in the northern part of the study area.

Landform E has a reticular to parallel drainage pattern. The channels meander and contain saline to brackish water, which is easily distinguishable on air-photos because of its black colour. Some of the oxbow lakes contain fresh water whereas others are brackish.

The parent materials are calcareous, clayey sands or silty sands. The ground-water table is shallow during much of the year. Soil development is minimal. Many soils have an ESP > 15 which increases with depth.

Shrubs and grasses grade into a halophytic vegetation towards the beach ridges. This vegetation and the poor drainage are responsible for the vaguely textured dark tones of the estuarine plain on the air-photos. The area is partly used for some irrigated crops, e.g. beans, alfalfa, or for grazing.

Alluvial fans (F) occupy the higher parts of the delta plain, comprising actually the only transition to the surrounding uplands, since terraces are not present in the delta area. This landform has only a minor extent in the study area; it occurs between 4 and 15 meters ASL. The fans are gently sloping in a typical deltaic form (slope grade 2-6%). the drainage pattern consists of individual channels fading out near the base of the fan. The drainage pattern of the fan occurring in the west part of the study area (see Fig. 2.27) is partly man-made to avoid flooding of the lowland.

The soil materials are generally calcareous, gravelly with sub-rounded and angular gravel, and crudely stratified sand-silt mixtures, especially towards the apex of the fan or the creek or channel. The materials become finer-textured towards the fan-base.

Due to their relatively higher elevation, slope grade and gravel content, the soils of the fans are well to excessively drained and have a very deep ground-water table. They are cultivated with grapes, pears, apples, peaches, olives, and with annual crops such as winter wheat and irrigated maize.

2.4.4 Hydrology

The Peneios river debouches into the Aegean sea in two channels. The northernmost channel flows south of the Paliopirgos village (see Fig. 2.27) and was reactivated by Man after 1945. It now discharges half of the Peneios water into the sea. This, together with a number of other constructions such as small dikes, drainage channels, etc., minimized the flooding hazard in the area over the last few decades.

Two more major channels cross the northern part of the study area towards the sea. They have been active in earlier times but contain only brackish water today, due to salt intrusion from the sea, which is felt to more than 1.5 km upstream in the summer months.

Many small, natural and some man-made water courses cross the area and serve as irrigation canals. Another source of irrigation water is the ground water; it occurs at 1-5 meters below the flood plain surface, and slightly deeper in the alluvial fans.

2.4.5 Population and land use

Three communities are situated within the margins of the study area: Omolio, Stomio and Paliopirgos, the latter including the Kouloura village (Fig. 2.25). Much of the study area belongs administratively to the village of Pirgetos. The total population is 3,652 persons in 1,137 families (see Table 2.15). More than 90% of the families are connected with agriculture: 85% of them are farmers or farmers-shepherds whereas another 6% is indirectly dependent on agriculture. Note also that in the period 1961-81 the population declined by 20 percent.

About 82 percent of the study area is arable land and only few areas are used for grazing (Nat. Serv. of Stat., 1981). The average holding is 3.5 ha. Land reform has not taken place as yet.

Maize, wheat, alfalfa and sugar beet are the most important crops, and grown in 75% of the study area. Soft wheat (20%) is the commonest winter cereal and produces an average 4 tons of grain per hectare. It is sown in November and harvested at the end of June to mid-July. Irrigated maize grows on 30% of the fields. The hybrids Pioneer 3183 and 3165 are sown at the end of April to mid-May. Under proper management, 12 tons grain/ha or more may be harvested in September (average 10 t/ha). Sugar beet is sown in May, irrigated 3-4 times and produces an average of 56 t/ha. Beans have gained popularity over the last decade and are grown on many fields. The average production is 1.8 t/ha. Grapes and fruits, e.g. pears, apples, almonds and olives, occupy minor areas especially on the alluvial fans.

Table 2.15. Population of the study area.

Community	Population	Families	Farmers+ shepherds	Jobs connected with agriculture	Other jobs
Omolio	806	255	693 (220)	48 (15)	65 (20)
Stomio	598	189	526 (167)	36 (11)	36 (11)
Paliopirgos	258	82	232 (74)	13 (4)	13 (4)
Pirgetos	1,390	611	1,583 (501)	135 (43)	212 (67)
Total	3,652	1,137	3,014 (962)	232 (73)	326(102)

(in parentheses no. of families; after Nat. Serv. Stat., 1981).

2.4.6 Methods

Desk studies

The materials collected and studied prior to the field work include the topographic maps and air-photos obtained from the Greek Army Geographical Service (G.Y.S.). They are: (a) the 1:5,000 topographic map sheets 4354/5, 4354/6, 4354/7, 4364/7 and 4364/2; and the 1:50,000 sheet "Rapsani"; and (b) fourteen black and white air-photos at an approximate scale 1:43,000. Two pairs are of the year 1945 and coded F200-66, F200-67, F200-68 and F200-69; 5 pairs are of the year 1981 and coded 130724, 130725, 130836, 130837, 130838, 130880, 130881, 130926, 130927 and 130928.

An older soil report containing data on the electrical conductivity and exchangeable sodium percentage of 42 sites in the delta area (Tsitotas, 1972) was kindly supplied by the Land Reclamation Service, Larissa (YEB., Dept. of Agriculture).

Field methods and map compilation

A number of exploratory trips were made to the area in the spring of 1989. The experience gained helped to correctly interpret the available sets of air-photos. Next, a physiographic map of the study area was compiled.

The complexity and variability of the soils made it necessary to do a detailed soil survey in the summer of 1989, during which some 400 sites were described to a depth of 1.5 meter. The descriptions were recorded on 1:5,000 base maps, using the Greek pedon code. As explained earlier (see Fig. 2.12), this code includes information on the direction of soil development as well as the texture, gravel and stones content throughout the soil profile, the presence of carbonates, the erosion of the soil, the kind and depth of limiting layers or special properties, e.g. salinity, sodicity, etc., and soil drainage.

The main taxonomic units distinguished in the area are documented with full descriptions of representative soil profiles. These descriptions were made on freshly dug pits following the "FAO Guidelines for Soil Descriptions" and are presented in Appendix A.3.

A final soil map with a descriptive legend was compiled at a publication scale 1:25,000.

Laboratory methods

Soil samples were collected from 8 selected soil profiles and 10 soil sections and analyzed for soil texture, organic matter content, total calcium carbonate content, pH, C.E.C., exchangeable potassium and sodium, and electrical conductivity at the ISMC-Larissa. The procedures are briefed in paragraph 2.2.4.

A total of 16 undisturbed soil samples were taken from selected soil profiles and transported to Wageningen, where the moisture retention curve (pF) was determined at the laboratory of the Dept. of Soil Science and Geology, WAU. Ten infiltration experiments were carried out at representative sites in the pilot area using the single-ring infiltrometer.

Cooperation links

The soil survey was carried out in cooperation with the ISMC-Larissa. Three Greek soil scientists of this Institute participated during parts of the field work and description of the soil profiles. These are: L. Toulios, M.Sc., Th. Trigas and Dr. Ch. Tsandilas.

2.4.7 The soils

Aspects of genesis and classification

The greater part of the study area consists of soils formed in recent alluvial, calcareous deposits of the Peneios river, which frequently flooded the area until recent times. These soils are therefore very young, stratified and calcareous; they have "fluvic" properties and lack diagnostic horizons other than an ochric epipedon. Depending on their position in the landscape, they have a deep to very shallow ground-water table. They are classified as Typic Xerofluvents, Aquic Xerofluvents, Aeric Fluvaquents and Typic Fluvaquents (USDA, 1975), or as Calcaric Fluvisols (FAO, 1988). Note that the soils of the area with very deep ground water have a xeric moisture regime (see paragraph 2.3.2).

Typic Xerofluvents occur on the drier alluvial fans, and in the channel- and meander river belt: the ground water is very deep in the alluvial fans, but it fluctuates between 1.5 and 3.5 meters from the soil surface in the flood plain.

By definition, the Aquic Xerofluvents are saturated with water within 150 cm from the surface for some time. These soils occur in the floodplain, and particularly in the meander belt and the backswamps; their ground-water tables fluctuate between 90-100 cm from the surface in the winter but may be below 150 cm in the summer.

The Aeric Fluvaquents occupy low areas in backswamps and estuarine plains. They are mottled soils with gley colours at shallow depth. The depth of the ground water fluctuates normally between 130-150 cm from the surface in the summer and may be at 50 cm or shallower in the winter. Many soils of the estuarine plains have an ESP value >15 in the upper soil, increasing with depth, and/or an electrical conductivity value in excess of 4 mmhos/cm at some depth below the surface.

The Typic Fluvaquents are saturated with water during most of the year. However, they cover only minor areas in the backswamps.

There is a clear relation between soil moisture and degree of soil development in the study area. The moister the soils, the higher their porosity and organic matter content, and the better the structure of the topsoil, and the infiltration and permeability. The sequence Typic Xerofluvents --> Aquic Xerofluvents --> Aeric Fluvaquents shows decreasing stratification of the rootzone and increasing loss of calcium carbonate, which is leached from the surface- to the subsoil. In some Aeric Fluvaquents, a moderately structured, decalcified B-horizon developed below the ochric epipedon but is still too thin (<15 cm thick) to qualify as a cambic horizon (FAO, 1988).

The soils of the backswamps in the north and west of the study area were never flooded in recent times. Due to their low positions, they are hydromorphic soils (aquic moisture regime) and they have a shallow ground-water table. Development is relatively more advanced in these soils; a cambic B horizon has formed. Calcium carbonate is leached from the upper soil parts and is visible as soft powdery lime in the substratum, but the quantity is less than required for a true calcic horizon (<15%). Some topsoils may be calcareous due to secondary enrichment with carbonates. Such (slightly developed) soils are classified as (Aquic) Xerochrepts or Haplaquepts depending on the depth of ground-water table. In the western part of the area, finely textured soils are found which have vertic properties, e.g. upon drying, cracks wider than 1 cm that extend down to more than 50 cm from the soil surface; these soils are classified as Vertic (Aquic) Xerochrepts and Vertic Haplaquepts. The Vertic and Aquic Xerochrepts are saturated with water for some time in the winter (within

75 cm from the surface), whereas the ground-water table drops below the control section in the summer. The Vertic Haplaquepts have mottles and gley colours very close to the surface and a ground-water table which fluctuates between the soil surface and a depth of 120-140 cm. Vertic soils have the highest organic matter contents in the study area, which remains at relatively high levels at great depth. This is attributed to the vertic (cracking) character of these soils.

The soils of the beach ridges are too young to develop any diagnostic horizon. Below 25 cm from their surface, the texture is finer than loamy fine sand. The ground-water table occurs at depths greater than 50 cm, and the soils have a xeric moisture regime. They are classified as Typic Xeropsamments.

Systematics and nomenclature

The Greek pedon code was not employed in the final compilation of the soil map. The legend of the soil map is based on landforms, viz. soils of the beach ridges (BR), soils of the channel belt (Ac), soils of the meander belt (Am), soils of the backswamps (Ab), soils of the alluvial fans (F), and soils of the estuarine plain (E).

At a lower level in the system, the subdivision is based on the Soil Taxonomy (1975) classification, in line with the Greek system. The soils of the study area fall within two Orders, viz. Entisols (E) and Inceptisols (I). To arrive at Subgroup level the codes of Suborder, Great Group and Subgroup must be subsequently specified:

Order	Suborder	Great Group	Subgroup
E = Entisol	a = aquic	f = fluvic	a = aquic
I = Inceptisol	f = fluvic	o = ochric	e = aeric
	p = psammic	x = xeric	t = typic
	h = haplic		v = vertic

For example, AmEfxa stands for Aquic Xerofluvent of the meander belt; AbEafe for Aeric Fluvaquent of the backswamps; and so forth. Some further simplifications could be made:

Entisols:
- if subscript t is missing, the typic subgroup is assumed
- subscript f can be skipped, as all but the Entisols of the BR (Psamments) have fluvic properties, viz. Fluvents or Fluvaquents.

For example, AcEx is a Typic Xerofluvent of the channel belt; the above examples (AmEafe and AbEafe) will be simplified as AmEae and AbEae.

Inceptisols:
- if subscript t is missing, the typic subgroup is assumed
- Xerochrepts are the only Ochrepts present, and therefore the subscript "o" can be omitted, viz. Ix: Typic Xerochrept, Ixv: Vertic Xerochrept, Ixa: Aquic Xerochrept.
- the only Aquepts present are the Vertic Haplaquepts and coded Iav.

At the third (and lowest) level, the legend separates soils with different texture in the same taxonomic subgroup (if needed). A number from 1 (coarser soils) to 3 (finer textured soils) may be used.

The use of taxonomic classification units serves practical and correlation purposes. Here, it also gives a very good indication of the depth of the ground-water table. With the present setup, information on the drainage conditions, the slope, the presence of carbonates, and erosion (all included in the analytical pedon code; see Fig. 2.12), can be easily inferred from the soil unit symbol. For instance, the slope is flat (0-2%; "A") and erosion is 0 (none) in all soils except those of the alluvial fans, where the slope is "B" (3-6%) and the erosion class 0-1. The calcium carbonate parameter is 3 ("calcareous throughout") in all Entisols, but only 1-2 ("calcareous subsoil") in the Inceptisols. And so forth.

Alkalinity and/or salinity are indicated on the soil map as phases.

The soil legend of the Peneios delta study area (key to the soil map)

1. Soils of the beach ridges (BR)

BREpx1	Very coarse-textured, excessively drained soils.
BREpx2	Coarse-textured, excessively drained soils.

2. Soils of the channel belt (Ac)

AcEx1	Sandy loamy soils, somewhat excessively drained.
AcEx2	Medium over coarse-textured soils, well drained.

3. Soils of the meander belt (Am)

AmEx1	Coarse over medium-textured, well drained soils.
AmEx2	Medium to moderately fine over coarse-textured soils, well to moderately well drained.
AmEx3	Moderately fine-textured soils, well to moderately well drained.
AmExa	Coarse to medium-textured soils, moderately well drained.
AmEae	Medium-textured, poorly drained soils.

4. Soils of the backswamps (Ab)

AbIxv	Slightly developed, cracking clayey soils, imperfectly to poorly drained.
AbIav	Slightly developed, cracking clayey soils, very poorly drained.
AbIxa	Slightly developed, moderately fine-textured soils, imperfectly drained.
AbExa	Stratified, medium-textured soils, imperfectly drained.
AbEae	Stratified, medium over moderately fine-textured soils, poorly drained.
AbEa	Fine-textured soils, very poorly drained (wetlands).

5. Soils of the alluvial fans (F)

FEx1	Very gravelly, coarse to medium-textured soils, excessively drained.
FEx2	Very gravelly, loamy soils, excessively drained.
FIx	Slightly developed, moderately fine-textured soils, well drained.

6. Soils of the estuarine plain (E)

EI/Exa	Association of young (Exa) to slightly developed (I), moderately fine-textured soils, poorly drained.
EEae	Stratified, medium to fine over coarse-textured soils, poorly drained.

Soils of the beach ridges (BR)

These soils include the calcareous, excessively drained, bare or vegetated sands of the dunes and sand flats. They cover 1,229.4 ha (21.5%) and are subdivided according to their texture into 2 soil mapping units:

Unit BREpx1; very coarse-textured, excessively drained soils.
Main 000 Classification
pedon code: A---Epxt USDA (1975): Typic Xeropsamments
A03 FAO (1988) : Calcaric Fluvisols

This unit accommodates the nearly flat to flat, excessively drained, calcareous, coarse sandy soils of the beach ridges. These soils have an extremely low "available water capacity" and poor fertility status. They are under a sparse natural vegetation of xerophytic shrubs and are used for recreation purposes only.

This unit totals some 850 ha or 69% of the beach ridges.

Unit BREpx2; coarse-textured, excessively drained soils.
Main 001 Classification
pedon code: A---Epxt USDA (1975): Typic Xeropsamments
A03 FAO (1988) : Calcaric Fluvisols

This unit consists of nearly flat to flat, excessively drained, calcareous, very coarse beach ridge soils. The surface horizon consists of light brown loamy sand about 20-30 cm thick and enriched with organic materials. The subsoil and substratum are brown and consist of sand to loamy sand with a low "available water capacity".

Until some years ago, the soils were all under a natural vegetation of xerophytic plants and bushes. Today, some areas are used for irrigated production of vegetables (beans), but yields are low. The soils are only marginally suited for cultivated crops or pasture because of their very low fertility status, partly because fertilization involves the risk of ground-water contamination. The soils are suited for recreation only.

This soil unit covers 379.4 ha or 31% of the beach ridges.

Soils of the channel belt (Ac)

These are very young, deep, distinctly stratified, young alluvial soils with fluvic properties. They are calcareous throughout, coarse to medium-textured, and well to excessively drained Typic Xerofluvents. They cover 1,150.1 ha (20.1%) and are further subdivided, according to their texture, into the following two mapping units:

Unit Ac1; sandy loamy soils, somewhat excessively drained.
Main 112 Classification
pedon code: B--- Efxt USDA (1975): Typic Xerofluvents
A03 FAO (1988) : Calcaric Fluvisols

This unit includes the nearly flat to flat, somewhat excessively drained, coarse-textured soils of the natural levees (channel belt).

The surface horizon (Ap) consists of yellowish brown, friable to very friable, sandy loam, and is about 30 cm thick. The subsoil and substratum are stratified and consist of layers of light yellowish brown, loose, structureless sandy loam, loamy sand or sand, but predominantly sandy loam.

The "available water capacity" is low; infiltration is somewhat rapid. The organic matter content is very low at the surface (< = 1%) and decreases irregularly with depth. Calcium carbonate is present throughout and makes up 5-7% of the matrix (pH=7.8-8.3). The CEC ranges between 8 and 12 cmol(+)/kg in the topsoil and between 3 and 7 cmol(+)/kg in the deeper layers.

The soils are planted to irrigated summer crops, viz. maize, sugar beets, beans and alfalfa. Their main limitation is the low water-holding capacity.

This soil unit covers 318.3 ha or 28% of the channel belt.

Unit Ac2; medium over coarse-textured soils, well drained.

Main pedon codes: Classification
113 123 USDA (1975): Typic Xerofluvents
B---Efxt B---Efxt FAO (1988) : Calcaric Fluvisols
A03 A03

This unit includes the nearly flat to flat, well drained and in places somewhat excessively drained, medium over coarse-textured soils of the channel belt, the natural levees and old splays.

The surface layer (Ap) of a typical profile such as profile P7 (Appendix A.3), is brown to dark yellowish brown, structureless to weakly structured, friable, loam to silt loam and 30-40 cm thick. The subsoil and substratum are structureless and stratified, consisting of layers of yellowish to light yellowish brown, loose, sandy loam, loam, loamy sand or sand, but predominantly sandy loam and in some cases silt loam to loam.

The water-holding capacity is low to moderate. Infiltration is very slow. The ground-water table is generally very deep, but it may be not much deeper than 120 cm for some period in the winter.

The organic matter content is 1.3% or less and decreases irregularly with depth. The calcium carbonate content is between 5 and 7% throughout; the pH is 7.8 to 8.3. The CEC ranges between 14 and 28 cmol(+)/kg in the topsoil and between 3 and 18 cmol(+)/kg in the deeper layers (note: 5-8 cmol(+)/kg in the sandy loamy layers).

The soils are cultivated with irrigated summer crops such as maize, sugar beet, beans and alfalfa. Winter wheat gives low yields. The main limitations of these soils are the low "available water capacity" and the low permeability of the surface soil.

This soil unit covers 831.8 ha or 72% of the channel belt.

Soils of the meander belt (Am)

These are nearly flat, deep to very deep, stratified alluvial soils with fluvic properties. They are calcareous throughout and have a ground-water table at great depth below the solum (Typic Xerofluvents) to only 100 cm from the surface (Aquic Xerofluvents), or even shallower (Aeric Fluvaquents). The soils cover 1,954.9 ha or 34.2% of the study area and belong to the following mapping units:

Unit AmEx1; coarse over medium-textured, well drained soils.

Main 133 Classification
pedon code: B --- Efxt USDA(1975): Typic Xerofluvents
A03 FAO (1988): Calcaric Fluvisols

This unit consists of very deep, well drained soils, formed in nearly flat, recent calcareous alluvial deposits in the meander belt, particularly in the area WSW of the Kouloura village at elevations of 2.8-4.0 meters ASL.

The surface soil of a typical profile such as profile P2 (Appendix A.3; see also Plate 6A) consists of brown, friable to firm and sticky loam and is about 30 cm thick. The subsoil is pale to light yellowish brown, structureless, very friable, stratified sandy loam and loamy sand and extends to a depth of 70 cm. The substratum is stratified and consists of layers of brown and friable clayloam and loam, and light yellowish brown sandy loam, but predominantly moderately fine-textured.

The organic matter content is 1.3% in the topsoil and decreases irregularly with depth. The soils are calcareous throughout with calcium carbonate contents between 6.0 and 8.5% (pH=8.0-8.3).

The ground-water table is normally below the control section. In the winter months, it may occur at 150 cm below the soil surface but it drops to more than 250 cm in the summer. The soils are deeply rooted with roots found at 150 cm depth, and deeper. The water-holding capacity is therefore high. The infiltration rate is very slow (<3 cm/hour).

The soils are cultivated with beans, maize, sugar beet, alfalfa, etc. Winter cereals also give good yields.

This soil unit covers 101.9 ha or 5% of the meander belt.

Unit AmEx2; medium to moderately fine over coarse-textured soils, well to moderately well drained.

Main pedon codes:				Classification
213	213	214	314	USDA:Typic Xerofluvents
B---Efxt	C---Efxt	B---Efxt	C---Efxt	FAO: Calcaric Fluvisols
A03	A03	A03	A03	

This unit includes the very deep, well to moderately well drained soils in nearly flat, recent calcareous alluvial deposits in the meander belt, particularly in the Eufora area, at elevations of 3-4.5 meters ASL and in the area north of the Kouloura village at elevations of 1.3-1.8 meters ASL.

The surface soil consists of dark yellowish brown, friable loam to dark greyish brown or brown, friable to firm silty clayloam, and is about 30 cm thick. The subsoil is stratified, yellowish brown to brown, structureless, friable to very friable, loam, sandy loam, silt loam or silty clayloam, but predominantly silt loam to silty clayloam, and extends to a depth of 80 cm. The substratum is stratified, structureless, light yellowish brown, slightly mottled, friable sandy loam to loam, very friable loamy sand or loose sand, but predominantly sandy loam to loamy sand.

The organic matter content of the topsoil is 1.3-1.6% and decreases irregularly with depth. Calcium carbonate is present throughout in quantities between 4 and 8%; the pH is about 8.0.

The soils are porous, deeply rooted and have a moderately high water-holding capacity. The infiltration rate is slow to moderate (0.6-1.2 cm/h). The ground-water table may occur at a depth of 150 cm in the winter months. It drops to great depths in the summer months.

The soils are cultivated with winter wheat or irrigated maize, beans, alfalfa and sugar beet and produce good yields. Cotton was found on a few parcels in the Kouloura area.

This soil unit covers 410.6 ha or 21% of the meander belt.

Unit AmEx3; moderately fine-textured soils, well to moderately well drained.

Main pedon codes:			Classification
334	234	334	USDA(1975): Typic Xerofluvents
C---Efxt	C---Efxt	B---Efxt	FAO(1978): Calcaric Fluvisols
A03	A03	A03	

This unit includes deep to very deep, (moderately) well drained soils formed in nearly flat, calcareous alluvial deposits in the meander belt, at elevations of 1.5-5.0 meters ASL.

The surface soil of a typical profile consists of dark brown to dark yellowish brown, friable sandy clayloam to firm and sticky clayloam or silty clayloam, and is about 30 cm thick (see also soil sites T2, T6, T8). The subsoil is stratified, yellowish brown to dark yellowish brown, weakly structured, friable to very friable silt loam or silty clayloam, and extends to a depth of 80 cm. The substratum is stratified, pale brown to light yellowish brown, structureless, friable silty clayloam, clayloam or firm and sticky clay.

The organic matter content of the topsoil is 1.5-1.9%; it decreases irregularly with depth but may remain at relatively high levels, e.g. 1% at 60 cm depth, in the wetter parts of the belt. The soils are calcareous throughout, with $CaCO_3$ contents of 2 to 8%; the pH is 7.9-8.2. The CEC ranges between 0.5 and 0.7 cmol(+)/kg clay, or 14-27 cmol(+)/kg soil.

The soils are normally rooted to a depth of 80-90 cm. They have a high water-holding capacity but a slow infiltration rate (0.6 cm/h). The depth of the ground-water table varies seasonally. In may occur below 150 cm in winter but drops to great depths in the summer.

The soils are planted to winter wheat or irrigated maize, beans, alfalfa and sugar beet; they may produce high yields under proper management.

This soil unit covers 528.1 ha or 27% of the meander belt.

Unit AmExa; coarse to medium-textured soils, moderately well drained.

Main pedon codes:				Classification
113	123	213	223	USDA: Aquic Xerofluvents
C---Efxa	C---Efxa	C---Efxa	C---Efxa	FAO: Calcaric Fluvisols
A03	A03	A03	A03	

This unit includes deep, moderately well drained soils formed in nearly flat, calcareous, alluvial deposits of the meander belt, particularly between the Omolio-Stomio road and the southern Peneios branch, at elevations of 1.5-4 meters ASL.

In a typical profile such as profile P5 (Appendix A.3; see also Plate 6B), the surface horizon consists of dark yellowish brown, friable to firm silt loam or loam, 30-50 cm thick. The subsoil is structureless, yellowish brown, friable, sandy loam to loam, and extends to a depth of 80 cm. The substratum is stratified and consists of layers of loamy sand and sand over yellowish to dark yellowish brown, mottled, loam to clayloam below 100-120 cm.

The organic matter content of the surface soil is 1.2% and decreases irregularly with depth. The calcium carbonate content lies between 4 and 10% (pH= 7.8-8.5).

The water-holding capacity is moderate; the infiltration rate is slow to very slow (<0.3 cm/hour). Before 1945, these soils were frequently flooded but the flooding hazard became less with the activation of the northern Peneios branch which conducts half of the river's discharge. Today, the ground-water table is normally below 110-120 cm in the wet season and at great depth in the summer.

The soils are used to cultivate wheat or irrigated maize, beans and alfalfa.

This soil unit covers 831.8 ha or 43% of the meander belt.

Unit AmEae; medium-textured, poorly drained soils.

Main	D 224	Classification
pedon code:	- --- Eafa	USDA(1975): Aeric Fluvaquents
	F A03	FAO (1988): Calcaric Fluvisols

This unit includes flat, poorly drained, medium-textured soils with a clayloamy topsoil, formed in deep, calcareous alluvial deposits in the meander river belt, at elevations of 0.6-1.5 meters ASL.

In a typical profile such as profile P1 (Appendix A.3), the surface soil is of brown, firm clayloam, about 40 cm thick. The subsoil consists of stratified, weakly structured, yellowish brown, friable sandy loam over brown, mottled, friable, loam, and extends to a depth of 80 cm. Below the Ap horizon, a partially decalcified Bw horizon may be present, which however is too thin (<15 cm) to classify as a cambic B horizon. The substratum is stratified and consists of layers of olive, mottled, friable silt loam alternating with dark greyish brown, mottled, friable loam and olive brown, mottled, loose, sandy loam.

The organic matter content is 1.6% in the topsoil and decreases irregularly with depth. The soils are calcareous throughout, though some $CaCO_3$ has leached out of the top 40 cm. The $CaCO_3$ content is about 2% in the topsoil and between 5 and 12% in the layers below. The pH is 7.5 in the topsoil and increases with depth to a value of 8.0. The CEC is about 25 cmol(+)/kg soil in the topsoil, 9-12 cmol(+)/kg in the subsoil and 16-18 cmol(+)/kg in the substratum.

The soils are deep and very porous. They have a high biological activity and are normally rooted to a depth of 100 cm. They have a high water-holding capacity and a moderately slow infiltration rate (1.2 cm/h). The ground-water table fluctuates between 60 cm in the winter months and 130-150 cm in the summer.

Most of the soils are planted to irrigated beans, alfalfa or maize.

This soil unit covers 82.5 ha or 4% of the meander belt.

Soils of the backswamps (Ab)

These soils are nearly flat, medium to fine-textured and imperfectly to poorly drained with a seasonally high ground-water table (aquic soil moisture regime). The Entisols are all calcareous throughout, whereas many Inceptisols are partially decalcified. The soils cover 1,007 ha (17.6%) and are subdivided according to their degree of development and texture into the following mapping units:

Unit AbIxv; slightly developed, cracking clayey soils, imperfectly to poorly drained.

Main pedon codes: Classification
425 435 D 435 USDA(1975): Vertic Xerochrepts
D---Ioxv D---Ioxv - ---Ioxv FAO(1988): Vertic Cambisols
A01 A01 F A02

This unit includes the flat, imperfectly to poorly drained clay soils of the backswamps, particularly in the Papapouli area where they occur at elevations between 3 and 4.5 meters ASL.

In a typical profile such as profile P3 (Appendix A.3; see also Plate 6D), the surface layer (Ap) consists of dark brown, firm to very firm and very sticky clay, and is about 30 cm thick. The subsoil (Bw horizon) consists of brown, dark brown to dark greyish brown, mottled, firm to very firm and very sticky clay with a moderate, medium subangular blocky structure, and extends to a depth of 80 cm. The substratum (Ck horizon) consists of yellowish brown, mottled, structureless, firm to friable (moist), sticky to very sticky (wet), stratified loam, silt loam to silty clayloam or clayloam.

The "available water capacity" is high in these soils. Infiltration of water is rapid. The ground-water table is shallow in winter but drops below 120-150 cm from the surface in the summer months. The soils remain wet during spring and cultivation and sowing of summer crops may be delayed.

The organic matter content is moderate at the surface (2.7%); it decreases irregularly with depth but remains at relatively high levels, and is still >0.8% at a depth of 80 cm. Calcium carbonate is leached from the surface- and subsoil and is present in the substratum, partly as soft lime pockets, but in quantities less than 8.5%. Subsequent enrichment of the surface soil has taken place in some soils. The pH ranges from 7.5 (Ap horizon) to 8.3 (Ck horizon).

These soils are suitable for (and actually cultivated with) irrigated summer crops such as maize, sugar beets, beans and alfalfa. Winter wheat is also grown, though in some years yields are depressed by excess moisture. Wetness and workability are the major limitations of these soils.

This soil unit covers 226.9 ha or 23% of the backswamps.

Unit AbIav; slightly developed, cracking clay soils, very poorly drained.

Main E 435 Classification
pedon code: - ---Iahv USDA(1975): Vertic Haplaquepts
F A03 FAO (1988): Gleyic Cambisols

This unit includes the very poorly drained soils of the lower positions of nearly flat backswamps in the west of the study area, at elevations of 2.5 to 3.3 meters ASL.

The surface layer (Ap) of a typical profile, such as profile P4 (Appendix A.3; see also Plate 6E), consists of dark greyish brown, firm and sticky to very sticky clay, about 35 cm thick. The subsoil (Bg horizon) consists of dark greyish to greyish brown, mottled, moderately structured, very firm and very sticky clay, and extends to a depth of 90 cm. The substratum (Cg horizon) consists of olive grey, mottled, firm and very sticky clayloam.

The "available water capacity" is very high. Infiltration of water is moderately rapid. The ground-water table is always shallow; it is between 80 and 100 cm from the surface during the summer months and rises up to the surface in the wet season. The surface soil remains very wet during spring which delays sowing and cultivation of summer crops.

The organic matter content of the topsoil is 2.5% and remains at relatively high levels even at great depth. The soils are calcareous throughout, though some lime has leached from the B horizon to pockets of secondary powdery forms in the C horizon below. The calcium carbonate content is 2-11% throughout (pH=8-8.4).

The soils are suitable for growing annual summer crops. They are actually cultivated with beans, sugar beet and corn which give high yields in favourable years, e.g. 17 tons grain/ha. Supplemental irrigation is not applied to winter cereals which suffer from excessive wetness. Wetness and workability are major constraints to proper use and management of these soils.

This soil unit covers 42.5 ha or 4% of the backswamps.

Unit AbIxa; slightly developed, moderately fine-textured soils, imperfectly drained.

Main 434 D 434 Classification
Pedon codes: D---Ioxa - ---Ioxa USDA(1975): Aquic Xerochrepts
A01 F A01 FAO(1988): Eutric Cambisols

This unit includes the imperfectly drained soils of the nearly flat to flat backswamps, particularly in the Kalorizia area at elevations between 0.7 and 2.0 meters ASL.

The surface soil (Ap) of a typical profile, such as profile P8 (Appendix A.3), consists of dark yellowish brown, friable, sandy clayloam to clayloam, and is about 35 cm thick. The subsoil (Bw horizon) consists of dark brown, mottled, firm and sticky clay, and has a moderate medium subangular blocky structure. It extends down to about 65 cm depth. The substratum (Ck horizon) consists of brown, mottled, structureless to weakly structured, firm and sticky clayloam.

The organic matter content is about 1.3% in the topsoil and decreases with depth but remains above 0.4% until a depth of 120 cm. Calcium carbonate has leached from the top- and subsoil and is present (in soft secondary forms) in the substratum in amounts of 5 to 10%. The pH ranges from 7.6 to 8.1; the CEC ranges from 18 to 28 cmol(+)/kg in the topsoil to 30-40 cmol(+)/kg in the deeper layers.

The "available water capacity" is very high. The infiltration rate is moderate (3 cm/h). The ground-water table is shallow in the winter. The soils remain wet during spring; cultivation and sowing of summer crops is normally delayed. In the summer, ground-water occurs at great depths.

The soils are mostly planted to beans, corn and alfalfa, which produce high yields in favourable years. Winter cereals are also grown, though often hindered by excessive moisture. Wetness and workability are the major constraints of these soils.

This soil unit covers 351.9 ha or 35% of the backswamps.

Unit AbExa; stratified, medium-textured soils, imperfectly drained.

Main pedon codes: Classification
223 213 233 USDA(1975): Aquic Xerofluvents
D---Efxa D---Efxa D---Efxa FAO(1988): Calcaric Fluvisols
A03 A03 A03

This unit includes the deep, imperfectly and moderately well drained soils of the flat backswamps north of the Omolio-Stomio road, i.e. in the Pyknophito and Kalamaki areas.

The surface soil consists of dark yellowish brown to brown, friable to firm, silt loam to loam and about 40 cm thick. The subsoil is stratified and structureless with yellowish brown, friable loam to sandy loam extending to a depth of 70-80 cm; and friable sandy loam to loose loamy sand or sand, to a depth of 80-100 cm. The substratum is also stratified. Below 100-120 cm, it consists of dark yellowish brown, mottled, firm loam or clayloam.

The organic matter content of the surface layer is about 1.5% and decreases irregularly with depth. The calcium carbonate content ranges from 4 to 10%. The pH is about 8.0.

The water-holding capacity is moderate, and the infiltration rate is moderately slow. Where a ground-water table exists, it fluctuates between 90 and 100 cm depth in the winter and is below 150 cm in the summer months. Before 1945, these soils were frequently flooded. When the Peneios' northern branch, conducting a great part of the river's discharge, became activated, the flooding hazard was greatly reduced.

The soils are mainly used for wheat and/or irrigated maize, beans and alfalfa.

This soil unit covers 292.6 ha or 29% of the backswamps.

Unit AbEae; stratified, medium over moderately fine-textured soils, poorly drained

Main	D 233	Classification
pedon code:	- --- Eafa	USDA(1975): Aeric Fluvaquents
	F A03	FAO (1988): Calcaric Fluvisols

This unit occurs in the nearly flat and poorly drained backswamps adjacent to the beach ridges, at elevations of 0.7-1.8 meters ASL.

The surface layer of a typical profile such as profile P6 (Appendix A.3; see also Plate 6C) consists of dark yellowish brown, friable loam, of about 30 cm depth. The subsoil is yellowish brown, mottled, and stratified and consists of silt loam, loamy sand and loam, but predominantly silt loam, to a depth of 100 cm. The substratum below is sandy clayloam; it has gley colours (5Y 5.5/2) and is mottled.

The organic matter content of the surface soil is about 1.4% and decreases irregularly with depth. The calcium carbonate content ranges from 6.5 to 12.5% (pH=8.2-8.4); the electrical conductivity may reach 6 mmhos/cm below the rootzone (>80 cm).

The ground-water table may rise to about 50 cm from the soil surface in winter. At the onset of the summer, it is found at 100 cm depth; it becomes deeper later in the season. The infiltration rate is slow as the surface soil is susceptible to slaking.

The soils are mostly under beans which perform well under proper management. Wheat is also grown on these soils and gives good yields except in the very wet years.

This soil unit covers 71.2 ha or 7% of the backswamps.

Unit AbEa; fine-textured soils, very poorly drained (wetlands).

Main	E 435	Classification
pedon code:	- --- Eaft	USDA(1975): Typic Fluvaquents
	G A03	FAO (1988): Calcaric Fluvisols

This unit covers the fine-textured, calcareous, very poorly drained soils, which occur in some flat depressions in the east-northeastern part of the study area, at elevations at or close to the sea level.

The soil texture is clay to silty clay or silty clayloam throughout. The ground-water table is within 30 cm of the surface, and the soils are saturated with water for most of the time in an average year. The soils' natural vegetation is a forest of hydrophytic trees.

This soil unit covers 21.7 ha or 2% of the backswamps.

Soils of the alluvial fans (F)

These are gently undulating, very young (Entisols) to slightly developed soils (Inceptisols), formed in calcareous and normally very gravelly and stony alluvial fan deposits. The soils are generally calcareous, but $CaCO_3$ has leached from the surface soil to deeper layers if the soils are (relatively) well developed. The soils of the fans are well drained or even excessively drained and are all characterized by a very deep ground-water table. They cover 144 ha or 2.5% of the study area.

Unit FEx1; gravelly, coarse to medium-textured soils, excessively drained.

Main pedon codes:

xxx xxx xxx (note: x denotes gravel content 15-60%)
112 113 213 Classification
A---Efxt A---Efxt A---Efxt USDA(1975): Typic Xerofluvents
B13 B13 B13 FAO(1988): Calcaric Fluvisols

This unit includes the slightly undulating, excessively drained, coarse to medium-textured soils, of recent, calcareous fan deposits, particularly near the apex of the fan and adjacent to creeks or channels in the southern part of the study area, at elevations 5-11 meters ASL.

The topsoil consists of gravelly loam or sandy loam, 30 cm thick. The subsoil is of structureless, gravelly, sandy loam or loam. The substratum consists of structureless, gravelly to very gravelly stratified sandy loam, loamy sand or sand, but predominantly sandy loam.

The organic matter content of the surface soil is about 1.2% and decreases abruptly with depth. The soils are calcareous throughout. They have a moderately rapid infiltration rate and a low water-holding capacity. The ground water is very deep.

These soils are cultivated with winter wheat but produce also (irrigated) summer crops such as maize or vegetables. Grapes and orchards (pear, apple and almonds) are also common.

This soil unit covers 21.9 ha or 15% of the alluvial fans.

Unit FEx2; very gravelly, loamy soils, excessively drained.

x
Main 003 Classification
pedon code: A---Eoxt USDA(1975): Typic Xerorthents
B13 FAO(1988): Calcaric Regosols

This unit includes the excessively drained, moderately fine-textured, very gravelly soils, formed in slightly undulating, recent, calcareous deposits of alluvial fans, particularly in the west of the study area.

The topsoil consists of yellowish brown, friable, gravelly loam and in places clayloam, about 30 cm thick. The subsoil consists of structureless, very gravelly, clayloam to loam, and extends down to 75 cm. The substratum consists of very gravelly loam, clayloam, sandy loam or sandy clayloam, but predominantly clayloam.

The organic matter content of the surface soil is about 1.2%. The soils are calcareous throughout, with $CaCO_3$ contents 5 to 10% (pH about 8.0).

Due to their high gravel content, the soils have a low water-holding capacity; the infiltration rate is rapid. The ground-water table is very deep. Winter cereals (wheat and barley) and perennial crops, e.g. grapes, olives and almonds are widely grown.

This soil unit covers 44.4 ha or 31% of the alluvial fans.

Unit FIx; slightly developed, moderately fine-textured soils, well drained.

Main pedon code:
334 Classification
B --- Ioxt USDA(1975): Typic Xerochrepts
B11 FAO (1988): Eutric Cambisols

This unit includes deep, moderately fine-textured and well drained soils, formed in slightly undulating (slope 3-5%), calcareous, alluvial deposits in the lower parts of alluvial fans, at elevations 4-8 meters ASL.

The surface horizon consists of brown, firm and sticky clayloam, about 30 cm thick. The subsoil consists of yellowish brown, friable, sticky clayloam with a moderate medium subangular blocky structure, and extends to a depth of about 75 cm. The substratum is yellowish brown, structureless, clayloam.

The organic matter content of the topsoil is 1.2% and decreases regularly with depth. Calcium carbonate has leached from the surface to deeper layers, where it is present in soft powdery forms, but in quantities of less than 15%. The soils have a high water-holding capacity. The ground water is very deep.

The soils are cultivated with wheat or irrigated maize, beans and alfalfa. Grapes and some olives are also grown on these soils.

This soil unit covers 77.5 ha or 54% of the study area.

Soils of the estuarine plain (E)

These are flat, poorly to very poorly drained, medium to fine-textured, young to slightly developed alluvial soils. Due to their low elevation and landscape position, they commonly have high ESP and/or ECe values. These soils cover 225 ha or 3.9% of the study area.

Unit EI/Exa; association of young (Exa) and slightly developed (I), moderately fine-textured soils, poorly drained.

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Main pedon codes:
C 434              C 334              D 434              C 435
- ---Efxa          - ---Efxa          - ---Ioxa          - ---Ioxa
F A03              F A03              F A01              F A01
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Classification:

Association of Aquic Xerofluvents and Aquic Xerochrepts (USDA, 1975) or Calcaric Fluvisols and Gleyic Cambisols (FAO, 1988).

This unit comprises the poorly drained soils of the flat estuarine plains in the north of the study area at elevations slightly above the sea level.

The texture is silty clayloam to clayloam, or even finer in the topsoil. The topsoil and part of the subsoil are commonly decalcified; if so, the (structural) B horizons are considered cambic, and the soils are classified as Inceptisols.

The organic matter content of the topsoil is 2% and decreases regularly with depth, but remains at relatively high levels at great depths, viz. >0.4% at 120 cm depth. The $CaCO_3$ content is between 0 and 4% in the topsoil and reaches 6-12% in the substratum. In places, the electrical conductivity may exceed 4 mmhos/cm. The ESP may be 10 in the surface soil and increase to a value of 21 or more deeper down.

The soils are cultivated with winter wheat and irrigated beans or are grazed. This soil unit covers 169 ha or 75% of the estuarine plain.

Unit EEae; stratified, medium to fine over coarse-textured soils, poorly drained.

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                     C 314              C 213              D 314
Main pedon codes:    - ---Efxa          - ---Efxa          - ---Eafa
                     F A03              F A03              G A02
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Classification;

Aquic Xerofluvents and Aeric Fluvaquents (USDA, 1975) or Calcaric Fluvisols (FAO, 1988).

This unit holds the poorly to very poorly drained soils of the flat estuarine plains adjacent to the beach ridges (sand flats) in the northern part of the study area, at elevations slightly above sea level.

The texture is silt loam to silty clayloam in the top- and subsoil, over a sandy loam to loamy sandy substratum. The soils have a moderately structured B-horizon. They are calcareous, though the topsoil may be partially decalcified ($CaCO_3$=3-14% throughout).

The organic matter content of the topsoil is 2% and decreases regularly with depth, but remains at relatively high levels at great depths, viz. >0.4% at 120 cm depth. The electrical conductivity may exceed 4 mmhos/cm at some depth. The soils have ESP values from 6-13 in the topsoil to 20-40 in the subsoil and substratum (pH=7.6 in the topsoil to 9.4 in the deeper layers).

Few parcels are cultivated; most of the land is used for grazing or is still under its natural vegetation cover. This soil unit covers 56.3 ha or 25% of the estuarine plain.

Description of the chemical soil properties

Soil organic matter

The organic matter contents of the cultivated (top)soils of the study area are between 0.7 and 3.4%.

Figure 2.28 shows that the clay content correlates fairly well with the organic matter content of the studied soils. There is also a positive correlation with the drainage status of the soil; the rate of organic matter decomposition is slower and the annual input of organic residues is higher in wet soils than in drier soils.

Accordingly, the well to excessively drained, coarse to medium textured soils of the river channel belt and the gravelly soils of the alluvial fans have low organic matter contents of only 0.7-1%. The highest contents are found in the poorly drained, fine-textured soils of the backswamps, viz. 2.5-3.4%. Vertic soils in particular (Vertic Haplaquepts, Vertic (Aquic) Xerochrepts) have high organic matter contents even at considerable depths, viz. 1-1.7% at 80 cm from the soil surface.

Considering the average C/N ratio of the agricultural soils in the Larissa plain (viz. 8-12) and the average potential mineralization rate under Greek conditions, i.e. 100 mg N/kg soil (Kosmas *et al.*, 1990), there is probably a need for N-fertilization. Increased N and P application is largely held responsible for the recent increases in crop yield in the area.

Cation exchange capacity

CEC values are indicators of the overall potential fertility of the soil. Figure 2.29 demonstrates that the CEC correlates well with the clay content of the soils of the study area. The intercept of the curve with the y-axis reflects the effect of the organic matter on the CEC value, whereas the slope of the curve indicates an average CEC value of 69 cmol(+)/kg clay (presence of mica and montmorilonite in the clay fraction).

Using CEC values corrected for the organic matter content (assuming 200 cmol(+)/kg organic matter) did not improve the correlation of Fig. 2.29. There is no indication that a better relation exists for the surface layers.

Potassium

The soils of the study area are rich in mica, which is a source of potassium upon weathering. The maximum concentration of NH_4OAc-extracted K was found in the surface horizon of the studied soils, probably due to the continuous enrichment with crop residues (potassium fertilizers are not commonly used in the area). The extracted potassium varies from 0.21 to 0.45 cmol(+)/kg in the topsoil; the concentrations are between 0.04 and 0.30 cmol(+)/kg soil in the subsoil and substratum.

Adsorbed K^+ ranges between 1 and 3% of the CEC in the surface horizons. The cambic B-horizons (Inceptisols) contain more than 0.2 cmol of adsorbed K^+ per kg soil.

Based on the above and on the limited experimental data available (Intensive Fertilization Project, Dept. of Agric.), it is believed that the soils of the study area provide enough K^+ to adequately meet the needs of crops. The coarse-textured Typic Xerofluvents of the river channel belt may be an exception.

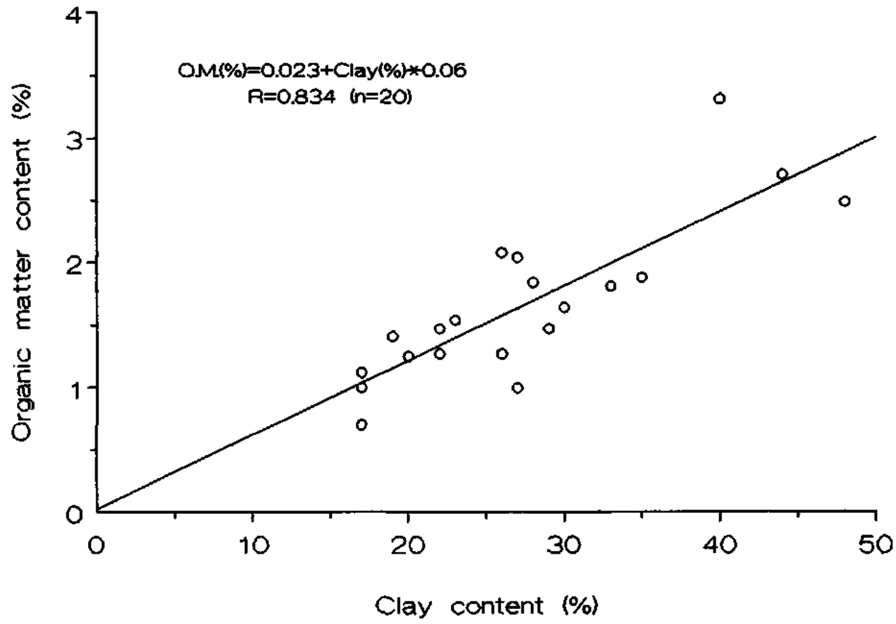


Fig. 2.28. Organic matter versus clay content of the topsoil in the Peneios delta study area.

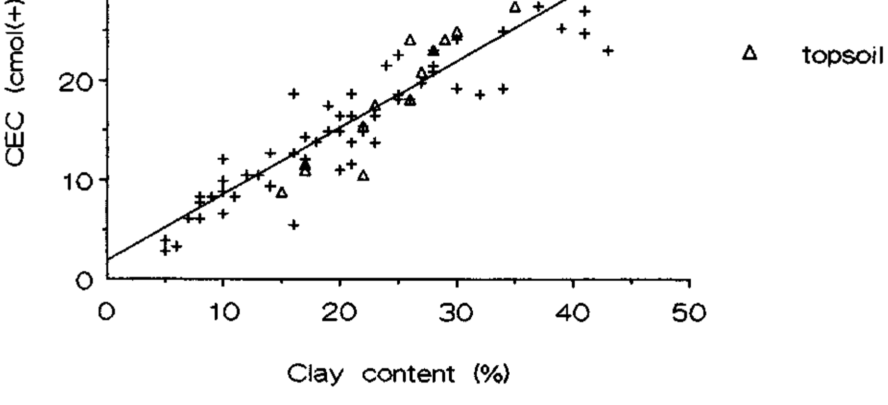


Fig. 2.29. The cation exchange capacity-clay content relation in soils of the Peneios delta study area.

Some physical properties

Bulk density-porosity

Data on bulk density are presented in Table 2.17 for a number of soils in the study area. An additional set of data is available from the ISMC (Larissa); whereas bulk density values of a large number of topsoils in the Peneios delta are presented in the Tsitotas (1972) report.

The bulk density, and consequently the porosity, of the soils of this study area do not correlate with the clay content, and there is no significant variation in bulk density values among the different soil units. Differences in the soil moisture content, degree of slaking, compaction, and time since cultivation are responsible for the variable pore size distribution and structure of the soils.

Bulk density and porosity values are grouped for different textural classes of surface soils in Table 2.16. The porosity has been calculated according to:

$$SMO = \frac{2.65 - BD}{2.65} \qquad (2.15)$$

where

SMO is the porosity (cm^3cm^{-3}),
2.65 is the approximate value of the specific density ($g\ cm^{-3}$), and
BD is bulk density ($g\ cm^{-3}$).

The bulk density seems to increase with soil depth (see Table 2.17) as the effects of cultivation and organic matter content decrease.

Soil moisture characteristics

The measured soil moisture characteristics of representative soils are presented in Table 2.17.

The soil moisture content at 16 bar suction ($pF=4.2$) is correlated with the clay content (Fig. 2.30):

$$SMPWP = 0.59*Clay - 1.41, \quad (r=0.982,\ df=15), \qquad (2.16)$$

where

SMPWP is the moisture content at 16 bar (%, v/v), and
Clay is the clay content (%).

The soil moisture content at low matric suction and particularly below field capacity is mainly determined by capillary forces and is affected by soil structure, rather than soil texture. The moisture content at saturation is not strongly affected by the texture of the soils.

The "available water capacity" (AWC, in % v/v) is calculated by subtracting the moisture content at wilting point ($pF=4.2$) from that at field capacity ($pF=2$) (see Table 2.17).

For the data of Table 2.17, the logarithmic model, described in Section 2.2.5 (Equation 2.2), was tested in the range of the available water contents between $pF=2$ and $pF=4.2$.

Table 2.16. Bulk density (BD, in g cm^{-3}) and porosity (SMO, in cm^{3}cm^{-3}) for different textures of the topsoil in the Peneios delta study area.

Textural class	BD (g cm^{-3})	No. of samples	standard deviation	SMO (cm^{3}cm^{-3})
LS	1.39	2	0.028	0.48
SL	1.44	4	0.130	0.46
L	1.42	10	0.156	0.46
SiL	1.28	17	0.179	0.53
SiCL	1.31	5	0.105	0.51
SCL	1.40	6	0.210	0.47
CL	1.31	12	0.157	0.51
SiC	1.23	1	---	0.54
C	1.27	12	0.127	0.52

Table 2.17. Bulk density and soil moisture characteristics (%, v/v) of a number of young alluvial soils (Entisols and Inceptisols) in the Peneios delta study area.

Site no.	Classification	Depth cm	Clay %	pF-values					AWC % vol	BD kg/lt
				0	2.0	2.4	3.0	4.2		
P2	Typic Xerofluvent	20	20	52.3	36.6	29.2	20.5	11.7	24.9	1.266
		65	14	50.6	30.4	17.5	8.4	3.8	26.6	1.310
		80	32	49.1	36.7	34.1	20.1	16.4	20.3	1.350
P3	Vertic (Aquic) Xerochrept	10	44	52.7	44.3	43.1	34.2	25.7	18.6	1.254
		20	44	49.0	40.8	39.2	36.6	24.2	16.6	1.352
		45	51	46.7	43.1	41.3	39.6	24.8	18.3	1.412
		55	51	46.4	42.3	40.7	40.8	30.8	11.5	1.420
		80	42	44.5	39.4	37.8	35.9	26.5	12.9	1.471
		80	42	45.8	38.4	35.0	33.8	22.6	15.8	1.435
P4	Vertic Haplaquept	10	48	52.4	42.0	40.3	34.6	27.0	15.0	1.263
		65	56	54.8	46.5	44.7	49.5	31.7	14.8	1.197
P5	Aquic Xerofluvent	35	17	42.0	30.4	27.2	20.2	8.3	22.1	1.537
P6	Aquic Xerofluvent	10	19	49.1	31.9	30.5	22.4	9.0	22.9	1.350
		20	19	45.7	38.9	31.5	21.9	9.7	29.2	1.440
		35	7	48.2	18.4	8.7	5.3	4.0	14.4	1.373
		80	19	49.3	41.2	36.8	28.7	11.5	29.7	1.342

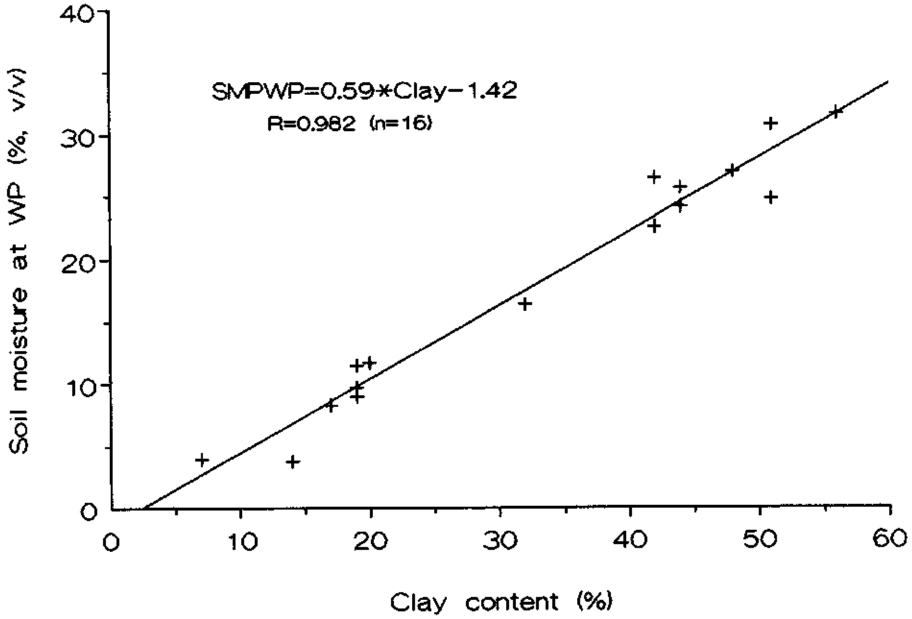


Fig. 2.30. Soil moisture at permanent wilting point [SMPWP(pF=4.2)] versus clay content for some soils in the Peneios delta area (see Table 2.17).

It was found that the soil moisture content is largely conditioned by the soil moisture potential and the clay content, according to the formula:

$$SM = SMO \exp[(0.000481*Clay-0.02877)*\ln(PSI)\hat{}2] \quad (r^2=0.90, n=64) \qquad (2.17)$$

where

SM is the soil moisture content (cm^3cm^{-3}),
SMO is the saturated moisture content (cm^3cm^{-3}),
PSI is the soil moisture tension (cm), and
Clay is the clay content (%).

Figure 2.31 demonstrates the agreement between simulated and measured soil moisture characteristics, taking the first two soils of Table 2.17 as examples.

Infiltration parameters

Infiltration is determined by sorptivity (S) and soil permeability (A). The methodology to establish these infiltration parameters in the field and the results of infiltration experiments at representative sites in the study area are presented in Section 3.3 (Infiltration capacity of the soils).

It appears that the sorptivity and permeability values of the loamy (or finer) Entisols of the flood plain are the lowest in the study area. This precludes irrigation at high application rates, e.g. with travelling guns, on these soils (which cover a considerable part of the study area).

The well drained Typic Xerofluvents of the river channel- and meander belts have a massive topsoil with a very low organic matter content. They have the lowest S and A values, viz. $S<0.03$ cm $min^{-1/2}$ and $A<0.005$ cm min^{-1}.

Moderately well to imperfectly drained Typic and Aquic Xerofluvents of the meander belt which have a moderately fine textured topsoil (mainly clayloam or sandy clayloam) have permeabilities between 0.005 and 0.01 cm min^{-1}. The (standard) sorptivities of these soils assume values of less than 0.16 cm $min^{-1/2}$.

Aeric Fluvaquents are the wettest (cultivated) Entisols of the study area. Their weakly structured topsoil and relatively high organic matter content account for their relatively high sorptivity and permeability values, e.g. $S=0.467$ cm $min^{-1/2}$, $A=0.005$ cm/min.

Inceptisols have higher organic matter contents than Entisols and a better structure. Their sorptivity and permeability values are around 0.540 cm $min^{-1/2}$ and 0.027 cm min^{-1}, respectively. The Vertic Xerochrepts and Vertic Haplaquepts are the wettest soils of the study area (they occur in the backswamps). They are fine-textured, have the highest organic matter contents, and their permeabilities range from 0.04 to 0.062 cm min^{-1}, which is higher than the highest irrigation intensity applied in the Larissa plain. The (standard) sorptivity may reach values as high as 2 cm $min^{-1/2}$.

Indicative values of the standard sorptivity and permeability values of the main soil units in the Peneios delta area are summarized in Table 2.18. The momentary sorptivity can be calculated from the soil moisture content using the parabolic relation or -for the vertic soils- the linear relation, described in Section 3.3.

Table 2.18. Indicative values of the infiltration parameters in the Peneios delta area.

Soil unit	S0 ($cm\ min^{-1/2}$)	A ($cm\ min^{-1}$)
AcEx2	0.014	0.005
AmEx1, AmExa, AbExa	0.032	0.0004
AmEx2, AmEx3	0.160	0.001
AbEae, AmEae, Eae	0.467	0.005
AbIxa, FIx, EI/Exa	0.540	0.027
AbIxv	1.950	0.062
AbIav	1.950	0.040
AcEx1, FEx1, FEx2	0.800	0.050

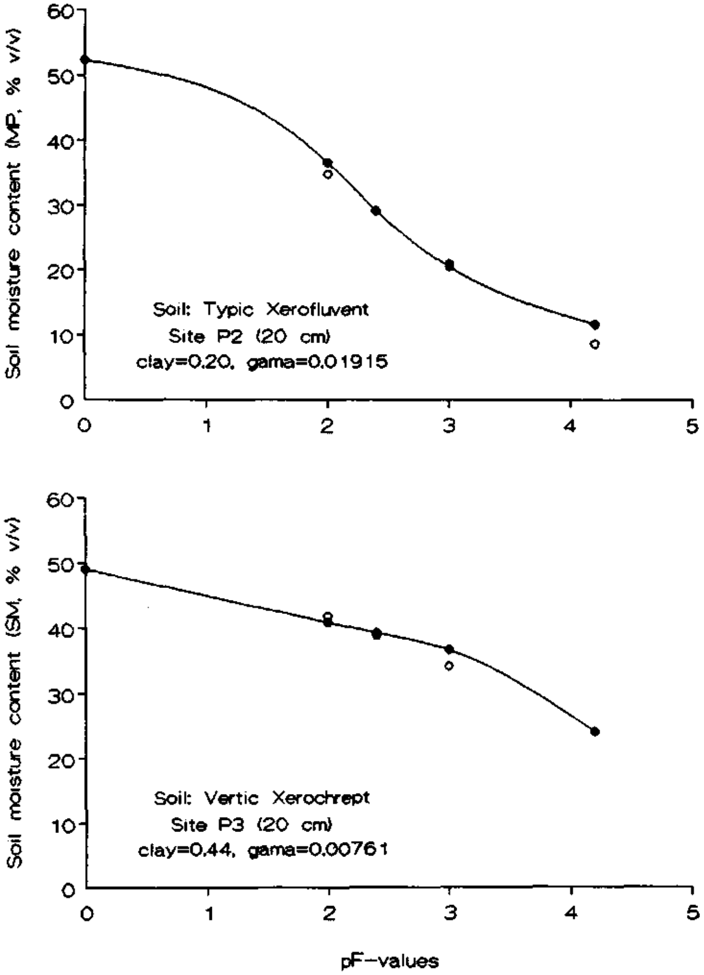


Fig. 2.31. Measured (●—●) and approximated (o) soil moisture characteristics for two soils (sites P2 and P3, see Table 2.17) in the Peneios delta area. For the equation used for the approximation see text. "gama"=0.02877-0.000481*Clay.

2.5 The Karla basin and its surroundings

2.5.1 Introduction

The Karla basin is in the south-eastern part of the Larissa lowland. It is an extensive, closed basin with homogeneous, deep, cracking, clay soils. Although its reclamation started some decades ago, large areas of the basin exhibit serious salinity and/or sodicity problems.

The effects of salinity and sodicity on water uptake and crop production are handicaps for quantifying the productivity of the Karla soils. Bypass flow through the strongly swelling soils of the area adds further uncertainty. No detailed survey was carried out. In the following paragraphs, a short description of the Karla basin is given based on information supplied by the ISMC, Larissa, and on experience gained in the area.

2.5.2 The environment

Location

The Karla basin measures 35 km from North-west to South-east (see Figs. 2.3 and 2.1) and is 9-14 km wide. It includes a level area (slopes < 1%) between 44 and 70 m ASL. The surrounding lowlands below the 100 m contour, are known as "Parakarlia"; they include approx. 5,300 ha of flat to undulating piedmont slopes (1-8%). The Karla basin and Parakarlia areas occur between 39°25' and 39°40' North, and between 22°30' and 22°56' East and cover a total of 42,500 hectares.

Geology

Though the Karla basin is geographically a continuation of the Larissa plain, it is distinguished as a different geological unit. Unlike the Larissa depression which was formed in the Pliocene, the Karla basin subsided in the Pleistocene. Initially, deposition of lacustrine materials took place, followed by deposition of alluvial, fine-textured materials (I.G.M.E, 1987). The latter deposits were transported by the Peneios river and other streams in the area. Along the margins of the basin, the deposits are coarse, shallow and confined to alluvial fans, scree and talus cones.

The basin is surrounded by crystalline rocks, schists and gneisses in the north, east and south-east (see Fig. 2.1). In the southern part of the basin, limestones and marble are overthrust on top of the crystalline rocks. In the western part, the basin is bordered by the Pliocene fluvio-terrestrial formations. The centre of the Karla basin is the lowest part of the Thessaly plain, which means that Karla has no exit to the sea.

Hydrology-Drainage structures

The Karla basin receives runoff water from its catchment area of about 1,050 km^2. Originally, the basin had no outlet, and all excess water accumulated in the (Karla) lake (see Fig. 2.3). The impermeable geologic formations (except for the limestones) and the unfavourable natural drainage conditions resulted in shallow water tables, excessive soil moisture and soil degradation in large parts of the basin.

Today, the only drainage exit of the basin is the tunnel of Karla which, since 1961, discharges maximally 8.5 m³/sec of excess water to the Aegean Sea. Before the construction of the tunnel, 6,000 ha of the Karla area formed the Karla lake. Another 18,200 ha included degraded soils and were used only for grazing. Spring crops were grown in dry years only. After drainage, the lake was reclaimed, and additional structures were added for flood protection, viz. dikes, 9 main drainage canals and the drainage network of Platykambos village. The latter network is also used for irrigation with water pumped from the Peneios river.

However, flood hazard still exists as the tunnel cannot handle all runoff water flowing into the basin. In the period 1967-1983, about 2,000 ha of the former lake area were flooded every year for as long as 5 to 61 consecutive days. The extremes are: 6,000 ha flooded in 1975 and no flooding at all in 1983.

Floods, excessive soil moisture and poor natural drainage cause serious problems. It is estimated that artificial drainage is needed in 12,000 ha, including the reclaimed lake area.

Land use, land tenure and irrigated area

The greater part of the Karla basin (38,500 ha) consists of arable land. Some 6,000 ha are reclaimed from the old lake and are State property; 4,000 ha of it are given to farmers of the surrounding villages for cultivation. Some 2,000 ha are seasonally flooded bottom lands. The total arable land is used as follows:

Crop	Area (ha)	Area (%)	Av. Yield (t/ha)
Rainfed:			
Winter cereals	25,000	65.0	3
Irrigated:			
Cotton	7,020	18.2	3
Maize	2,025	5.2	10
Sugar beets	1,620	4.2	56
Alfalfa	945	2.4	13
Orchards	540	1.4	-
Others	1,350	3.6	-
Total	38,500	100.0	

(National Service of Statistics, 1989; the urban areas occupy 2,000 ha)

About 35% of the arable land, i.e. 13,500 ha, are irrigated. Irrigation is realized with:

- 1,082 private pumps discharging a total of 35,000 m³/hour (average discharge per pump is 35 m³/hour),
- 16 public pumping stations discharging a total of 1,640 m³/hour, and
- surface water of the Peneios river.

This suffices to irrigate:

- 9,180 ha (68%) with private pumps,
- 450 ha (3.3%) with the public pumps, and
- 5,480 ha (35%) with surface waters of the Peneios river.

The water is pumped from the Peneios channel and is conducted to the drainage network of Platykambos village. This has already caused a 2 to 10-fold increase in the electrical conductivity of the irrigation water in the primary network. Obviously, the salinity hazard is considerable.

The Karla basin includes 21 Communities with a population of 20,334 in 6,366 families. Ninety percent of these are connected with agriculture (Nat. Serv. of Stat., 1981). The average holding is 6.6 hectares. Land reform has not taken place, except for the village of Stefanovikeio.

2.5.3 The soils of the Karla basin

Soil reports are available for the Karla basin (Koutsos, 1963; Tsitotas, 1978; Min. of Agric., 1987; Giolas, 1989; etc.). These, however, are either on a reconnaissance scale or are detailed studies of only small parts of the basin. A detailed soil report focusing also on the saline and sodic areas does not exist.

The soils of the basin can be divided into two broad units (Giolas, 1989):

- Unit B1, comprising 11,000 hectares with flat, deep to very deep, clay to clayloam soils classified as Mollisols, Vertisols and Inceptisols. The soils are very calcareous with $CaCO_3$ contents between 15 and 35% (pH=7.2-8.5). Organic matter contents range from 1.5 to 2.5%; the C.E.C. lies between 15 and 40 cmol(+)/kg. The soils are sufficiently fertile for annual crops such as cereals, cotton and sugar beet. The occurrence of a calcic horizon means a limitation for tree crops. This unit, extending between 52 and 70 m ASL, was not affected by seasonal floods before the construction of the Karla tunnel.

- Unit B2, comprising 24,200 hectares of degraded soils, i.e. saline and/or sodic soils. These are all poorly-drained heavy clays, rich in calcium carbonate and with a pH reaching up to 10.4. The organic matter content and the C.E.C. are as in unit B1. The soils were affected by seasonal floods (49-52 m ASL) and degraded before the construction of the Karla tunnel; the lowest 6,000 hectares (44-49 m ASL) were permanently under water.

After reclamation, the soils of this unit (B2) can be broadly divided as follows:

- 4,000 ha saline soils;
- 3,900 ha sodic soils;
- 15,300 ha saline and sodic soils; and
- 1,000 ha soils without limitations.

Saline soils are characterized by an electrical conductivity of 4-15 mmhos/cm at a depth of 30-150 cm. They are formed between the upper and the lower inundation level of the flood water. Since the reclamation of the basin, however, considerable leaching of the salts by rain- and irrigation water has taken place, so that the upper 30 cm became free of soluble salts. Giolas (1989) reports a leaching rate of 3-4 mmhos/cm per decade in the period 1963-1985.

Sodic soils have a low electrical conductivity, but ESP values of 15-50; they have pH values equal to or greater than 10. The structure and pores of these soils are totally degraded. The soils were formed after (artificially) draining the saline and sodic soils without precautions to keep the soil flocculated. As in the saline soils, sodicity becomes more pronounced deeper than 30 cm from the soil surface.

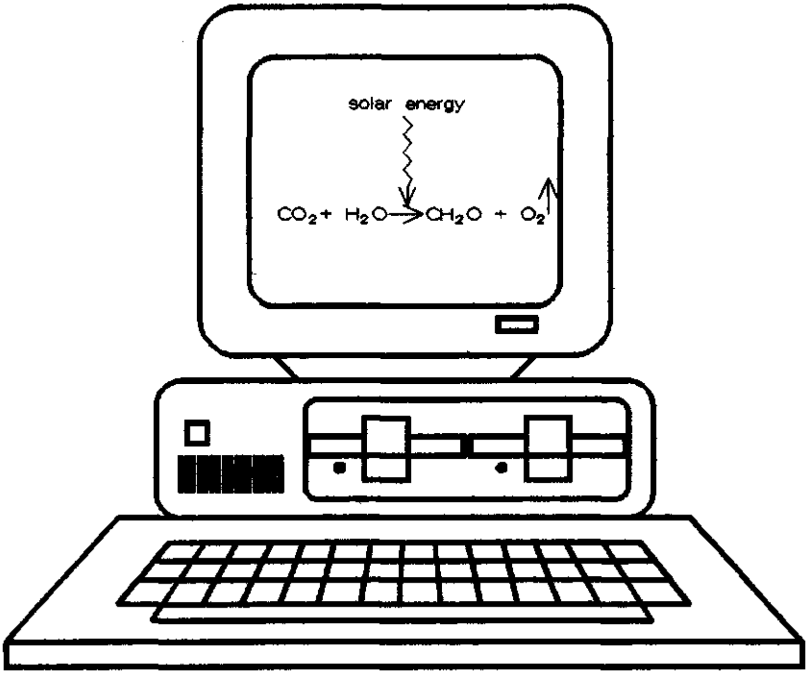
Saline and sodic soils are characterized by both high electrical conductivity (EC=4-15 mmhos/cm) and ESP values (usually 15-25), normally between 30 and 150 cm from the soil surface. The pH of these soils is usually less than 8.5.

Most soils of unit B2 are cultivated with winter wheat and give acceptable yields because the sodicity and/or salinity exists deeper than 30 cm from the soil surface. Crops tolerant to salinity and sodicity, viz. cotton and sugar beet, may yield as those on the B1 soil unit, in areas with access to good quality irrigation water.

Reclamation of the saline and sodic soils of the area requires further study. Widening of the Karla tunnel, application of gypsum (cheap in the area) and leaching with initially salty water should be considered.

The "Parakarlia" areas, which surround the Karla basin, cover approximately 5,300 ha which consist of coarse-textured, well drained, gravelly soils with a fairly stony surface, that are classified as Entisols and Inceptisols (USDA, 1975). The parent materials in the east are derived from schists and gneisses; these soils are moderately fertile and cultivated with almonds and potatoes (approx. 3,200 ha). The soils in the other parts of "Parakarlia" are derived from limestone and characterized by high surface stoniness. They are mainly cultivated with almonds.

3 METHODOLOGY



Quantifying the biophysical production potential
Quantifying the water-limited production potential
Quantifying the infiltration capacity

3.1 Quantifying the biophysical production potential

(Production Situation 1 or PS-1)

3.1.1 Gross canopy assimilation

General

Part of the incoming solar energy at canopy level is used for the reduction of atmospheric CO_2 to carbohydrates $(CH_2O)n$ according to the general equation:

$$CO_2 + H_2O + \text{solar energy} \text{ ----> } CH_2O + O_2 \tag{3.1}$$

The assimilation rate is determined by the photosynthesis response curves of individual leaves, the incoming radiation and the leaf area index. Leaf angle distribution, and extinction and reflection coefficients must also be known since they influence the interception of incoming radiation.

This computational problem was essentially solved by de Wit (1965). Goudriaan and van Laar (1978) revised part of this early work later on and calculated daily rates of CO_2 assimilation for closed canopies (Leaf Area Index=5), both under standard clear and standard overcast skies. The actual assimilation rate was subsequently obtained by accounting for the actual number of hours during which the sky is either clear or overcast. Photosynthesis at LAI-values lower than 5 was assumed to be proportional to the decrease in absorbed radiation with an additional reduction factor to account for light saturation of photosynthesis. This approach was used in the early versions of the simulation models SUCROS (van Keulen *et al.*, 1982) and WOFOST (Rappoldt, 1986), but Latinga (1985) and Spitters *et al.* (1986) stressed that an interpolation based on such a switch-on-off effect of cloudiness underestimates the effect of diffuse light on the assimilatory activity of plants. This under-estimation disturbed seriously the simulation of maize production in Greece (Danalatos & Sgouras, 1987). Spitters (1986) proposed to separate the diffuse and the direct components of the global radiation in the calculation of canopy photosynthesis. This modification produced more realistic functional relations, applied in the more recent versions of SUCROS and WOFOST. An additional improvement was the Gaussian integration of the instantaneous rate of leaf photosynthesis over canopy depth and over the day (Goudriaan, 1986). Sensitivity tests have confirmed the superiority of this new approach (Spitters, 1986; Kropff *et al.*, 1987).

In the model developed here, the latest SUCROS version is implemented for the calculation of gross canopy assimilation. Moreover, the photosynthetic rate at light saturation was made dependent on the average canopy temperature during the process. A summary of the background theory, the functional relations and the assumptions made, will be given in the following.

Photosynthesis of single leaves

The relation between available radiation and CO_2 gross assimilation by a single leaf is described by an asymptotic exponential relation (de Wit *et al.*, 1978) according to equation (3.2); this is presented in Fig. 3.1.

$$FG = AMAX * (1 - EXP(- EFF*PAR/AMAX)), \tag{3.2}$$

where FG is the assimilation in kg(CO$_2$)ha^{-1}(leaf)h^{-1} and PAR is the photosynthetically active radiation (400-700 mm) in J m^{-2}s^{-1}.

It can be seen (Fig. 3.1) that the assimilation-light response curve is characterized by only two parameters:
- the light use efficiency (EFF) in kg ha^{-1}h^{-1}/J m^{-2}s^{-1}, which gives the curve at low light intensity, and
- the maximum rate of CO$_2$ assimilation (AMAX) in kg(CO$_2$)ha^{-1}(leaf)h^{-1}, which determines the level of the curve at light saturation.

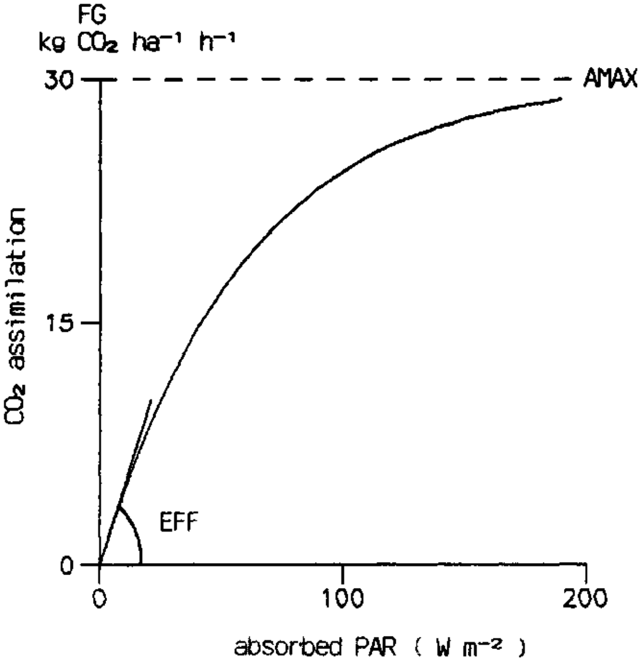


Fig. 3.1. Photosynthesis-light response curve of a single leaf.

EFF is largely independent of CO$_2$ concentration, light intensity, depth of canopy and temperature, and its value is roughly equal to 0.5 for most crops (van Laar & Penning de Vries, 1972; de Wit *et al.*, 1978). AMAX, on the other hand, differs widely among crops; it expresses the combined effects of CO$_2$ assimilation and photorespiration at light saturation. This explains why it has a much higher value for C4 crops (with negligible photorespiration) than for C3 crops (with high photorespiration).

The temperature has a pronounced effect on AMAX which has been studied in controlled conditions by many workers. These experiments have limited applicability in land evaluation as the situation in the field is not controlled, and the variation of AMAX with temperature is influenced by a gradual process of adaptation to the varying environmental conditions.

Table 3.1. Classification of crops according to photosynthetic pathway and climatic adaptation

C3 crops		C4 crops	
from temperate climates (I)	from warm climates (II)	from warm climates (III)	cvs. adapted to low temperatures (IV)
wheat	rice	maize	maize
barley	cassava	millet	sorghum
potato	soyabean	sorghum	
sugar-beet	cotton	sugar-cane	

(Source: Versteeg & van Keulen, 1986).

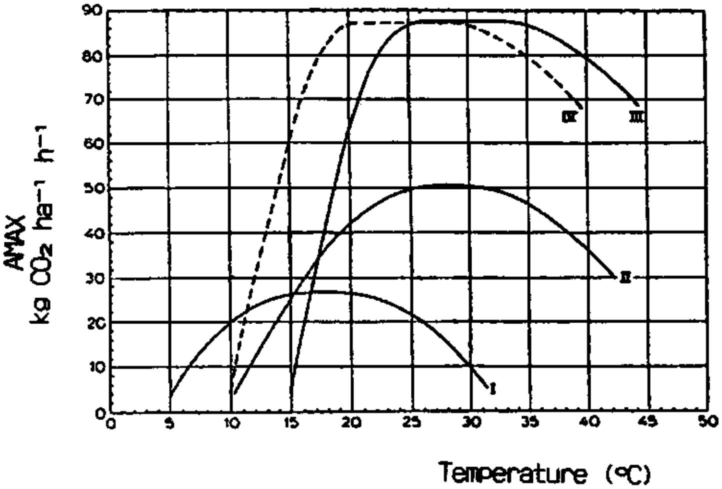


Fig. 3.2. Average relationship between AMAX and temperature for different crop groups. (Source: Versteeg & van Keulen, 1986).

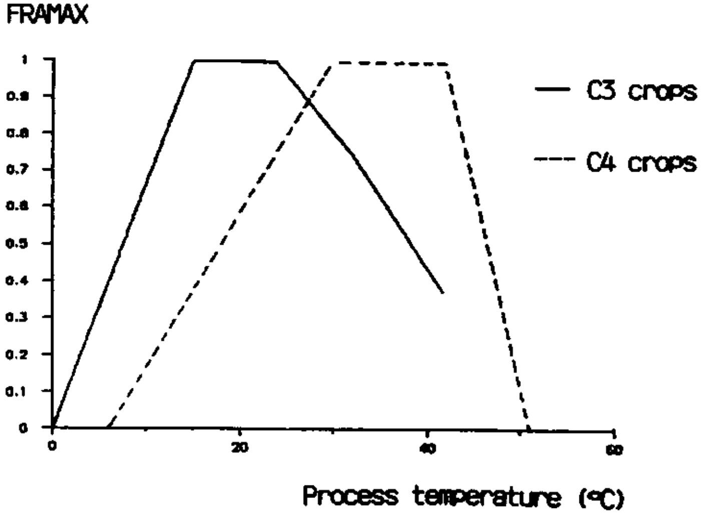


Fig. 3.3. Relation between process temperature and reduction factor for the maximum gross assimilation rate of a single leaf, for C3 (spring wheat) and C4 (maize) crops. (Source: van Diepen *et al.*, 1988).

In practice, assimilation shows a wide range of optimal temperatures (van Keulen & Seligman, 1987), depending on the crop considered and its climatic adaptation. Versteeg & van Keulen (1986) distinguish four main groups of crops. The optimum range of temperatures is higher for C4 crops than for C3 crops; among species with the same photosynthetic pathway, a distinction is made among species from temperate and from warm climates and between thermophile cultivars and cultivars adapted to temperate climates. This classification is presented in Table 3.1 for some important crops; the generated relationship between AMAX and temperature is shown in Fig. 3.2.

In the present study, the effect of temperature on AMAX is accounted for by a reduction factor (FRAMAX=AMAX(T)/AMAX(OPT)) which modifies the maximum gross assimilation rate; the optimum temperature range for gross assimilation is marked by a value of FRAMAX close to 1, where AMAX(T) is the value of AMAX at a given temperature T, and AMAX(OPT) is the value of AMAX at the optimum temperature for assimilation. The relation between process temperature and FRAMAX for C3 (wheat) and C4 crops (maize) is depicted from Fig. 3.3, where, for simplicity, a linear approximation of the parabolic curves is used. A different relation will be adopted for cotton in Chapter 4, where the concept of the "process temperature" will be also discussed. The optimum values of AMAX for the studied maize-, cotton- and wheat cultivars in the study area are 85, 50 and 40 kg(CO_2) $ha^{-1}h^{-1}$ respectively (Chapter 4).

Note that the value of AMAX changes proportionally to the CO_2 concentration in the range 0-500 ppm (De Wit, 1965; Goudriaan *et al.*, 1985; - & Ruiter, 1983; a.o.). However, considering that the CO_2 concentration is normally around 330 ppm, this effect is neglected here. Furthermore, the value of AMAX varies with the depth in the canopy. This effect is also neglected, for lack of supporting literature.

Photosynthesis of the canopy

The gross CO_2 assimilation of a single leaf is used to describe the gross CO_2 assimilation of a canopy, by accounting for the specific photosynthesis-light response curve typical for the crop, and by estimating the amount of the photosynthetically active radiation (direct and diffuse flux) absorbed by the canopy as a whole. The incoming radiation and actual crop assimilation values calculated are average values over the day.

The photosynthetically active radiation (PAR) is equal to about half of the total global radiation (AVRAD; 300-3000 nm), and is considered constant despite different atmospheric conditions and solar elevation angles (B). Directly measured AVRAD values are lacking in Greece. Instead, AVRAD is estimated from the available sunshine duration data, using the Angtroem formula (1924):

$$\text{AVRAD} = \text{DSO} * \text{ATMTR}, \quad \text{in J m}^{-2}\text{d}^{-1} \text{ and} \qquad (3.3)$$

$$\text{ATMTR} = (\, a + b * n/\text{DAYL}\,), \qquad (3.4)$$

where DSO is the extra-terrestrial irradiance (J $m^{-2}d^{-1}$) and ATMTR the atmospheric transmission; a and b are location-specific constants which have the values 0.20 and 0.56 respectively (Frère and Popov, 1979), in agreement with measurements in Greece (Papadakis, pers. communication). The parameter "n" denotes the actual sunshine duration (in hours) as measured with a Campbell-Stokes recorder, and DAYL represents the daylength (in hours).

DSO is calculated from the solar constant (1370 J $m^{-2}s^{-1}$), the DAY of the year (counted from the 1st January onwards) and the elevation of the sun (B) integrated over the daylength:

$$SO = 1370 * [1+0.033*\cos(2*\pi*DAY/365)]* \int_{0}^{DAYL} [\sin(B)dt], \text{ in J } m^{-2}d^{-1} \qquad (3.5)$$

The astronomical daylength (DAYL in hours) and the solar elevation (sin(B)) are given by:

$$DEC = -\arcsin(\sin(23.45*RAD) * \cos(2*\pi*(DAY+10)/365)) \qquad (3.6)$$

$$SSIN = \sin(RAD*LAT) * \sin(DEC) \qquad (3.7)$$

$$CCOS = \cos(RAD*LAT) * \cos(DEC) \qquad (3.8)$$

$$DAYL = 12 * (1+2*\arcsin(SSIN/CCOS)/\pi)3. \qquad (3.9)$$

$$\sin(B) = SSIN + CCOS * \cos(2*\pi*(HOUR+12)/24)) \qquad (3.10)$$

where DEC stands for the declination of the sun, LAT for the latitude and HOUR for the hour of the day; RAD is the transfer coefficient from degrees to radians (RAD=1/180).

The contribution of diffuse radiation (FRDIF) to AVRAD is calculated from the ATMTR, according to the relations established for daily totals in De Bilt (De Jong, 1980):

$$FRDIF/AVRAD = 1 \qquad \text{FOR } ATMTR < 0.07 \qquad (3.11a)$$
$$FRDIF/AVRAD = 1 - 2.3*(ATMTR-0.07)^2 \qquad \text{FOR } 0.07 \leq ATMTR < 0.35 \qquad (3.11b)$$
$$FRDIF = 1.33 - 1.46*ATMTR \qquad \text{FOR } 0.35 \leq ATMTR < 0.75 \qquad (3.11c)$$
$$FRDIF = 0.23 \qquad \text{FOR } 0.75 \leq ATMTR \qquad (3.11d)$$

The instantaneous fluxes of PAR, diffuse PAR (PARDIF) and direct PAR (PARDIR) are estimated from the daily values of AVRAD [Eqs.(3.3) through (3.5)], assuming a sine pattern in the fluctuation radiation over the day:

$$PAR = 0.5 * AVRAD * \sin'(B) \Big/ \int_{0}^{DAYL} [\sin'(B)dt], \text{ in J } m^{-2}s^{-1} \qquad (3.12)$$

$$PARDIF = 0.5 * AVRAD * FRDIF * \sin(B), \text{ in J } m^{-2}s^{-1} \qquad (3.13)$$

$$PARDIR = PAR - PARDIF, \text{ in J } m^{-2}s^{-1} \qquad (3.14)$$

where $\sin'(B)=\sin(B)*(1+0.4*\sin(B))$. The factor $(1+0.4*\sin(B))$ is added to account for the diurnal course of ATMTR that is associated with the diurnal pattern of the solar elevation. The intensity of the light, which penetrates the canopy, decreases exponentially with the LAI according to the following general equation:

$$VIS = (1-REFS) * PAR * \exp(-K*LAI), \text{ in J } m^{-2}(\text{leaf})s^{-1} \qquad (3.15)$$

where VIS is the net light intensity at depth LAI (from the top), PAR is the light intensity at the top of the canopy (J m^{-2}(ground)s^{-1}) and K is the extinction coefficient. REFS is the reflection coefficient for spherical leaf angle distribution.

In analogy with Eqn.(3.15), the profiles of the net diffuse flux (VISDF), the total direct flux (VIST) and the direct component of the direct flux (VISD) are given by:

VISDF = (1-REFS)*PARDIF*KDIF*EXP(-KDIF*LAI), in J m^{-2}(leaf)s^{-1} (3.16a)

VIST = (1-REFS)*PARDIR*KDIRT*EXP(-KDIRT*LAI), in J m^{-2}(leaf)s^{-1} (3.16b)

VISD = (1-SCV)*PARDIR*KDIRBL*EXP(-KDIRBL*LAI), in J m^{-2}(leaf)s^{-1} (3.16c)

where SCV is the coefficient of scatter (SCV=0.2), and KDIF, KDIRT and KDIRBL are the extinction coefficients of diffuse flux, and of total direct flux and the direct component of the direct flux, respectively. The extinction coefficients are approximated by Goudriaan (1977, 1982) as follows:

KDIF = 0.8 * SQR(1-SVC), SVS = 0.2 (3.17a)
KDIRBL = 0.5 / sin(B) (3.17b)
KDIRT = KDIRBL * SQR(1-SCV), (3.17c)

where 0.5 approximates the average projection on the ground surface of leaves showing spherical angle distribution, and 0.8 is the value of 0.5/sin(B) averaged over inclination (B) of incident radiation under an overcast sky. Note that a spherical leaf distribution is assumed for the considered crops.

The reflexion coefficient (REFS) is calculated with the combination of the following relations:

REFH = [1-SQR(1-SCV)] / [1+SQR(1-SCV)] (3.18a)
REFS = REFH * [1/(0.5+sin(B))] (3.18b)

Eqn.(3.18a) calculates the reflexion for a canopy with horizontal leaves (REFH) according to Goudriaan (1977). The second part of Eqn.(3.18b) is an approximate correction factor for a spherical leaf angle distribution (Goudriaan, 1988). Note that the tabulated value 0.5 is used again, as in Eqn.(3.17), to denote the average projection of spherical leaves on the ground.

The absorbed diffuse flux (VISSHD) is the sum of the net diffuse flux (VISDF; Eqn.(3.16a) and the diffuse part of the direct flux [VIST-VISD; Eqn. (3.16b-c)], and it is used, according to the general equation (3.2), for the calculation of the assimilation rate by shaded leaves (FGRSH):

FGRSH = AMAX * (1-EXP(-VISSHD*EFF/AMAX)), in kg(CO_2)$ha^{-1}h^{-1}$ (3.19)

The absorbed direct flux (VISSP) amounts to:

VISSP = (1-SCV)*PARDIR/sin(B), in J m^{-2}(leaf)s^{-2} (3.20)

resulting in an assimilation rate of the sunlit leaves (FGRSUN) of:

FGRSUN = AMAX * [1-(AMAX-FGRSH) *
* (1-EXP(-VISPP*EFF/AMAX)) / (EFF-VISPP)] (3.21)

The assimilation rate per unit leaf area (FGL), averaged over a canopy layer, is the sum of the assimilation rates of sunlit and shaded leaves, weighted by their share in that layer:

$$FGL = FSLLA*FGRSUN + (1\text{-}FSLLA)*FGRSH,\ \text{in kg}(CO_2)ha^{-1}h^{-1} \qquad (3.22)$$

where FSLLA is the fraction sunlit leaf area. FSLLA is equal to the fraction of direct incident radiation on the canopy layer according to:

$$FSLLA = EXP(-KDIRBL*LAI) \qquad (3.23)$$

The rate of daily canopy assimilation is approximated by the weighted average of the assimilation rates at three selected canopy depths at 3 moments during the day (3x3 discrete points). The three selected depths in the canopy (LAIC) and the 3 hours of the day (HOUR) are respectively:

$$LAIC(I) = 0.5*LAI + LAI*I*SQR(0.15),\ \text{and} \qquad (3.24)$$

$$HOUR(I) = 12 + DAYL*0.5*(0.5+I*SQR(0.15)),\ \text{where } I=-1,0 \text{ and } 1. \qquad (3.25)$$

The total canopy assimilation at the selected moments of the day is given by:

$$FGROS(I)=(FGL(-1)+1.6*FGL(0)+FGL(+1))*LAI/3.6,\ \text{in kg}(CO_2)ha^{-1}d^{-1} \qquad (3.26)$$

which, integrated over the day gives the gross canopy assimilation rate:

$$FGC=(FGROS(-1)+FGROS(0)*1.6+FGROS(+1)*DAYL/3.6,\ \text{in kg}(CO_2)ha^{-1}d^{-1}. \qquad (3.27)$$

Finally, the carbohydrate assimilation rate (FGASS) is obtained by multiplying the rate of CO_2 reduction by 30/44, the ratio of the molecular weights of CH_2O and CO_2:

$$FGASS = FGC * 30/44,\ \text{in kg}(CH_2O)ha^{-1}d^{-1} \qquad (3.28)$$

3.1.2 Respiration

Respiration is the reverse of assimilation, viz. the conversion of carbohydrates to CO_2 and H_2O; it occurs all day long in all plant organs and releases chemical energy required by the plant to support energy demanding processes e.g. protein turnover and transport processes against ionic gradients. Basically, respiration is described by:

$$CH_2O + O_2 \text{ ---> } CO_2 + H_2O + \text{chemical energy} \qquad (3.29)$$

Total respiration is made up of two major components: photorespiration and dark respiration.

Photorespiration affects mainly the C3 crops and is, for all practical purposes, negligible in C4 crops. It causes losses of CO_2 in the sunlit photosynthetic organs, which increase with light intensity and temperature. Photorespiration explains why C3 crops have a lower temperature optimum than C4 crops (see earlier and Fig. 3.2). Indicative values of the optimum temperature for photosynthesis are 15-25 °C for C3 crops and 30-40 °C for C4 crops (Black, 1973). The process is, in fact, an integral part of the (gross) assimilation process. In this model, the impact of photorespiration is taken into account in the choice of the AMAX value. In the remainder of this paragraph we shall focus on the simulation of the dark respiration.

Two components of *dark respiration* are distinguished (McCree, 1970), viz. maintenance respiration, providing the plant cells with energy to meet maintenance requirements, and growth respiration providing the energy for the conversion of the primary photosynthates into structural plant material such as cellulose, proteins, lignin and fats.

Maintenance respiration

Following a biochemical approach, Penning de Vries (1975) estimated the respiration needed to offset protein turnover in vegetative tissues at some 7-13 mg glucose/g total dry matter, and the respiration needs for maintaining ion concentrations in the range 6-10 mg glucose/g dry weight per day. Measured values of maintenance costs are scarce and the existing data exhibit a large variation. Nevertheless, there is a fair agreement between theoretical values and values reported in the literature for experiments with medium light intensities and temperatures around 20°C. Above this temperature, the maintenance respiration rate increases drastically with a Q_{10} value of about 2 for both C3 and C4 crops. This temperature dependence is typical for enzymatic reactions in plants.

Different plant organs tend to have different maintenance respiration needs reflecting differences in chemical composition -proteins and mineral content- and in metabolic activity. The maintenance respiration rate, MRR(org), can be approximated from relative maintenance respiration rates for the various plant organs:

$$\mathrm{MRR(org)} = \mathrm{R(org)} * \mathrm{S(org)} \qquad (3.30)$$

where R(org) is the relative maintenance respiration rate for plant organ "org" in $\mathrm{kg(CH_2O)\ kg^{-1}(dry\ matter)d^{-1}}$, and S(org) is the momentary dry weight of that (living) organ, in $\mathrm{kg(dry\ matter)ha^{-1}}$.

Penning de Vries (1975; -& van Laar, 1982) and Van Diepen *et al.*(1988) report indicative values of R(leaf) of 0.030, values for R(stem) of 0.015, and values for R(root) and R(st.org.) of 0.010 for maize, wheat and cotton (all values in $\mathrm{kg(CH_2O)kg^{-1}(dry\ matter)d^{-1}}$). These values are slightly higher than the values originally proposed by Penning de Vries (1975) but they refer to slightly higher temperature e.g. 25°C vs. 20°C. However, they seem somewhat too high for application under Greek conditions (see Chapter 4) or other warm environments. They probably lead to slight over-estimation of the dry matter production when applied in production calculations for temperate regions (Minère, 1989). The values adopted here (see Chapter 4) are used for calculating an "equivalent" total daily maintenance requirement rate (MRRS), valid at a crop-specific reference temperature (TREF). The actual maintenance requirement (MRR) is subsequently found by correction for the average growth temperatures. See also Spitters *et al.* (1988). The MRR is computed as follows:

$$\mathrm{MMR} = \mathrm{R(org)} * \mathrm{S(org)} * \{Q_{10}{**}\{(\mathrm{TCAN-TREF})/10)\}\}. \qquad (3.31)$$

Here, TCAN is the canopy temperature, the approximation of which will be discussed in Section 3.2. TREF denotes the reference temperature, which, for summer crops in Greece is taken equal to 30°C (see Chapter 4).

Growth respiration

The growth respiration rate of both C3 and C4 crops shows an optimum temperature range similar to the one for the gross assimilation rate. This temperature dependence is characteristic for synthetic processes, and the rate of growth respiration per unit of converted assimilates, known as conversion efficiency, remains almost constant over a wide temperature range. There is no hard evidence that plant respiration -including maintenance respiration- is greatly affected by other environmental factors than temperature, such as water stress or salinity (Penning de Vries, 1978). The conversion efficiency appears to vary only with the composition of the structural plant material viz. its contents of fats, lignin, proteins, nucleic and organic acids etc. The conversion efficiency values (EC) of 0.72, 0.69 and 0.72, tabulated for leaves, stems and roots respectively, are thought to apply for all crops considered in this study (Penning de Vries & van Laar, 1982). For storage organs, however, a higher EC value applies in the case of cereals than for cotton viz. 0.73 vs. 0.61. This reflects the higher concentration of lipids in cotton bolls; these lipids are produced at much higher (respiration) cost (Penning de Vries *et al.*, 1983).

3.1.3 Dry matter accumulation and distribution

The next step in the quantitative description of crop production is the description of the net assimilation rate, and how the assimilates are allocated for growth of the various plant organs. This allocation of the assimilates is described as a function of the development stage, accounting for the losses of conversion from carbohydrates to structural plant material (growth respiration). In the next paragraphs, the background and the functional relations for development, net assimilation rate, partitioning of the dry matter and growth of the crop are discussed.

Development

Firstly, a distinction should be made between development and growth. Growth means the increase in dry weight and volume; on the other hand, development is defined as the passing of the crop through consecutive phenological stages characterized by the appearance of vegetative and reproductive plant organs. The relative development rate of a crop is calculated accounting for the accumulated effective thermal units (temperature minus threshold temperature) over two periods: from emergence till anthesis and from anthesis till maturity. The following equations are involved:

$$\mathrm{DVS} = \mathrm{TACT}/\mathrm{TSUM} \qquad (3.32)$$

$$\mathrm{TACT} = (\mathrm{TCAN}-\mathrm{TH}) + \mathrm{TACT(old)}, \qquad (3.33)$$

where DVS stands for the development stage (from 0 to 1). TACT is the accumulated effective temperature of the crop till a given interval (in °C days). TCAN denotes the leaf temperature (°C) (see Section 3.2). TH is the threshold temperature for development (°C), TACT(old) is the effective temperature accumulated till (n-1) time intervals (°C-days) and TSUM is the sum of thermal units of the crop required for full development, in °C-days.

If the crop development is calculated for two stages of development with different thermal units for pre-anthesis and for the period from anthesis to maturity, the following corrections are needed:

$$\text{IF TACT/(TSUM(1))} < 1 \text{ THEN DVS} = 0.5^{*}\text{(TACT/TSUM(1))} \tag{3.34a}$$

$$\text{IF TACT/(TSUM(1))} >= 1 \text{ THEN DVS} = 0.5 + 0.5^{*}\text{(TACT-TSUM(1))/TSUM(2),} \tag{3.34b}$$

where TSUM(1) and TSUM(2) are respectively the temperature sums required from emergence to anthesis and from anthesis to maturity, in °C-days.

Net assimilation and dry matter distribution

According to the "Wageningen approach", subtraction of the total maintenance respiration rate (MRR) from the potential gross assimilation rate yields the rate of potential net assimilation (NET), which will be invested in the formation of new plant matter:

$$\text{NET} = \text{FGASS-MRR,} \quad \text{in kg(CH}_2\text{O)ha}^{-1}\text{d}^{-1} \tag{3.35}$$

A substantial difference in the present algorithm is that the maintenance cost per plant organ is subtracted from the assimilates allocated to the specific organ. This approach, though open to criticism, offers a far better fit to measured growth curves (see Chapter 4).

The partitioning of the assimilates over the various plant organs (leaves, stems, roots and storage organs) is a dynamic process that changes continuously during development. This is accounted for with a crop-organ specific partitioning fraction, FR(organ) expressed as a function of the DVS. This relation as well as the effects of environmental conditions, other than temperature, on FR(organ) will be discussed later (in the Chapter on Field experiments). As stated earlier, the losses incurred in the conversion of the net assimilatory products to structural plant matter (growth respiration) are accounted for with organ-specific conversion factors (EC). On the basis of the processes presented above, the daily rate of increase in structural dry organ weight of a crop can now be approximated with the formula:

$$\text{DWI(org)} = [\text{FGASS*FR(org)-MRR(org)}] * \text{EC(org)} \tag{3.36}$$

instead of the earlier formula:

$$\text{DWI(org)} = \text{NET * FR(org)* EC(org),} \tag{3.36a}$$

where DWI(org) is the potential increment in dry organ weight in kg(dry matter) $\text{ha}^{-1}\text{d}^{-1}$. MRR(org) is given by Eqn.(3.31).

Living plant material dies off after a certain time: the leaf tissue life span (LLS). The LLS is considered here as temperature dependent, and a certain number of thermal units must have accumulated above the threshold temperature, before leaf tissue starts to die. Then a counter is activated which makes it possible to decrease DWI(leaf) by the dying rate of leaves which is further dependent on the availability of water:

$$\text{IF TACTLLS} >= \text{TSUMLLS THEN DWIL}=\text{DWIL}-\text{LDR(CFW)} \tag{3.37}$$

where TACTLLS is the actual temperature sum, in °C-days; TSUMLLS is the tabulated heat sum for leaf life span, in °C; DWIL denotes the dry weight increase of leaves, in kg ha^{-1}; and LDR(CFW) is the dying rate of leaves as a function of the water availability and expressed by the ratio of actual over potential transpiration (CFW; see Section 3.2). This function is further discussed in Section 4.1.

At the end of each interval calculation, a new LAI value is computed from the specific leaf area (SLA) and the updated dry leaf weight. SLA is a temperature and light dependent crop parameter; measured values (Chapter 4) are used for the considered crops.

The description of plant growth during each interval of calculation is concluded with the adjustment of all organ weights, as follows:

$$S(org) = S(org) + DWI(org), \tag{3.38}$$

where S(org) is the total dry organ weight, in kg(dry matter)ha^{-1}.

3.2 Quantifying the water-limited production potential
(Production Situation 2 or PS-2)

In this section crop performance is assumedly conditioned by the availability of light, temperature and water; the supplies of nitrogen and mineral elements to the crop are assumed not to constrain crop performance.

3.2.1 The water balance

A general water balance equation keeps track of the soil moisture potential over time. A multi-layered soil profile is considered. The upper boundary is the soil surface; the lower profile boundary is the lower boundary of the lowermost compartment. Apart from surface losses/influx and loss or gain of water through the lower boundary, loss of water takes place from the rooted interior part of the profile through uptake by the roots. Neglecting -for the time being- any movement inside the soil system, the water balance can be described as follows:

$$RSMs = IM-(D+CRISE)-TR(RD), \qquad (3.39)$$

where

RSMs	is the change in moisture content of the system,
IM	is the rate of net influx through the upper system boundary,
(D+CRISE)	is the rate of net outflux through the lower system boundary, composed of capillary rise (CRISE) and drainage to the subsoil (D),
TR(RD)	is the rate of water loss from the interior of the rooted profile.

All variables are expressed in cm d^{-1}.

The rate of net water supply at the soil surface (IM) is the sum of precipitation, irrigation and infiltration of water stored on top of the soil surface (if any), minus run-off and evaporation losses according to:

$$IM = (PREC+IRR+DS-ROFF) - EA, \qquad (3.40)$$

where

PREC and IRR are the effective precipitation and irrigation rates,

DS	is the rate at which water stored on the surface declines (DS>=0),
ROFF	is surface run-off, and
EA	is the actual evaporation rate

(all in cm d^{-1}).

3.2.2 Soil moisture dynamics

Many earlier studies demonstrated that assimilation, respiration and transpiration can be accurately simulated on a daily basis. For other processes however, such as infiltration of water in soil, this is impossible. Consider, for example, a loamy soil with a maximum infiltration capacity of some 15 cm per day. As demonstrated in Section 3.3, this soil will be ponded within 1/2 hours, if irrigated at a (usual) rate of 1.5 cm h^{-1}.

Besides water availability, oxygen availability may constrain the potential productivity on some irrigated soils, if the irrigation induces temporary lack of soil air.

Describing the infiltration of water in soils (and its consequences for oxygen availability) requires that relevant soil physical properties be known with sufficient detail. This is particularly clear for detailed models such as the ones of van Keulen & van Beek (1971), Stroosnijder *et al.*(1972), de Wit & van Keulen (1975), a.o. For such accurate simulations, temporal resolution is often of the order of seconds, which becomes prohibitive if such models are to be linked to crop-growth models that span periods of 120-150 days and more. Moreover, such models are usually not practicable because rainfall and/or soil data are rarely available in such detail. As a result, growth simulation is normally based on grossly simplified approaches as the model for soil moisture flow developed here. The present "simplified" model is largely based on a more detailed model by van Keulen and van Beek (1971), which is referred to as "the detailed model" hereafter.

The "simplified model"

As already stated, a layered soil profile is considered here, with a total depth DEPTH=140 cm. The rooting zone comprises only part of the soil profile, as the roots normally penetrate less deeply than 140 cm. As shown in Fig. 3.4a, the profile consists of 7 soil compartments of 20 cm. Differentiation of soil properties can occur only in three soil layers viz. A: 0-20 cm, B: 20-80 cm and C: 80-140 cm. In other words, all compartments in the same soil layer have the same soil physical properties, which facilitates application of the information supplied by the National Soil Map (see Fig. 2.12). The number and depth of the soil layers can however be easily modified.

In Fig. 3.4b, a slab from the middle of the rooted soil is shown, including three soil compartments viz. (n-1), (n) and (n+1). The soil parameter values known are the soil moisture content (SMPSI, in cm^3cm^{-3}), matrix suction (PSI, in cm), and hydraulic conductivity (KPSI, in cm d^{-1}). Assuming, that the flow of water occurs from the centre of each compartment to the centre of an adjacent one, the driving forces of this flow are described by the difference in hydraulic head between the central points of the adjacent compartments. Considering the compartment (n) in Fig. 3.4b, in- and outflux of water (V1 and V2), follow Darcy's law:

$$V1=KAV1*(HEAD(n-1)-HEAD(n))/(0.5*(TCOM(n-1)+TCOM(n))), \text{ in cm d}^{-1} \qquad (3.41a)$$

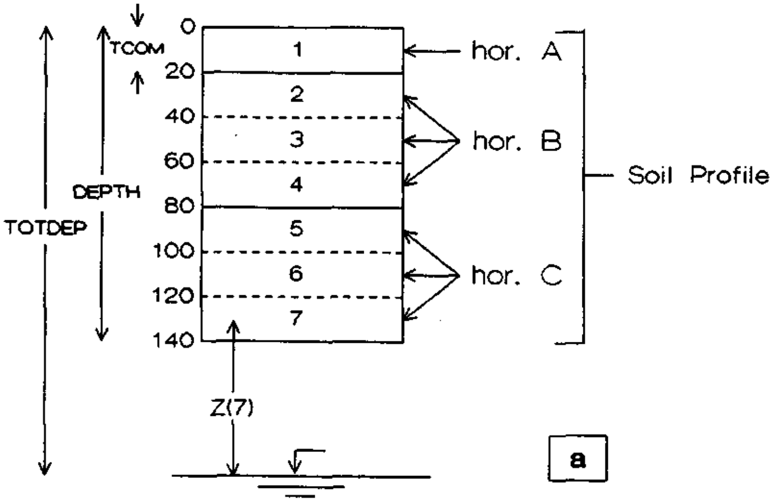
$$V2=KAV2*(HEAD(n)-HEAD(n+1))/(0.5*(TCOM(n)+TCOM(n+1))), \text{ in cm d}^{-1} \qquad (3.41b)$$

where HEAD(n) is the hydraulic head in the centre of compartment (n), and TCOM(n) is the size of compartment (n). KAV1 and KAV2 are the arithmetic averages of the hydraulic conductivities, given by:

$$KAV1 = 0.5*(KPSI(n)+KPSI(n-1)), \text{ in cm d}^{-1} \qquad (3.42a)$$

$$KAV2 = 0.5*(KPSI(n)+KPSI(n+1)), \text{ in cm d}^{-1} \qquad (3.42b)$$

where KPSI(n) is the hydraulic conductivity in the compartment (n) expressed in cm d^{-1}.



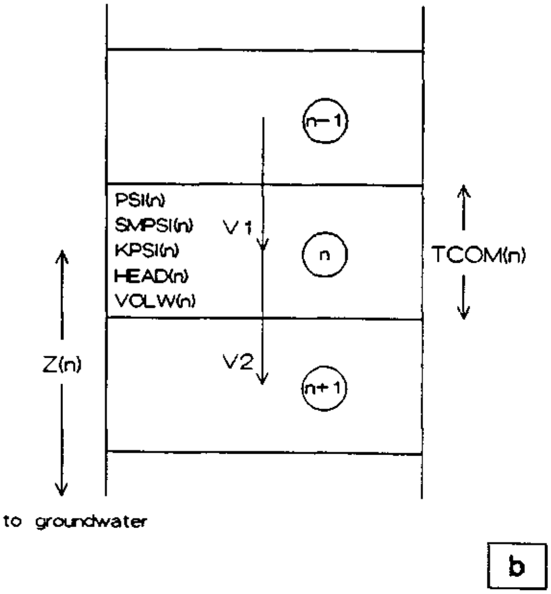


Fig. 3.4. Schematic representation of the soil profile (a), and a part from the middle of the soil column (b).

The hydraulic head in the middle of compartment (HEAD(n)) is given by:

$$\mathrm{HEAD(n)} = \mathrm{Z(n)} - \mathrm{PSI(n)}, \text{ in cm} \tag{3.43}$$

where PSI represents the matrix suction, i.e. the absolute value of the matrix potential (cm), and Z(n) the distance from the centre of compartment (n) to ground-water table.

At ground-water level, Z=PSI=HEAD=0. Thus, Eqn. (3.43) assumes a positive value for water moving in downward direction (HEAD>0). At the middle of each soil compartment, Z is then calculated according to the following formulations:

$$Z(1) = TOTDEP - 0.5*TCOM(1), \text{ in cm} \tag{3.44a}$$
$$Z(n) = Z(n-1) - 0.5*(TCOM(n-1)+TCOM(n)), \text{ in cm} \tag{3.44b}$$

where TOTDEP is the depth of the ground water from the soil surface (cm).

The rate of change in the moisture content of each soil compartment is:

$$RSM = V1 - V2 - TRCOM, \text{ in cm d}^{-1} \tag{3.45}$$

where TRCOM represents the actual water loss by transpiration (cm d^{-1}). The updated volume of water and the corresponding new soil moisture content are given by:

$$VOLW(n)new = VOLW(n)old + RSM*DELTAT, \text{ in cm} \tag{3.46}$$

$$SMPSI(n) = VOLW(n)new / TCOM(n), \text{ in cm}^3\text{cm}^{-3} \tag{3.47}$$

where VOLW is the water volume, and DELTAT is the time interval of calculations.

In the described set-up, all dependent variables reflect the state of the system at any moment. The actual water uptake (TRCOM) is discussed in the next paragraph. The flow rates through the boundaries of the soil system, i.e. V1 of the uppermost soil compartment and V2 of the lowermost soil compartment are calculated separately (see Eqs.(3.39) and (3.40)). This will be the subject of paragraph 3.2.4.

3.2.3 Water uptake

Maximum transpiration rate

A modified Penman formula is used to approximate the potential rate of evapo-transpiration from meteorological data available in the study area. The calculations start with calculation of the evaporative heat loss above the canopy (LET):

$$LET = \frac{1}{PENX + g} * (PENX*NETRA+hu*(EASAT-EAC)), \text{ in J m}^{-2}\text{d}^{-1} \tag{3.48}$$

where

LET	is the evaporative heat loss above the canopy,
PENX	is the slope of the saturation vapour pressure curve at mean temperature,
g	is the psychrometer constant (=0.66 mbar °C^{-1}),
NETRA	is net absorbed radiation (J m^{-2}d^{-1}),
hu	is the sensible heat transfer coefficient (J m^{-2}d^{-1}K^{-1}),
EASAT	is the saturated vapour pressure at mean air temperature, and
EAC	is the actual vapour pressure (both in mbar).

The net radiation is found by subtracting the out-going long wave radiation (INRA) from the absorbed short-wave radiation (SHRA):

$$NETRA = SHRA - INRA, \text{ in J m}^{-2}\text{d}^{-1} \tag{3.49}$$

SHRA is given by:

$$SHRA = (1\text{-}r)*AVRAD, \quad \text{in J m}^{-2}\text{d}^{-1} \qquad (3.50)$$

where AVRAD is the total global radiation (J $m^{-2}d^{-1}$) (Eqn. 3.3), and r the albedo (reflection coefficient); for a green crop surface, r is roughly equal to 0.25.

For the calculation of INRA, Penman (1956) used an expression, which is derived from the Brunt-formula (Brunt, 1932):

$$INRA = 4900*(TA+273)^4*(0.56\text{-}0.079*EAC^{1/2})*(0.1+0.9*SD), \quad \text{in J m}^{-2}\text{d}^{-1} \qquad (3.51)$$

where SD is the sunshine duration ratio, i.e. the ratio of actual over maximum possible sunshine hours (DAYL), and TA is the average air temperature (°C). 4900 is the value of the Stefan-Bolzman constant (J $m^{-2}d^{-1}K^{-4}$); the factor 273 is added to convert to absolute temperature.

The value of the sensible heat transfer coefficient, hu, depends on atmospheric turbulence and may be expressed as an empirically determined function of mean wind velocity at a defined height (Penman, 1948):

$$hu = au*(1+WVAL*WIND), \quad \text{in J m}^{-2}\text{d}^{-1}{}^{\circ}\text{C}^{-1} \qquad (3.52)$$

where WIND is the mean wind velocity (m s^{-1}), and au and WVAL are empirical constants.

Frère & Popov (1979) suggest a value for au of $6.4*10^5$ J $m^{-2}d^{-1}{}^{\circ}C$. Indicative WVAL values are reported by Frère (1979) in the range 0.54-0.89 s m^{-1}, depending on the value of TMAX-TMIN; the parameters TMAX and TMIN represent the maximum and minimum daily temperatures (°C).

The saturation and actual vapour pressures are approximated with the following formulas:

$$EASAT=6.11*\exp(17.4*TA/(TA+239)), \text{ (Goudriaan, 1977)} \qquad (3.53)$$

$$EAC = EASAT * RH, \qquad (3.54)$$

where RH is the average air humidity (%); EAC and EASAT are both expressed in mbar. Tabulated values for PENX are found in tables prepared by Frère (1979) for various combinations of air temperature (TA) and altitude (ALT) in meters above or below sea level (in meters).

For the description of the canopy transpiration rate of a well-watered crop, some modifications are needed with regard to the absorbed radiation:

- The long-wave radiation is calculated with Brunt's equation (Eqn. 3.51). Transpiration occurs at daytime because the stomata are closed at night; the loss of long-wave radiation to be considered here concerns therefore only the fraction that is emitted during the day. The expression for INRA given in Eqn.(3.51) is therefore multiplied by DAYL/24, DAYL being the daylength, expressed in hours (see Eqn. 3.9).
- A (small) part of the incoming visible radiation is used for assimilation. For the reduction

of 1 kg CO_2, $10.8*10^6$ J are needed (Goudriaan, 1977). Since the light use efficiency, EFF, is $14*10^{-9}$ kg CO_2 per J visible radiation (note that this value is identical to the 0.5 kg $ha^{-1}h^{-1}/J\ m^{-2}s^{-1}$, reported in Section 3.1), it follows that maximally 15 percent of the visible radiation is used for CO_2-assimilation.

- The part of the incoming radiation transmitted towards the soil surface should be accounted for. Goudriaan (1973 -in van Keulen, 1975; 1977) showed that it is justified to use an exponential extinction of the total radiation, with an extinction coefficient of 0.5 for a spherical leaf area distribution.

On account of the foregoing, NETRA in Eqn.(3.48) is calculated by:

$$NETRA=(0.75*AVRAD-INRA*DAYL/24-FGC*1080)*(1-\exp(-0.5*LAI)),\ J\ m^{-2}d^{-1} \quad (3.55)$$

where FGC is the gross canopy assimilation (kg $ha^{-1}d^{-1}$) and LAI is the leaf area index of the canopy.

The maximum transpiration rate, TRM expressed in cm d^{-1}, is found by dividing the calculated value of the evaporative heat loss, LET, by the latent heat of vaporization of water:

$$TRM = 0.1 * LET / L, \text{ in cm } d^{-1} \quad (3.56)$$

where L is the latent heat of vaporization ($2.45*10^6$ J kg^{-1}); and 0.1 is used to satisfy the units.

Root growth and distribution

The maximum depth of the root system is affected by the permeability of the soil e.g. pans, dense soil layers, and the soil moisture content. As long as roots grow, their "rate of root growth" (RRG in cm d^{-1}) is practically constant (van Keulen, 1975). For crops grown under irrigated conditions, reported values of RRG range from 1.2 to 1.5 cm d^{-1}. The initial rooting depth, i.e. the rooting depth at the time of emergence, is determined by crop properties and management practice. Measurements in the study area suggest that a value of 10 cm can be used in all cases.

The increase in dry root weight is largely determined by the fraction of the total net assimilate production apportioned to the underground plant parts (FRROOT). FRROOT as well as the fractions allocated to the other plant parts, change with the development stage of the crop (DVS; see Section 3.1).

As will be discussed later in this paragraph, the actual rate of crop transpiration is co-determined by the soil moisture content. The functional relation used assumes even distribution and proper functioning of the rooting system. However, the limited data available on root distribution and root activity are collected from pot experiments and cannot always be applied to field crops. Nevertheless, there are obvious trends: Stroosnijder & van Keulen (1972) showed that growing root systems expand towards the water, rather than to rely on transport of water towards the roots. This is confirmed by Klepper *et al.* (1973) who observed that when water becomes available to part of an existing rooting system, the plant is able to quickly form new secondary roots (1-2 days) to take up the available water. In a simulation study, Van Keulen (1975) elaborated for different root distributions that neglecting the soil-water flux hardly influences the water availability to the plant roots.

The influence of soil moisture on root elongation was observed in the study area: a maize crop on a loamy Typic Xerofluvent in the Peneios Delta with ground water at 2 m depth (viz. Pedon 2 in App. A.3), developed a rooting system down to 150 cm at an average RRG of 2 cm d^{-1}. In contrast, rooting was entirely within 65 cm from the surface in a Larissa Entic Chromoxerert (RRG=0.9 cm d^{-1}); in this heavy soil the irrigation water penetrates no deeper than this depth. Shallow rooting occurs in soils that are too wet during the establishment of the crop. The farmers in the study area know that if the roots find plenty of water in the (wet) topsoil, they "do not bother" to go deeper in search of more. They are reluctant with early irrigations, aware of the fact that shallow rooting is dangerous later in the season when water becomes scarce. Shallow rooting has often proved fatal to maize exposed to strong "livas" winds in the summer.

The above considerations make it clear that dynamic simulation of the root growth is not particularly needed in the present land-evaluation-oriented context. The initial and the maximum rooting depths and the rates of root growth will be postulated. The initial rooting depth is set at 10 cm for all crops considered. The maximum rooting depth (RDM, in cm) takes a value according to each particular combination of crop and soil. In the case of a shallow impermeable soil layer or shallow ground water, the RDM is set at the depth of these features. Otherwise, the value of RDM is set according to observations on the actual rooting in studied soil profiles, using additional information supplied by the farmers. Root growth rates are remarkably variable in the area (RRG=0.9-1.8 cm d^{-1}). In practice, the value of RRG depends on the maximum rooting depth and the number of days elapsed since emergence, and holds as long as the root grows (FRROOT > 0), after which it becomes equal to zero.

$$\text{IF FRROOT}>0\ \text{THEN RRG=RRG ELSE RRG=0, in cm d}^{-1} \quad (3.57a)$$

$$\text{IF RD}<\text{RDM THEN RD=RD+RRG*DELTAT ELSE RD=RDM, in cm} \quad (3.57b)$$

where RD is the momentary rooting depth.

Actual transpiration rate

Earlier in this paragraph, the maximum transpiration rate (TRM, in cm d^{-1}) was calculated. The crop can only transpire at this maximum rate (TR=TRM) as long as the soil moisture content is in a specific optimum range. The lower limit of this range corresponds with a critical soil moisture potential, i.e. PSICR(soil), the highest matrix suction that the crop can still compensate for maximum water uptake. Considering continuity in the soil-plant system, the rate of water uptake equals the rate of transpiration:

$$\text{PSICR(soil)} = \text{PSI(leaf)} - \text{TRM} * [\text{R(plant)}+\text{R(root)}], \text{ in cm} \quad (3.58)$$

where PSICR(soil) is the critical soil moisture potential (cm) and PSI(leaf) is the moisture potential at the leaf surface (cm). R(root) and R(plant) are the flow resistances posed by the root surface and the plant tissue, respectively (d^{-1}).

Unfortunately, only approximate values of the above resistance terms exist, and the available data are too general to make Eqn.(3.58) applicable. Alternatively, a critical soil moisture content (SMCR, in cm^3cm^{-3}) at which the crop starts to sense water stress, can be calculated using a soil-independent "depletion fraction" of the total available soil moisture.

Table 3.2.A. Soil water depletion fraction (DEPLF) for crop groups and maximum (evapo)transpiration (TRM).

Crop Group	TRM (cm/day)								
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1	0.500	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.800	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

Table 3.2.B. Crop groups according to soil depletion

Group	Crops
1	onion, pepper, potato
2	banana, cabbage, grape, pea, tomato
3	alfalfa, bean, citrus, groundnut, pineapple sunflower, water melon, wheat
4	cotton, maize, olive, safflower, sorghum, soybean, sugar beet, sugar cane, tobacco.

(Source: Doorenbos & Kassam, 1979).

This method is widely used by irrigation engineers. The depletion fraction (DEPLF) assumes a crop/weather dependent value as presented in Table 3.2 for a number of plant groups and TRM values. A decrease of the soil moisture content below SMCR goes with a drop in transpiration, which for simplicity is assumed linear. Most plants are unable to take up any more water when the soil matrix suction exceeds 16 Atm (pF=4.2). The corresponding soil moisture content is, as said, the moisture content at permanent wilting point (SMPWP, in cm^3cm^{-3}).

The upper limit of the soil moisture range for maximum transpiration is set by the occurrence of stress due to lack of oxygen. The minimum soil-air content needed to maintain root activity is not well documented in the literature. Here, it is assumed that root activity stops entirely if the soil contains 2% air or less. Likewise, the air content required for full activity is postulated at 6% or more, in all cases. These values could satisfy simulation of the reduced growth observed in a maize planting in Larissa that suffered from excess moisture (viz. the "wet treatment" in Section 4.1). Obviously, such fixed values are not always correct, as the root activity varies over time, e.g. as a function of temperature. However, any attempt to describe the actual O_2 requirement of the root system as a dependent system variable would very much complicate the water balance calculations and it would probably not produce "better" results in the present context. In line with the above, calculations of the actual transpiration rate of crops can be done as presented in the self-explanatory Fig. 3.5.

SMCR = (1-DEPLF)*(SMO-0.02-SMPWP) + SMPWP, in cm^3cm^{-3} (3.59)

IF SMPSI > = (SMO-0.02) THEN TR=0 (3.60a)

IF (SMO-0.02) > = SMPSI > = (SMO-0.06) THEN
TR = TRM*(SMO-0.02-SMPSI)/0.04 (3.60b)

IF (SMO-0.06) > = SMPSI > = SMCR THEN TR=TRM (3.60c)

IF SMCR > = SMPSI > = SMPWP THEN
TR = TRM*(SMPSI-SMPWP)/(SMCR-SMPWP) (3.60d)

IF SMPWP > = SMPSI THEN TR=0, in cm d^{-1} (3.60e)

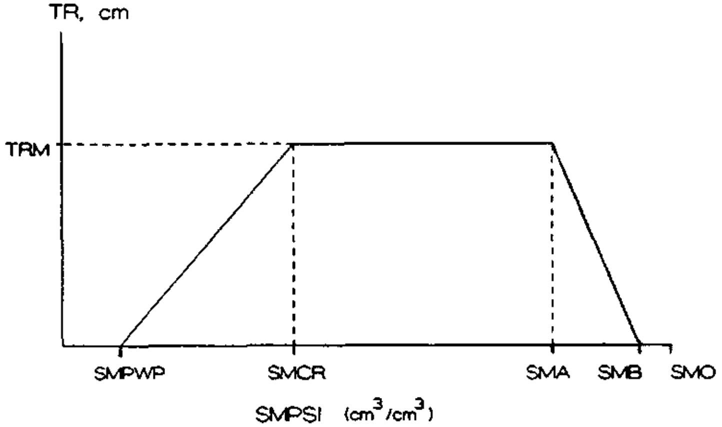


Fig. 3.5. Schematic relation between soil moisture content (SMPSI) and transpiration rate (TR). (Note that SMA=SMO-0.06 and SMB=SMO-0.02).

Evaluating the soil moisture content of a particular soil compartment, Eqn.(3.60) can be used to approximate the fraction of the water actually taken up from this particular compartment (TRCOM) (see Eqn. 3.45). For that, the maximum uptake rate (TRMCOM, in cm d^{-1}) is calculated assuming root activity evenly distributed over the entire rooting zone. If, for example, the rooting depth on a particular day is 85 cm, this will be distributed by 100% (full rooting) in the first 4 and by 25% in the 5th soil compartments (of 20 cm). A maximum transpiration rate of, say, TRM=6 cm d^{-1} would thus be divided over 5 rooted compartments: TRMCOM would be 1.41 cm d^{-1} for the first 4 compartments and 0.35 cm d^{-1} for the last one; these values are dictated by the equivalent root density of each of these compartments.

The total actual daily transpiration rate is calculated as:

$$TR = \int_0^{day} \int_0^{DEPTH} TRCOM(RD), \text{ in cm d}^{-1} \qquad (3.61)$$

where DEPTH stands for the depth of the soil profile and RD in parentheses denotes the dependence of the value of TRCOM on actual rooting depth.

The net radiation, NETRA, heats a wet surface until the sensible heat loss to the surrounding air plus the heat loss due to evaporation of water equals this net radiation, or:

$$\text{NETRA} = \text{H} + \text{LE}, \quad \text{in J m}^{-2}\text{d}^{-1} \tag{3.62}$$

where H is the sensible heat loss (J $m^{-2}d^{-1}$) and LE is the evaporative heat loss (J $m^{-2}d^{-1}$).

The loss of sensible heat of a surface to its surroundings is proportional to the temperature difference, according to:

$$\text{H} = \text{hu} * (\text{Ts}-\text{TA}), \quad \text{J m}^{-2}\text{d}^{-1} \tag{3.63}$$

where hu is the sensible heat transfer coefficient (J $m^{-2}d^{-1}{}^{\circ}C$) (see also Eqn. 3.48), and Ts and TA are the temperature of the evaporative surface and the temperature at standard screen height, respectively (°C).

Combination of Eqs.(3.62) and (3.63) yields:

$$\text{Ts} = \text{TA} + (\text{NETRA}-\text{LE})/\text{hu}, \quad \text{in }^{\circ}\text{C} \tag{3.64}$$

By substituting the value of transpiration heat loss (L*TR) for LE in Eqn.(3.64), the canopy temperature (TCAN) can be approximated:

$$\text{TCAN} = \text{TA} + (\text{NETRA}-10*\text{TR}*\text{L})/\text{hu}, \quad \text{in }^{\circ}\text{C} \tag{3.65}$$

where the coefficient 10 (mm cm^{-1}) is used to satisfy the units.

Equation (3.65) assumes that the flow resistance in the tissue is accounted for in the value of the actual transpiration. Although the so determined TCAN value is only an approximation, this substitution is essential, especially for predicting flowering and maturity times of cotton based on the accumulated thermal units method (see Section 4.2).

3.2.4 Boundary conditions

Actual evaporation

The gross water influx from the soil surface (PREC+IRR+DS-ROFF in Eqn. 3.40), diminished by the actual evaporation, represents the net influx of water through the upper boundary of the soil. The actual evaporation rate is a function of the maximum evaporation rate (EM), the hydraulic conductivity of the topsoil and the shading effect of the leaves (LAI).

The evaporative heat loss from a wet cropped soil (LE, in J $m^{-2}d^{-1}$) is approximated if, in Eqn.(3.48), NETRA is multiplied by exp(-0.5*LAI), to account for the energy flux reaching the soil surface (0.5 is the extinction coefficient of the canopy); EM (expressed in cm d^{-1}) is found if in Eqn.(3.56) LET is replaced by LE.

Apparently, the vapour pressure deficit and the wind function are included in the calculation of evaporation. These terms are important early in the growing season when the crop is short and the soil is moist. When the canopy is developed, an over-estimation of EM may occur. This bias is not significant, however, because on the one hand the energy flux towards the soil surface is very small (high values of LAI), and on the other, the soil surface is normally rather dry and evaporation diminished anyway (Ritchie, 1972).

The actual evaporation rate varies with the moisture content of the topsoil from zero to its maximum value (EM): when the surface soil is saturated, actual evaporation (EA) is at its maximum value (EA=EM). When capillary rise cannot fully cover evaporation losses, an air-dry "mulch layer" forms in the top few centimeters curbing further evaporation losses. Assuming a linear decline of actual evaporation between the two moisture extremes i.e. SMO for unhindered evaporation and SMAD for minimum evaporation from air-dry soil, EA follows from:

$$EA = EM*(SMPSI-SMAD)/(SMO-SMAD), \text{ in cm d}^{-1} \tag{3.66}$$

where SMPSI, SMO and SMAD represent the actual, saturation, and air-dry soil moisture contents of the topsoil respectively (cm^3cm^{-3}). Eqn.(3.66) applies <u>only</u> for the first soil compartment.

Precise determination of the SMAD is difficult. Here, it is assumed that the moisture content of air-dry soil is approximately one third of SMPWP (cm^3cm^{-3}).

Rainfall-Irrigation

In the case of rain or irrigation, the rain intensity (VO, in cm d^{-1}) and the total amount of water (INPREC or INPIRR, both in cm) are introduced as forcing variables. The duration of the irrigation or rain (DUR, in d) is also known or calculated as the ratio of INPIRR (or INPREC) over VO. In this case, the rate of water influx in the <u>uppermost</u> soil compartment, V1, is found as follows:

$$\text{IF } INPIRR > 0 \text{ THEN } DUR=INPIRR/VO \text{ ELSE } DUR=0 \text{ (d), and} \tag{3.67}$$

$$\text{IF } \sum(DELTAT) < DUR \text{ THEN } V1=(VO-EA) \text{ ELSE } V1=-EA \text{ (cm d}^{-1}) \tag{3.68}$$

Capillary rise to the lower system boundary

In the present context, capillary rise is upward flow from the ground water to the lower soil boundary. It takes place if the matrix suction there (PSI) is greater than the gravitational head (Z), according to:

$$\text{IF } PSI(n)>Z(n) \text{ THEN } V2(n)=CRISE \tag{3.69}$$

where PSI(n) (in cm) is the matrix suction at the centre of the lowermost soil compartment, and Z(n) (in cm) is the distance from this point to the ground-water table; CRISE is the rate of capillary rise (cm d^{-1}), and V2(n) is the flux through the lowermost soil boundary (cm d^{-1}).

Assuming that Z=PSI=0 at ground-water depth and that Z increases upwards, capillary rise (CRISE) over the distance between the lower soil boundary and the ground-water table amounts to:

$$\text{CRISE} = \text{KPSI} * [1-(d(\text{PSI})/d\,\text{Z})], \ \text{in cm d}^{-1} \tag{3.70}$$

where KPSI is the hydraulic conductivity (cm d^{-1}).

Working out Eqn.(3.70) in the low suction range (below the texture-specific suction limit, PSIMAX) results in:

$$\text{CRISE}=\frac{\text{KOn} * (\exp(-\text{ALF*Zn})-\exp(-\text{ALF*PSIn}))}{1 - \exp(-\text{ALF*Zn})}, \ \text{FOR Z} \leq \text{PSI} \leq \text{PSIMAX} \tag{3.71}$$

where KO is the rate of hydraulic conductivity at saturation (cm d^{-1}), and ALF (cm^{-1}) and PSIMAX (cm) are texture specific constants. The suffix (n) denotes the lowermost soil compartment. Note also that CRISE in the above equations has a negative value.

For the high suction range (PSI > PSIMAX), numerical integration is applied but only if the ground-water table is within the boundaries of the soil profile (see par. 3.2.2). Alternatively, tables prepared by Rijtema (1969) are used, relating | CRISE | over the distance Z to any combination of PSI and Z.

Deep percolation and adjustment of ground-water depth

Downward percolation takes place through the lowest soil boundary if the matrix suction at this boundary is less than the distance to the ground-water depth (PSI < Z):

$$\text{IF PSI(n)} < \text{Z(n) THEN V2(n)} = \text{D}, \tag{3.72}$$

where D is the percolation rate (cm d^{-1}).

In the study area, deep percolation is virtually absent in the growing period (Section 2.1). If it occurs, the percolation rate is approximated with:

$$\text{D} = \text{KPSI(n)} * (1\text{-}d(\text{PSIn})/d\text{Zn}), \ \text{in cm d}^{-1} \tag{3.73}$$

where KPSIn is the hydraulic conductivity of the lowermost compartment (in cm d^{-1}).

Any flow through the lowest soil boundary affects the moisture content of the subsoil and the depth to ground-water table, which increases (| CRISE | > 0) or decreases (D > 0) by a distance DZ. DZ is approximated with the following relation:

$$\text{DZ} = -2*(\text{D}+\text{CRISE})*\text{DELTAT}*/(\text{SMO}-\text{SMPSI}), \ \text{in cm} \tag{3.74}$$

and the ground-water depth is then adjusted by:

$$\text{TOTDEP} = \text{TOTDEP} + \text{DZ}, \ \text{in cm} \tag{3.75}$$

Relation (3.74) is based on the assumption that the moisture content of the subsoil increases linearly from its value, SMPSI(n), at the lowest soil compartment (n) to reach its saturated value, SMO, at ground-water depth. This situation is represented by line "A" in Fig. 3.6. If water flows into or out of the soil profile, the ground-water depth changes by a distance DZ, and a new moisture profile establishes itself over the subsurface layer between DEPTH and (TOTDEP+DZ). See line "B" in Fig. 3.6 for a situation with capillary rise. The amount of water moved through the lowermost profile boundary, i.e. (CRISE+D)*DELTAT, equals to the difference between the surface area under line "A" and the area under line "B".

The same relation is used if the ground-water table rests within the soil profile (TOTDEP < DEPTH). In the latter case, SMO refers to the saturated compartment and SMPSI refers to overlying compartment.

The simplification that is implicit in Eqn. (3.74), is not disturbing as long as (TOTDEP-DEPTH) is small. If the water table is deep, a symmetrical moisture profile over (TOTDEP-DEPTH) is unlikely, but, then, capillary rise (absolute) values are too low to decisively influence SMPSI anyway (Driessen, 1988).

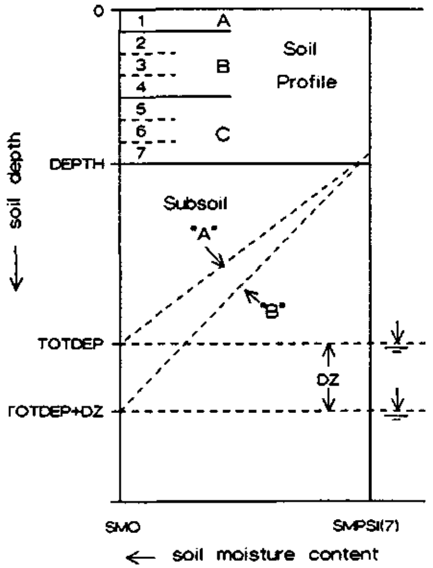


Fig. 3.6. The simplified moisture distribution in the subsoil before (line "A") and after (line "B") a change in ground-water depth.

3.2.5 The time interval

The permissible length of the time intervals, DELTAT, depends on the dynamics of ongoing processes in a system and is therefore influenced by the choice of compartment sizes. Generally the system oscillates if the change in the water content in one time interval exceeds half of the original volume of water in one or more soil compartments, viz. VOLW (cm) in Eqn. (3.46). In the absence of gravity, this implies that:

$$\mathrm{DELTAT*DIF*d(SMPSI)/TCOM = 0.5*d(SMPSI)*\ TCOM,\ \ or} \qquad (3.76)$$

$$\mathrm{DELTAT = 0.5 * (TCOM)^2 / DIF,} \qquad (3.77)$$

where DIF is the diffusivity ($\mathrm{cm^2d^{-1}}$).

The left part of Eqn.(3.76) represents flux of water ($\mathrm{cm\ d^{-1}}$) multiplied by the time (d), and their product is volume of water expressed in cm, viz. right part of Eqn.(3.76). When gravity is included, Eqn.(3.77), worked out by van Keulen & van Beek (1971), yields:

$$\mathrm{DELTAT} = \frac{0.5 * (\mathrm{TCOM})^2}{\mathrm{DIF + d(KPSI)/d(SMPSI) * TCOM}},\ \text{in days} \qquad (3.78)$$

It appears that DELTAT is proportional to the thickness of the compartments squared and depends furthermore on the diffusivity. In the detailed simulations reported here 20 compartments were considered viz. 10 compartments of 2 cm, 5 compartments of 4 cm and 5 compartments of 6 cm; the DELTAT was set at one second ($11.6*10^{-6}$d). The simplified model uses considerably larger time intervals, in line with the needs of the connected crop-production model. DELTAT was finally set at 15 min or $10.4*10^{-3}$ d; Eqn.(3.78) confirms that a compartment size of 20 cm can be safely used.

3.2.6 Performance

In this paragraph, the simplified soil water flow will be discussed; emphasis is placed on the soil moisture distribution. In cases of high precipitation (or irrigation) rates that induce surface ponding, the assessment of the net influx through the upper soil boundary and of surface run-off (if any) will receive special attention.

Two soil materials were selected for this discussion: a sandy clayloam (soil A) and a heavy clay (soil B), both from the set of standard soils in The Netherlands, with known physical properties. These resemble soils in the study area; soil A represents soils with an intermediate infiltration capacity, and soil B soils with very low permeability to water such as the Chromoxererts and Vertic Xerochrepts in the study area.

For the calculation of SMPSI, a semi-empirical relation is used which contains a texture-specific geometry constant gama (cm^{-2}):

$$\mathrm{SMPSI} = \mathrm{SMO} * \exp(-\mathrm{gama}*\ln(\mathrm{PSI})*\ln(\mathrm{PSI})) \tag{3.79}$$

Equation (3.79) is suggested by Driessen (1986) as an approximation to SMPSI-PSI relations of Dutch standard soil materials. For the KPSI-PSI relations, Rijtema (1969) suggests:

$$\mathrm{KPSI} = \mathrm{KO} * \exp(-\mathrm{ALF}*\mathrm{PSI}) \quad \mathrm{FOR} \quad \mathrm{PSI} =< \mathrm{PSIMAX} \tag{3.80a}$$

$$\mathrm{KPSI} = \mathrm{AK} * \mathrm{PSI}^{-1.4} \quad \mathrm{FOR} \quad \mathrm{PSI} > \mathrm{PSIMAX} \tag{3.80b}$$

where ALF (cm^{-1}) and AK (cm^{-2}) are texture-specific geometry constants, and PSIMAX (cm) is a texture-specific suction limit.

These relations are schematically shown in Fig. 3.7 for the two sample soils. The KPSI-SMPSI relations in this figure are based on the KPSI-PSI relations according to Eqs.(3.80). Relevant soil parameters can be found in Table 3.4 (Section 3.3), where the texture-specific constants of all standard soils are listed.

For simplicity, it will be assumed that the sample soils are homogeneous throughout. The ground-water table is at great depth so that capillary rise is negligible. The initial moisture contents are set at 0.22 and 0.35 respectively for soils A and B. These values correspond to PSI=5000 cm (pF 3.7), i.e. a matrix suction of a soil that needs irrigation.

In the case of soil (A), a daily transpiration rate is assumed of 0.57 cm, with 0.3 cm taken up from the top 20 cm of the soil, whereas no water is taken up below 65 cm from the soil surface. Fig. 3.8a presents the simulated soil moisture distribution as occurs during the first hours of irrigation with an application rate VO = $6.25 * 10^{-2}$ cm d^{-1} (1.5 cm $hour^{-1}$). This rate exceeds the saturated conductivity of soil A and causes saturation of the surface soil after 240 minutes of irrigation (0.167 days). It is assumed that irrigation stops at that moment.

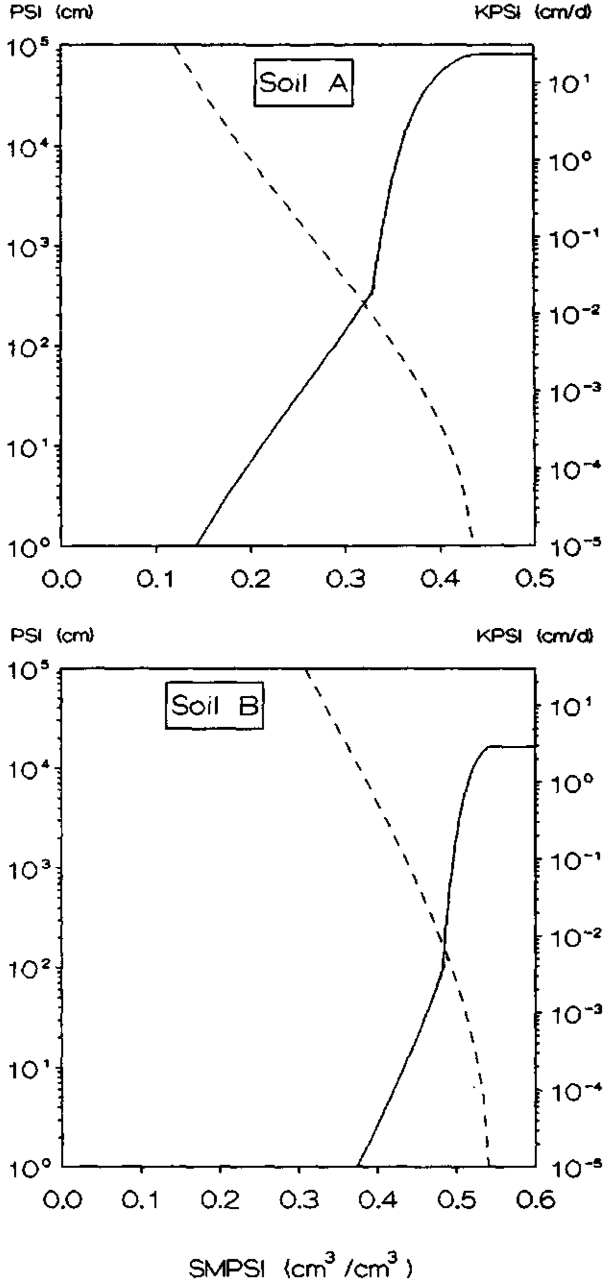


Fig. 3.7. Physical properties of two Dutch soils: a sandy clayloam (soil A) and a heavy clay (soil B). --- On left y-axis: PSI(SMPSI) after Driessen (1986). — On right y-axis: KPSI(S-MPSI) after Rijtema (1969), modified by Driessen (1986).

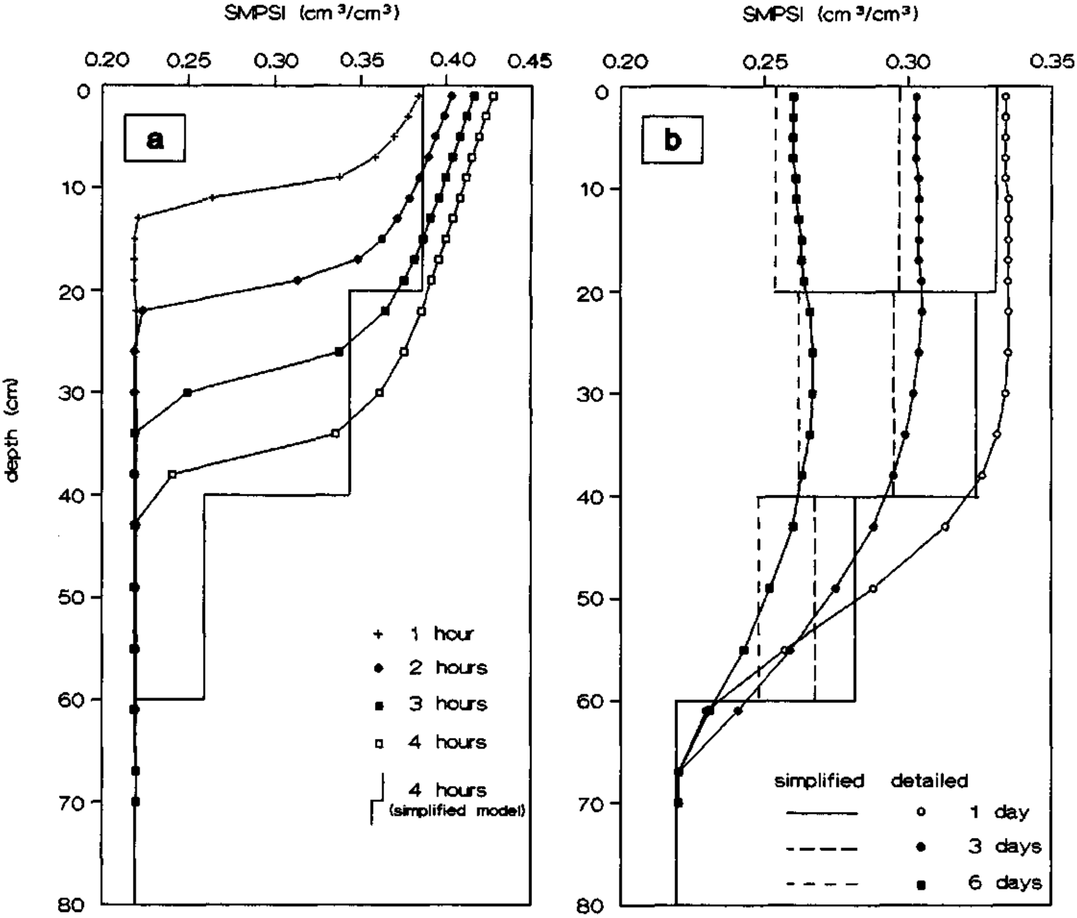


Fig. 3.8. Comparison of simulated soil moisture profiles with the detailed and the simplified model for a Dutch sandy clayloamy soil: during a shower of 1.4 cm/h (a), and during redistribution for 6 days (b). A water uptake rate of 0.57 cm/d is assumed from the upper 65 cm of the soil.

Fig. 3.8a suggests that a sharp wetting front has then advanced to 40 cm below soil surface. After irrigation stopped, rapid redistribution of soil moisture occurs for 24 hours; further redistribution proceeds at rather low rates (Fig. 3.8b). The (less sharp) wetting front after 24 hours has reached a depth of 55-60 cm, and this depth does not change much in the following days. The soil moisture profiles recorded after 3 and 6 days are slightly different mainly due to transpiration losses. The same figure demonstrates the good agreement between the results of the simplified and the analytical model. However, after short periods of infiltration (Fig. 3.8a) and/or in the first stages of redistribution, the simplified model underestimates the soil moisture content of the topsoil and overestimates that of the lower soil layers. Averaging of the moisture profile over the top 20 cm, with the simplified model, obscures surface ponding in the simulations.

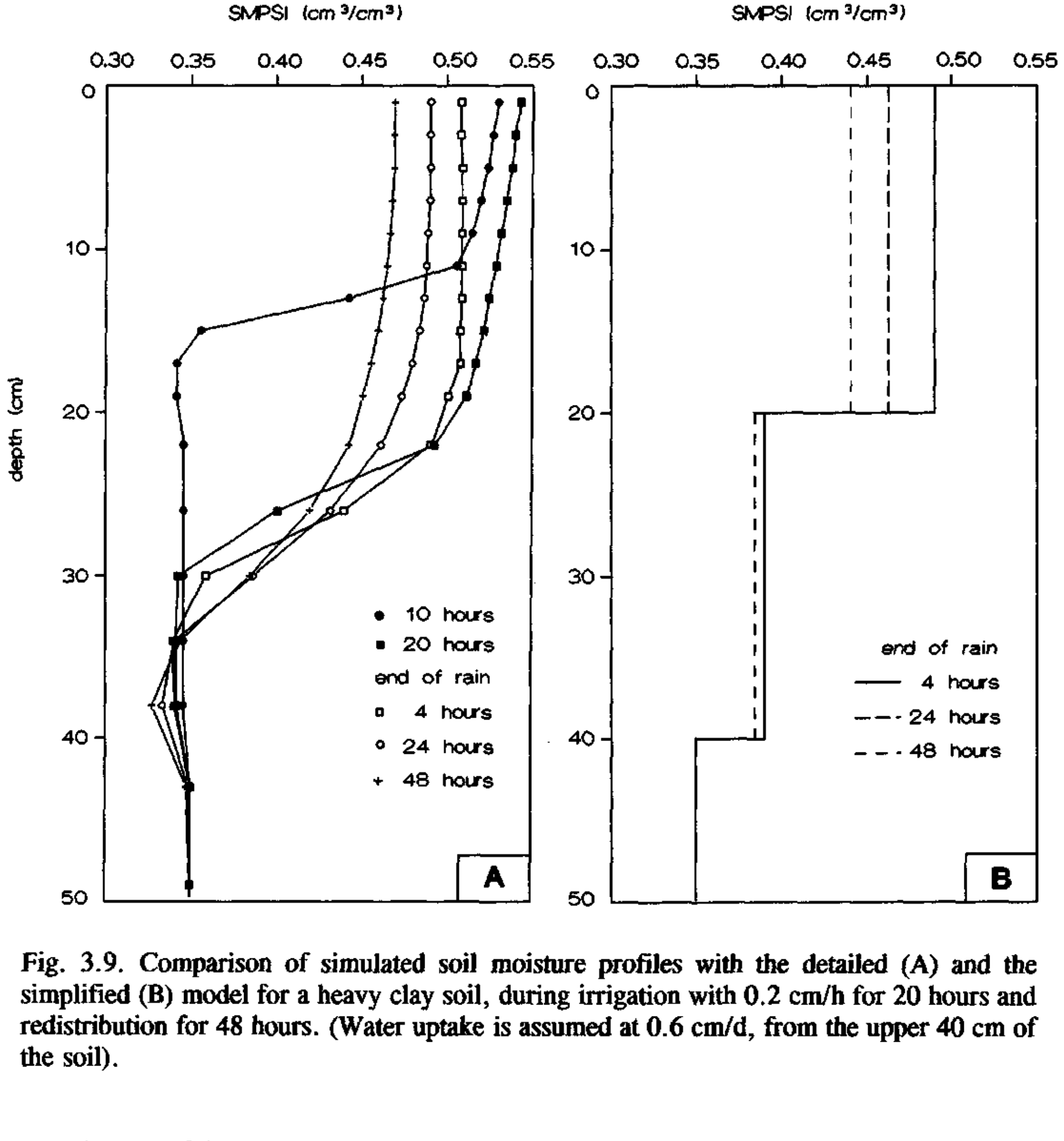


Fig. 3.9. Comparison of simulated soil moisture profiles with the detailed (A) and the simplified (B) model for a heavy clay soil, during irrigation with 0.2 cm/h for 20 hours and redistribution for 48 hours. (Water uptake is assumed at 0.6 cm/d, from the upper 40 cm of the soil).

In the case of the heavy clay soil (B), early surface saturation can be avoided only by using small application rates, as with drip irrigation. To apply 4 cm of irrigation water in the field, the application rate was set at $8.33*10^{-3}$ cm d^{-1} (0.2 cm $hour^{-1}$) for 20 hours (0.83 days). A daily transpiration rate of 0.6 cm d^{-1} is assumed from the upper 40 cm; 0.4 cm d^{-1} are taken up from the top 20 cm of the soil by the roots of the crop. Fig. 3.9A presents the moisture profiles simulated for irrigation and redistribution during 2 days after irrigation. It can be seen that rapid redistribution of the soil moisture brings the soil close to field capacity. In the following days, redistribution ceases; the changes in moisture profile are attributable to transpiration losses. The applied irrigation water, concentrated at shallow depth, induces lack of soil air, which -in the scenario used- lasts for 2 days. Water uptake by roots at 40 cm depth results in further water depletion and causes the moisture content to drop below its initial value. This observation seems to support the approach adopted for mimicking root growth, which sets the (maximum) rooting depth on the basis of -among others- the soil moisture distribution in a particular case. Fig. 3.9B shows simulated moisture profiles that are practically the same as those obtained with the simplified model, and more than 95% of all infiltrated water is stored at the same depth of the soil profile. The simplified model, although it slightly underestimates the moisture contents of the surface soil, may still indicate temporary shortage of oxygen. However, as in soil A, the time to ponding cannot be predicted with the simplified model.

3.2.7 Influx through the upper soil boundary

The simplified model underestimates the soil moisture content during irrigation/rain. This underestimation decreases with time and largely disappears during the first hours after the shower, due to redistribution of the soil moisture. Thus, soil moisture dependent variables such as evaporation and transpiration rates and oxygen availability can be satisfactory simulated with the simplified model using interval lengths of one day.

A disadvantage is that the time to ponding (if any) cannot be predicted with the simplified model. The time to ponding is of great importance for the calculation of surface water run-off and effective rainfall. Run-off depends on the depth of ponded water, on surface microrelief and on the slope of the land; in soils with low permeability, the time to run-off initiation controls the maximum application of irrigation water under a certain water management. As mentioned in Chapter 5, the farmers adapt the duration of irrigation rather than shifting to another irrigation method e.g. from travelling guns to small sprinklers or drip irrigation.

The problem is solved by introducing the "time to ponding" (TPONDING) as a function of (1) the infiltration characteristics of the soil and (2) the rain or irrigation intensity. This will be discussed in Section 3.3, where parameters for the various soil units in the study area will be established and used to quantify TPONDING. For now, considering TPONDING known, the assessment of the flux through the soil surface proceeds as follows:

The daily precipitation and/or irrigation rates (VO) and the duration of rain/irrigation (DUR) are known. If DUR<=TPONDING then the influx (V1) from the upper soil boundary is determined with combination of Eqs.(3.67) and (3.68). If ponding occurs, the excess water is stored on top of the soil (SST, in cm) until the maximum surface storage capacity of the soil surface (SSMAX, in cm) is reached, and any further surplus is lost as run-off (ROFF). Therefore:

IF DUR > TPONDING THEN
SST=SST+(DUR-TPONDING)*VO ELSE SST=SST, and (3.81)

IF SST >= SSMAX THEN
ROFF*DELTAT=SST-SSMAX (cm) and SST=SSMAX (cm) (3.82)

The actual duration of irrigation (DURIRR) or effective rain (DURRAIN) that replaces DUR in Eqn.(3.67) is approximated with:

DURIRR (or DURAIN) = TPONDING + SST/VO, in days (3.83)

This approximation is based on the following two assumptions: (i) the evapotranspiration losses do not seriously affect the value of SST, and (ii) SST will be infiltrated by the end of the interval day, so that DS (Eqn. 3.40) times DELTAT equals SST. These assumptions seem justified as rains and irrigation last rarely longer than a few hours. Moreover, all soils without very high ground-water tables in the study area infiltrate in 24 hours at least the few cm of water that a heavy shower might supply, while it is exceptional that such heavy rains occur for two or more consecutive days, especially during the growing period of summer crops.

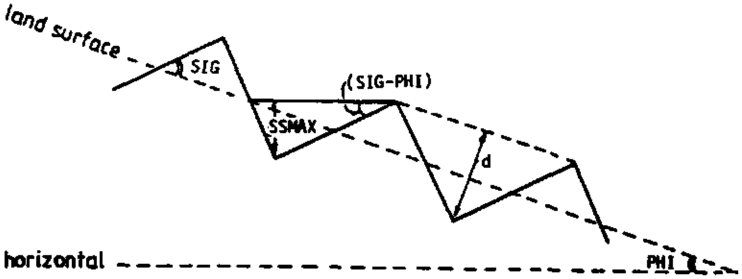


Fig. 3.10. Schematic representation of the surface storage capacity, SSMAX.

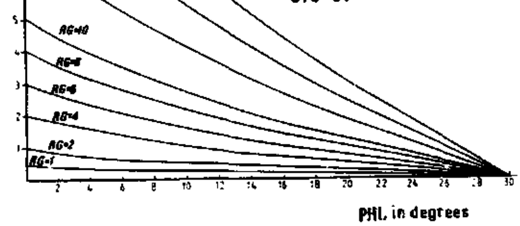


Fig. 3.11. Nomogram of SSMAX as a function of surface roughness, RG, and field slope, PHI, at a fixed clod/furrow angle (SIG) of 30°. (Source: Driessen, 1986).

The effective irrigation or rainfall depth are now calculated with:

$$\text{IRR (or PREC)*DELTAT} = \text{TPONDING * VO + SST, in cm} \qquad (3.84)$$

The maximum surface storage capacity of the soil is determined by the surface properties and the slope angle of the land (Fig. 3.10). SSMAX is mathematically described as:

$$\text{SSMAX}=0.5*\text{RG} * \frac{\sin^2(\text{SIG-PHI})}{\sin \text{SIG}} * \frac{\text{cotan(SIG+PHI)}+\text{cotan(SIG-PHI)}}{2*\cos(\text{SIG})*\cos(\text{PHI})} \text{ (cm)} \qquad (3.85)$$

where PHI is the slope angle of the land (°), RG is the surface roughness (cm), and SIG is the clod/furrow angle (°).

A nomogram based on Eqn.(3.85) is presented in Fig. 3.11 for a SIG value of 30°, that is generally valid in the study area.

3.2.8 The transpiration-assimilation ratio

It has been demonstrated (de Wit, 1958) that temporary water shortage in the soil affects assimilation and transpiration to approximately the same extent. The value of the transpiration-assimilation ratio remains constant as long as atmospheric conditions remain constant and other land qualities are not constraining. This permits to quantify the effect of moisture availability on crop production:

The maximum transpiration rate is based on the potential evapotranspiration rate as determined with the Penman formula. The advantage of this method is that it gives values for TRM (cm d^{-1}) that are very close to those found under regulating stomata conditions (van Keulen & van Laar, 1986), as apply for the studied crops. If the actual transpiration rate is lower than the maximum transpiration rate, the gross canopy CO_2 assimilation falls short of its maximum value (TR < TRM). The actual gross CO_2 assimilation rate is then directly determined from the actual transpiration rate by dividing the latter by the transpiration assimilation ratio:

$$\text{PGC} = \text{TR / TAR, in kg}(CO_2)ha^{-1}d^{-1}\text{, or}$$

$$\text{PGC} = \text{FGC * TR/TRM, in kg}(CO_2)ha^{-1}d^{-1} \qquad (3.86)$$

where PGC and FGC are respectively the actual and maximum assimilation rates; TAR is the transpiration-assimilation ratio, expressed here in cm water transpired for each kg of CO_2 reduced per hectare of land.

Replacing FGC by PGC in Eqn.(3.28; Section 3.1) yields:

$$\text{FGASS} = \text{FGC * TR/TRM * 30/44, in kg}(CH_2O)ha^{-1}d^{-1} \qquad (3.87)$$

The above relation links the water balance model to the crop-growth model at hierarchical level 2 (Production Situation 2).

3.3 Quantifying the infiltration capacity

3.3.1 Introduction

Staff of the Institute of Soil Mapping and Classification, Larissa, have conducted infiltration measurements on most soil units in the Thessaly Plain. In all cases, single ring infiltrometers were used, and measurements continued until near constant infiltration rates, i.e. basic intake rates were recorded. The USBR classification system was used (Table 3.3), and permeability maps were compiled for the purpose of irrigation and drainage design.

Evidently, the basic intake rates estimated with this method are only approximations, supplementary to local experience.

The large variability of the values measured on one Soil Type, attributable to differences in the degree of surface crusting, compaction and soil moisture content at the time of the measurements, is a first problem.

A second problem lies in the fact that all soils outside the flood plain and in areas along the margins of the Larissa plain, have a "low to moderately low" infiltration capacity of 0.1 to 2 cm h^{-1} (see Table 3.3). Many thousands of hectares in the Karla basin, on the Pleistocene terraces, etc. are grouped together in only one class, viz. 0.5 to 2 cm h^{-1}. However, the different productivities of these soils are in part attributable to variations in infiltration capacity and consequently in irrigation management.

Table 3.3. Infiltration categories according to USBR.

Class	Infiltration category	Basic infiltration rate (cm/h)
1	very slow	< 0.1
2	slow	0.1 - 0.5
3	moderately slow	0.5 - 2.0
4	moderate	2.0 - 6.0
5	moderately rapid	6.0 - 12.5
6	rapid	12.5 - 25.0
7	very rapid	> 25.0

The existing data cannot, therefore, be used as such for the purpose of dynamic production simulation, but in combination with thorough field experience and a limited number of well controlled experiments, they can perhaps help to establish realistic (approximate) infiltration parameters for the simulation of rain- or irrigation water intake by the soil. The still limited theoretical understanding of infiltration under field conditions and the modest number of experiments done made it necessary to restrict the study of infiltration to some major soil units in the Larissa area only. The infiltration behaviour of these soils will be briefly discussed, and attention will be given to the methodology used to assess the effects of common management practices.

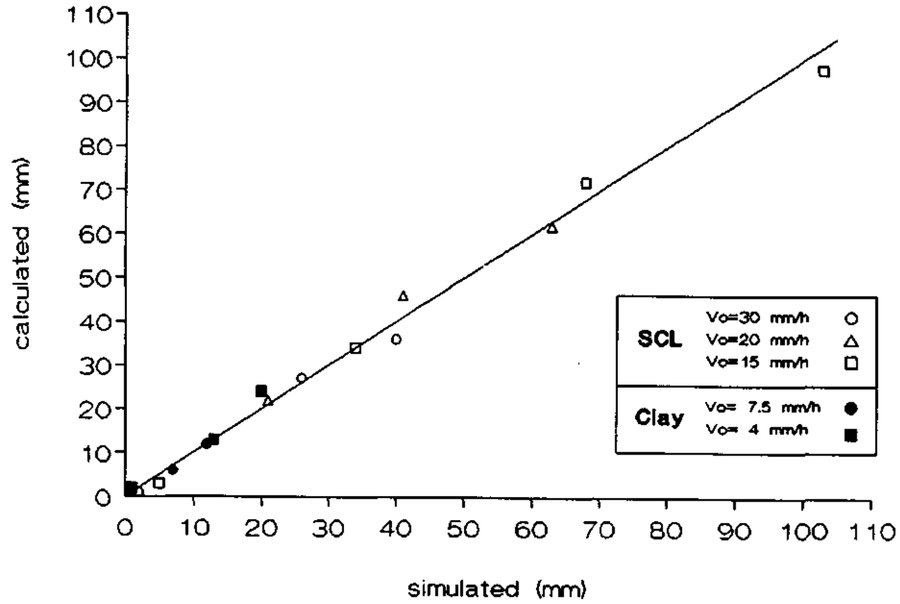


Fig. 3.18. Prediction of time to ponding and effective irrigation (or rainfall) depth: amount of water infiltrated into two Dutch soils to the time to surface ponding; simulated (x-axis), and predicted with $I=S^2/[2*(Vo-KTR)]$ (y-axis).

The same data demonstrate the different roles of KO and KTR. For KTR, Driessen (1986) suggests an equivalent value of KPSI at PSI=10 cm. The value 0.632*KO corresponds to PSI-values that are normally only slightly above 10 cm, depending on the texture-specific constant ALF (see also Eqn. 3.80a). For the 2 sample soils, a KTR value equal to 0.632*KO corresponds to KPSI at 12 cm suction (soil A) and 13 cm suction (soil B). Both approximations are satisfactory.

Although KTR values as suggested by Driessen (1986) are practically correct, they should not replace the second Philip parameter, as A assumes the value of KTR, only after prolonged infiltration.

Stroosnijder probably under-estimated the sorptivity values of the standard Dutch soils by introducing 0.632*KO in his calculations. Simulated results obtained in the present study seem to indicate that the original KO values suggested by Rijtema (Table 3.4) automatically result in an operative transmission zone permeability of about 0.632*KO (see Fig. 3.14).

Furthermore, it seems that the S-values found with numerical methods (Table 3.4) are still somewhat low for most soils under field conditions. Combining equations (3.90) and (3.94) - corrected for KTR- demonstrates that in most standard soils with a moisture content at about wilting point, ponding occurs quickly, already under normal irrigation intensities. The reason might be that the KO values suggested for these soils by Rijtema (1969) were determined under laboratory conditions.

3.3.4 Measured data

A number of infiltration experiments were done on representative soils of the Pleistocene and Holocene terraces, the alluvial plain, the meandering flood plain, the undulating Tertiary tracts and the Delta area. Single infiltrometers were used in all experiments. All sites were in the direct vicinity of examined soil pits, and care was taken to avoid wide cracks and krotovinas.

In the case of very dry soils, the ground around the rings was watered as well to curb horizontal infiltration. For a number of soils, the initial moisture content was determined gravimetrically. Complementary (undisturbed) samples were taken to Wageningen, where moisture retention curves were determined.

The infiltration data obtained were processed as follows:

The cumulative intake figures were plotted vs. $t^{1/2}$. Fig. 3.19a shows this with data from soil P3, a Vertic Calcixeroll of the Nikea valley system, which was wet upon examination. In line with the Philip equation, plotting I versus $t^{1/2}$ produced an initially straight line with slope angle S (Fig. 3.19a). As long as the line is straight, sorptive forces strongly exceed gravitational forces. After some time (about 10 min for the example of Fig. 3.19), the influence of the gravitational forces becomes apparent and the relation I vs. $t^{1/2}$ deviates from the straight line. The values of S and A were found with a regression of the type $A^*x + S^*z + d$, where x is the time and z the square root of time. In (near) ideal cases, as in the above example, the intercept with the y-axis (value of d) coincides with zero or is very close to zero.

In a number of I vs. $t^{1/2}$ plots, the deviation from linearity occurs soon after the beginning of infiltration. An example is Fig. 3.19b which refers to soil P5a (see pedon P5, App. A.1), a clayloamy, swelling Typic Calcixeroll on the lower slopes of the Nikea area. Initially, sorptivity assumes a high value (Sin) (part OA in Fig. 3.19b), but S decreases after only some minutes (4 min in the above example) to a constant value (trajectum AB in Fig. 3.19b). Extrapolation of the curve permits to approximate an equivalent initial value *d* (1.89 cm in Fig. 3.19b), attributable to initial bypass flow and referred to as "disturbance" hereafter. In all cases with *d*-values different from zero, the values of S and A were determined by curve fitting over the trajectum AB. Then, the value of *d* was identified.

In coarse soils that required frequent refilling of the rings, the effects of the inevitably variable water head are found back if the observed infiltration rates are plotted vs. time. Fig. 3.20 (line a) presents data from soil Pd (see Pedon P4 in App. A.2) and illustrates this clearly. In this particular case the ring needed refilling at 27, 43 and 100 minutes after the onset of infiltration (Fig. 3.20-a). Temporary increases in water head in the ring are associated with increases in intake rate, as the value of S is influenced by the water depth in the ring (Talsma, 1969). The deviation levels off as the contribution of S to infiltration decreases, unless, as in soil Pd, water is repeatedly added. Eye fitting of i-curves ignore these deviations. The cumulative intake (I) was calculated on the basis of the i-curves; Fig. 3.20 presents the cumulative water intake by soil Pd, both "as measured" (line b) and "adapted" (line c). The corrected cumulative intake data were further processed as described (see Fig. 3.19c).

The parameters found (S, A and *d*) and the squared correlation coefficients are summarized in Table 3.5. Basic intake rates (i_b) and some information on the main soil physical parameters and the land use are supplied in Table 3.5. More information about these soils can be found in Appendix A.

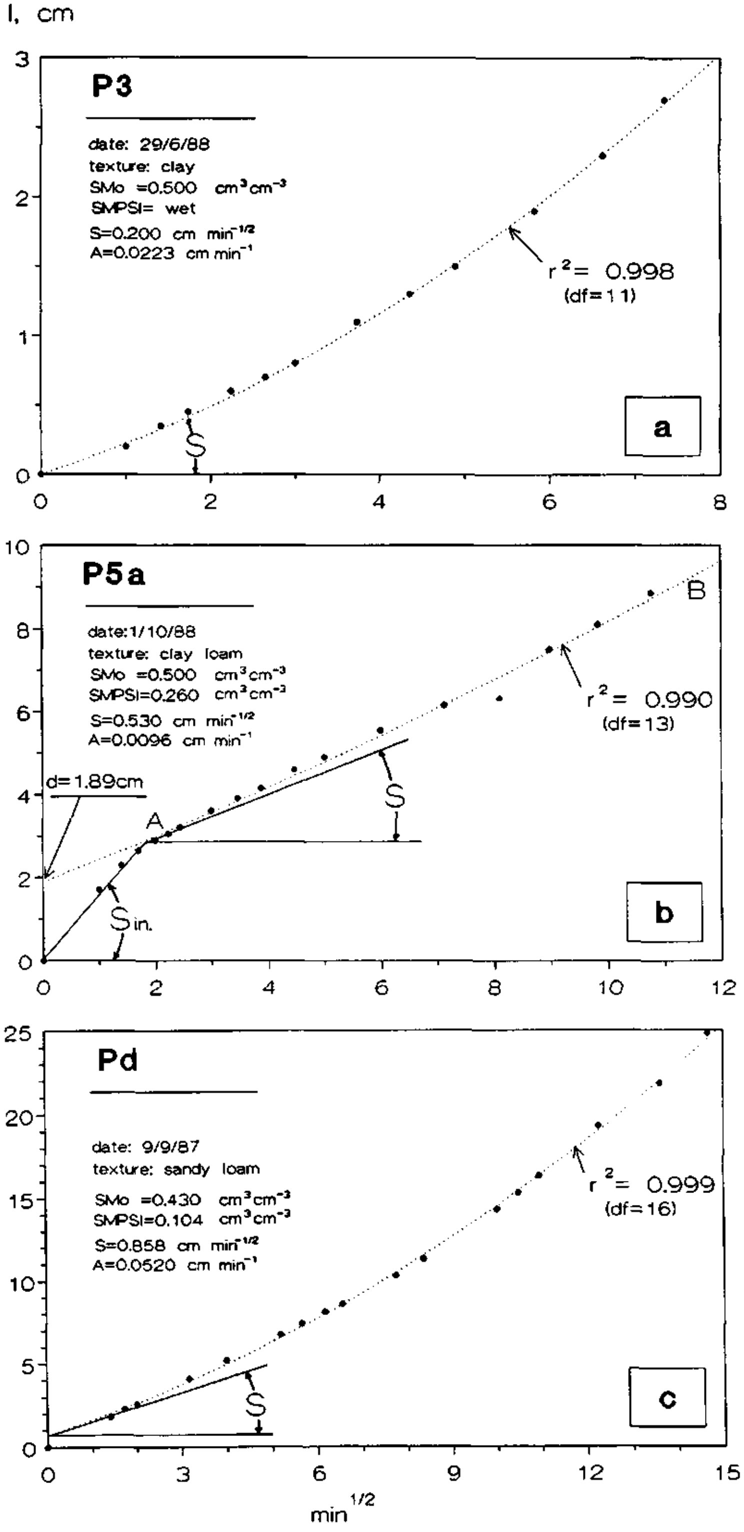

I, cm
P3
date: 29/6/88
texture: clay
SMo =0.500 cm^{3}cm^{-3}
SMPSI= wet
S=0.200 cm min$^{-1/2}$
A=0.0223 cm min^{-1}
r^2= 0.998
(df=11)
S
a
0
1
2
3
0
2
4
6
8
P5a
date:1/10/88
texture: clay loam
SMo =0.500 cm^{3}cm^{-3}
SMPSI=0.260 cm^{3}cm^{-3}
S=0.530 cm min$^{-1/2}$
A=0.0096 cm min^{-1}
r^2= 0.990
(df=13)
d=1.89cm
A
B
S
S in.
b
0
2
4
6
8
10
0
2
4
6
8
10
12
Pd
date: 9/9/87
texture: sandy loam
SMo =0.430 cm^{3}cm^{-3}
SMPSI=0.104 cm^{3}cm^{-3}
S=0.858 cm min$^{-1/2}$
A=0.0520 cm min^{-1}
r^2= 0.999
(df=16)
S
c
0
5
10
15
20
25
0
3
6
9
12
15
min$^{1/2}$

Fig. 3.19. Cumulative infiltration vs. $t^{1/2}$ measured for 3 soils of the Larissa area: (a) P3 = Vertic Calcixeroll; (b) P5a=(swelling) Typic Calcixeroll; (c) Typic Xerofluvent. The dotted lines represent the equation $S*t^{1/2}+A*t$. S=sorptivity; A=permeability; SMO=porosity; SMPSI= initial soil moisture content; *d*=disturbance.

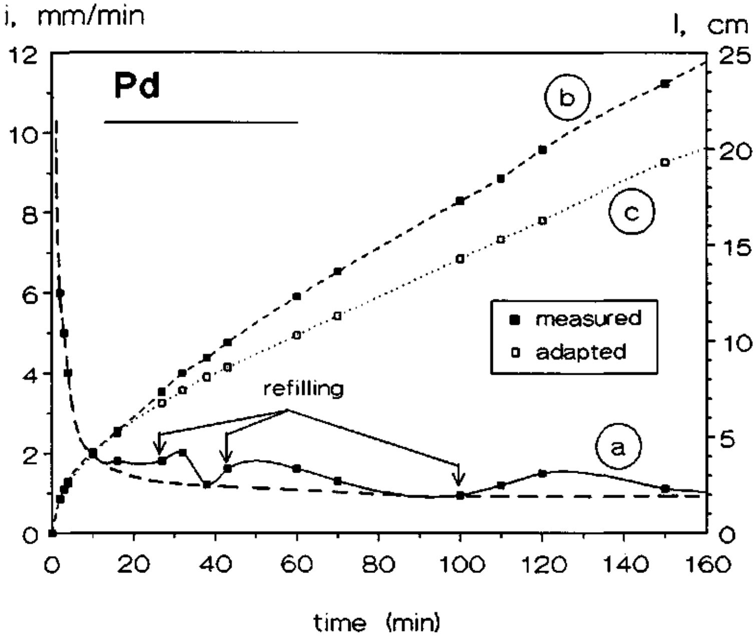


Fig. 3.20. Infiltration rate (i) and cumulative infiltration (I) vs. time (t) for soil Pd. Left axis: i(t) measured (solid line) and adapted (dashed line). Times of refilling the ring are indicated. Right axis: I(t) lines connecting measured (dashed line) and adopted (dotted line) I-values.

3.3.5 Infiltration values of major soil units

Table 3.5 shows that the Philip equation performs satisfactorily for all studied soils with the exception of strongly swelling Chromoxererts. Very high correlation coefficients were obtained if the equation was modified to account for disturbance, *d*, and time ranges applied as described above.

Initial disturbance

Values of *d*, though associated with cracks and fissures, range normally from 0 to some 1.8 cm. In dry, swelling soils the disturbance can reach even higher values, e.g. in soil Pcl in Table 3.5. The term "disturbance" is used to show that the initial infiltration value should not be used to evaluate the infiltration of rainfall and/or non-surface irrigation water.

Permeability

The Alfisols of the Pleistocene and the Holocene terraces have very low infiltration capacities. The Palexeralfs possess a thick, loamy eluvial E horizon with a very low organic matter content; this layer is hard and massive when dry and, unless ploughed, has a very low permeability. The same conditions develop in the clayey B2t or B3 if exposed to the surface due to erosion or/and deep ploughing (Haploxeralfs and eroded Inceptisols). The permeability of such soils, lying below 0.001 cm min^{-1}, has a negligible contribution to infiltration during the first hours of the process.

The coarse-textured alluvial soils on Holocene terraces and in the flood plain (Typic Xerofluvents and Fluventic Xerochrepts) have permeabilities in excess of 0.023 cm min^{-1}; the soils have a low field moisture content and therefore usually high sorptivities. The basic infiltrations are accordingly high (Table 3.5), so that surface ponding never occurs, even with the highest irrigation rates.

Mollisols on the lower slopes of the Tertiary tracts have permeabilities of 0.01 to 0.02 cm min^{-1} (Table 3.5). The structure of the topsoil and its high organic matter and gravel contents account for this. Inceptisols on the lower slopes have lower organic matter contents, and their ochric epipedons are generally massive. Table 3.5 illustrates that these soils have a lower permeability ($A=0.001$ and 0.003 cm min-1). In about the same range lies the permeability of vertic soils of the valley bottoms (Typic Chromoxererts, Vertic Calcixerolls) and the clayey Vertic Xerochrepts on the slopes ($A=0.001$-0.005 cm min-1). Many soils in the upper tracts (slopes and tops) are coarser-textured and, although they have no mollic epipedon, they have permeabilities similar to the Mollisols of the lower slopes.

In the Peneios delta area, the permeabilities of Inceptisols are much higher than those of Entisols. The topsoil of the slightly developed Vertic (Aquic) Xerochrepts and Vertic Haplaquepts is moderately structured, relatively rich in organic matter, and has a permeability value in the range 0.03-0.06 cm min^{-1}. On the opposite, Entisols have a structureless to weakly structured topsoil with permeabilities <0.01 cm min^{-1} and usually in the range 0.005-0.007 cm min^{-1}, depending on texture and organic matter content. As shown in Table 3.5, however, these values are combined with very low sorptivity values, which make irrigation with high intensities, e.g. large sprinklers, travelling guns, etc., practically impossible. Exceptions are the moister Aeric Fluvaquents (Table 3.5), which have a weakly structured topsoil with higher organic matter content than the rest of the Entisols in the area.

Table 3.5. Results of infiltration experiments, use and physical parameters of the soils tested.

Site no.	Date exam.	Soil	Use	texture C	Si	S	code	moist. condit.	SMPSI (cm³/cm³)	SMO	S cm/min	A cm/min	disturb. d(cm)	r^2	Ib cm
--- Alfisols and Inceptisols (eroded Alfisols)															
a. Pleistocene terrace[a]															
T1	2-07-86	Alfisol	cotton	35	22	43	CL	moist		0.46	0.409	0.0003	1.11	.999	1.5
T1a	2-07-86	do	cotton	35	22	43	CL	moist		0.46	0.380	0.0003	0.94	.997	1.2
Tp	20-04-89	do	ploughed	35	22	43	CL	moist	0.23	0.46	0.225	0.0029	1.30	.950	2.4
Pc	11-09-87	do	fallow	25	29	46	L	dry		0.38	0.057	0.0005	0.65	.998	0.6
Pe	10-09-87	Incept.	cotton	40	27	33	CL	wet	0.48	0.53	0.088	0.0006	0.67	.998	0.6
T11	3-07-86	do	almonds	15	40	45	L	dry		0.	0.103	0.0006	1.52	.997	0.6
b. Holocene terraces															
Pa1	9-09-87	Alfisol	pears	30	16	54	SCL	dry	0.13	0.40	0.043	0.0045	0.91	.998	0.6
Pa2	9-09-87	do	fallow	30	16	54	SCL	dry	0.13	0.40	0.013	0.0041	1.38	.981	0.6
Pb	10-09-87	do	maize	36	30	34	CL	v.wet	0.60	0.62	0.079	0.0021	0.20	.993	0.6
Ph	20-09-87	do	vines	26	37	37	L	moist	0.35	0.46	0.167	0.0022	1.38	.997	0.9
--- Soils on Tertiary tracts[b]															
a. Mollisols (swelling Calcixerolls)															
P1	27-04-88	do	maize	52	19	29	C	FC			0.100	0.0034	0.00	.996	0.6
P3	29-06-88	do	maize	46	26	28	C	FC		0.50	0.200	0.0223	0.00	.998	2.2
P4	30-06-88	do	maize	46	22	32	C	FC		0.50	0.033	0.0183	0.62	.994	1.0
P5	1-07-88	do	wheat	40	21	39	CL	moist		0.50	0.564	0.0169	0.25	.991	3.0
P5a	1-10-88	do	fallow	37	30	33	CL	dry	0.13	0.50	0.942	0.0218	1.67	.999	4.2
P5a	1-10-88	do	fallow	37	30	33	CL	moist	0.26	0.50	0.530	0.0096	1.89	.990	3.0
P5a	1-10-88	do	fallow	37	30	33	CL	moist	0.29	0.50	0.291	0.034!	0.40	.991	2.4
P5a	14-04-89	do	wheat	37	30	33	CL	FC	0.36	0.50	0.092	0.0006	1.23	.900	0.4
P7	5-07-88	do	wheat	65	21	14	C	dry			0.941	0.0020	0.00	.999	4.0
b. Inceptisols (non Vertic)															
P8	6-07-88	Mol/Inc.	wheat	32	26	42	CL	moist			0.070	0.0013	0.75	.998	0.6
P9	7-07-88	Incept.	wheat	38	26	38	CL	dry			0.656	0.0017	0.75	.997	2.7
P6	4-07-88	do	wheat	24	24	52	SCL	moist			0.540	0.0132	0.00	.999	3.0
P6a	12-10-88	do	fallow	20	32	48	L	dry	0.15	0.46	0.894	0.0151	0.00	.999	3.9
P6a	12-10-88	do	fallow	20	32	48	L	moist	0.21	0.46	0.739	0.191!	0.00	.998	13.8
P6a	12-10-88	do	fallow	24	24	52	L	wet	0.30	0.46	0.453	0.0917	0.00	.999	7.2
c. Vertic Inceptisols															
Pc1	13-10-88	do	fallow	45	28	27	C	v.dry	0.10	0.50	0.620	0.0047	4.95	.995	2.7
Pc1	13-10-88	do	fallow	45	28	27	C	dry	0.20	0.50	0.391	0.0036	2.73	.999	1.2
Pc1	22-04-89	do	wheat	45	28	27	C	moist	0.28	0.50	0.255	0.0000	0.90	.900	0.8
--- Sandy soils on meandering flood plain and adjacent Holocene terraces[a]															
T9	3-07-86	Incept.	cotton				L	moist		0.43	0.884	0.0084	0.08	.999	3.2
T9a	4-07-86	do	pasture				SL	dry		0.38	1.164	0.3072	0.00	.998	25.0
Pd	9-09-87	Entisol	vegetbls	17	8	75	SL	dry	0.10	0.41	0.858	0.0520	0.72	.999	6.0

---

[a] Soil map of Platanoulia area and Appendix A.2: Pa=Pedon P1, Pb=Pedon P2, Pc=Pedon P3, Pd=Pedon P4, Pe=Pedon P5, Ph=Pedon P8.

[b] Soil map of Nikea area and Appendix A.1.

Table 3.5. (Continued).

Site	Date	Soil	Use	texture				moist.	SMPSI	SMO	S	A	disturb.		Ib
no.	exam.			C	Si	S	code	condit.	(cm^3/cm^3)		$cm/min^{\frac{1}{2}}$	cm/min	d(cm)	r^2	cm
--- Soils of the Peneios delta area[c]															
a. Inceptisols															
P3	11-05-89	Vertic Xerochrept	sug.beet	44	31	25	C	dry	0.10	0.50	1.526	0.0620	0.00	.999	4.2
P4	14-06-89	Vertic Haplaquept	sug.beet	48	33	19	C	FC	0.40	0.52	0.000	0.0400	1.50	.999	2.4
P8	29-01-89	Aquic Xerochrept	alfalfa	26	19	65	SCL	moist	0.25	0.54	0.378	0.0270	0.00	.999	3.0
b. Entisols															
P1	13-04-89	Aeric Fluvaquent	beans	30	41	29	CL	moist	0.29	0.47	0.238	0.0050	1.30	.999	1.2
T8	16-11-89	Typic Xerofluvent	fallow	23	19	68	SCL	wet	0.42	0.46	0.001	0.0010	1.45	.999	0.6
P2	16-06-89	do	beans	22	42	36	L	moist	0.20	0.52	0.032	0.0004	1.16	.980	0.1
T9	29-11-89	do	avocado	15	34	51	L	moist		0.49	0.001	0.0049	0.20	.999	0.3
P7	04-12-89	do	fallow	17	30	53	L	moist	0.28	0.41	0.006	0.0050	0.80	.999	0.6
T2	13-12-89	do	alfalfa	35	39	26	CL	moist	0.31	0.55	0.092	0.0073	0.00	.979	0.6
--- Strongly swelling soils															
P2[b]	28-04-88	Vert.Typ	maize	50	23	27	C	FC			0.017	0.0030	0.00	.740	0.3
Pt1	18-10-88	Vert.Ent	cotton				C	moist	0.41	0.50	n.a.	n.a.	n.a.	n.a.	n.a.
Pt2	18-10-88	do	cotton				C	dry	0.23	0.50	n.a.	n.a.	n.a	n.a.	n.a.
Pt3	24-09-87	do	cotton				C	wet		0.50	n.a.	n.a.	n.a.	n.a.	n.a.

[c] Soil map of Peneios delta and Appendix A.3.

In Entic Chromoxererts of the Larissa plain, permeability values could not be determined as in (wet) soils of Typic subgroups. The unpredictable nature of infiltration in such soils will be discussed later.

Sorptivity and conductivity

As discussed, the initial soil moisture regime affects the sorptivity of a soil. Some soils, viz. P1, P2 of the Nikea valley system (Table 3.5), well tested in spring, they were still at field capacity and their sorptivities were accordingly low. Soils that were examined later in the summer were drier and -unless pre-wetted- showed higher S-values.

It was argued in paragraph 3.3.3 that Eqn.(3.90a) describes satisfactorily the relation between sorptivity and initial soil moisture content. Judging from the correlation between measured S(SMPSI) and porosity data, this relation can be used to establish SO values for the major soil units with rigid matrix geometry in the study area. If more than only one measured S(SMPSI) value is available, both SO and KTR-values can be established.

In Fig. 3.21, measured and simulated sorptivity values are plotted vs. the initial soil moisture content for soil P6a, a highly permeable loamy Calcixerollic Xerochrept situated on the upper slopes of the Nikea area (Pedon P6 in App.A.1 and Plate 3A). The measured PSI-

SMPSI relation of this soil was used for the numerical calculations (see Table 2.8), whereas for the KPSI-PSI relation (Eqn. 3.80), the geometry-constants for loamy soils were considered (Table 3.4). The simulated curves in Fig. 3.21 correspond to two different saturation conductivities KO=0.015 and 0.03 cm min^{-1}. This is done to demonstrate that a value of KO can be found (by trial and error) whereby simulated and measured data exhibit a good agreement. This method consumes less time than one might expect due to the range limits of KO=KTR(A)/ 0.632. Fig. 3.21 suggests that 0.03 cm min^{-1} is the KO-value at which simulated and measured data are in agreement.

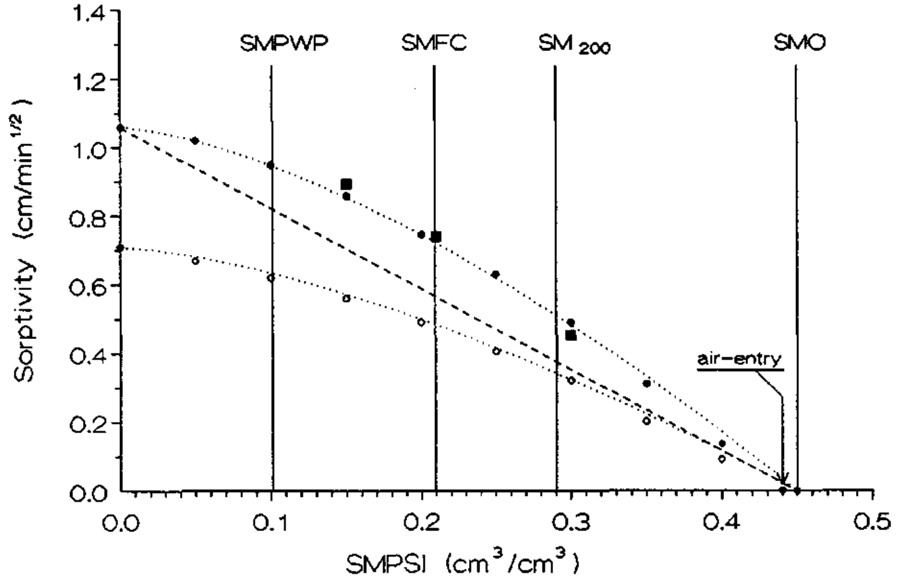


Fig. 3.21. Sorptivity vs. initial moisture content for a loamy Calcixerollic Xerochrept of Nikea area (P6a). (■ measured; ● simulated with KO=0.03 cm/min; o simulated with KO=0.015 cm/min;--- linear approximation (Driessen, 1986); ·······equation S = SO * [1 - $(SMPSI/SMO)^{1.5}$]; S=momentary sorptivity; SO = standard sorptivity; SMPSI=initial soil moisture content; SMO, SM_{200}, SMFC and SMPWP are soil moisture contents at saturation (PSI=0), at PSI=200 cm, at field capacity (PSI=300 cm), and at permanent wilting point (PSI=16 bars), respectively, where PSI is the matrix suction.

Dotted and dashed lines in Fig. 3.21, represent S-SMPSI relations, calculated with equations (3.90) and (3.90a), respectively. The good agreement of calculated and measured data is evident. The improved Eqn.(3.90a) gives a better approximation of the actual SO value and generally of the S-SMPSI relation in the dry region (see also Fig. 3.16).

Swelling soils

Not surprisingly, the swelling soils of the study area which, apart from the strongly swelling Vertisols are Vertic subgroups of Mollisols and Inceptisols, behave differently. This is shown by Figs. 3.22 and 3.23, where measured sorptivity values are plotted against the initial soil moisture contents of two soils of the sloping Nikea terrain, viz. P5a (swelling Typic Calcixeroll) and Pcl (Vertic Xerochrept). Three points are important here:

(i) For the duration of the infiltration experiments, the soils behave as rigid so that infiltration is adequately described by the Philip model (Table 3.5), but
(ii) unlike in rigid soils, sorptivity and permeability decrease with increasing initial soil moisture content, and
(iii) the sorptivity reaches a very small value at moisture contents close to field capacity (i.e. PSI=146-200 cm, in Figs. 3.22 & 3.23)).

Individual soil particles in swelling soils alternate between a dense (after drying) and loose (after wetting) configuration. In saturated soil, a decrease in SMPSI results in a denser packing of soil particles, often to the extent that the soil remains saturated (SMPSI=SMO). Only upon further drying or when SMPSI decreases more rapidly than SMO, will air-entry and crack formation take place. This phenomenon is known as residual shrinkage (Philip and Smiles, 1969).

Little is known about the degree of reversibility of the swelling process or how rapidly or slowly changes in matrix configuration approach equilibrium. Data on the subject are scarce; few experimental data collected in this study suggest that the (not extremely) swelling soils in the study area are commonly re-orientated in one day and that after only a few hours of infiltration the soils behave as rigid, with infiltration according to Eqn.(3.89).

In rigid soils, a drop in SMPSI is normally associated with a sharp reduction of KPSI, whereas consolidation of a swelling soil goes with only a modest decrease of KPSI with SMPSI because the soil remains initially saturated. After air-entry, during residual shrinkage, KPSI decreases much more steeply with reduced SMPSI (Philip & Smiles, 1969), due to a sharp reduction in pore space inside aggregates and/or clods. The remaining portion of porosity (void-volume), consists of macroscopic (structural) cracks and macropores. Flow through these features is known as "bypass flow" (Bouma, 1984) and in the field practice it contributes to the soil's conductivity. In the case of Vertisols, the saturation hydraulic conductivity is very low, so that irrigation management of such soils depends totally on bypass flow (Bouma & Loveday, 1988). Upon wetting, the cracks close; bypass flow drops sharply and infiltration reaches very low values.

Figs. 3.22 and 3.23 present some S-SMPSI relations for different KO-values. In these simulations, PSI-SMPSI relations measured in soils P5a and Pcl (see Table 2.8) were used to construct the KPSI-PSI relation with Eqn.(3.80), assuming a rigid matrix geometry. The figures confirm that the measured sorptivity values pertain to "equivalent" rigid soils with different S-SMPSI curves that correspond to different saturated conductivities. The latter decrease with increasing initial soil moisture content. It is, therefore, likely that a (slow) re-orientation of the matrix upon wetting of these Vertic soils resulted in a low "essential" conductivity value. This, in turn, explains the rapid drop in sorptivity and permeability with increasing initial soil moisture content.

The strong swelling of many soils in the study area is further documented by Fig. 3.24, which presents the "shrinkage characteristic", i.e. the total void volume vs. the moisture content, for a strongly swelling soil of the Peneios river Plain (Entic Chromoxerert). Note that the moisture ratio Θ (in cm^3 water per cm^3 solid phase) is used to denote the fractional volume of moisture (SMPSI), and that a void ratio (e, in cm^3 voids per cm^3 solid phase)

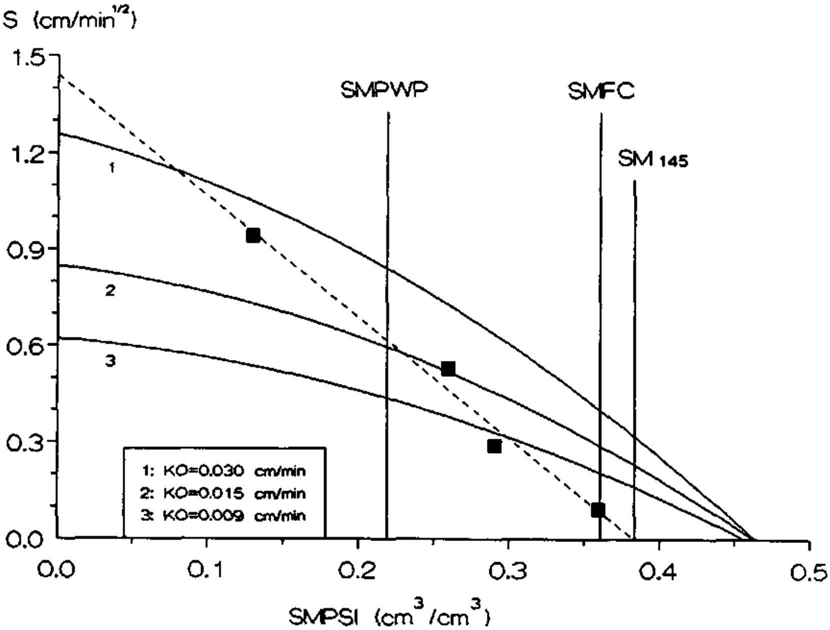


Fig. 3.22. Sorptivity (S) versus initial soil moisture content (SMPSI) of a swelling Typic Calcixeroll (P5a) of the Nikea (Larissa) area. (■ measured values; solid lines: S-SMPSI relation simulated for "equivalent" rigid soils with various saturation conductivity values (KO). Dashed lines: linear approximation used in the model. Soil moisture contents as in Fig. 3.21.

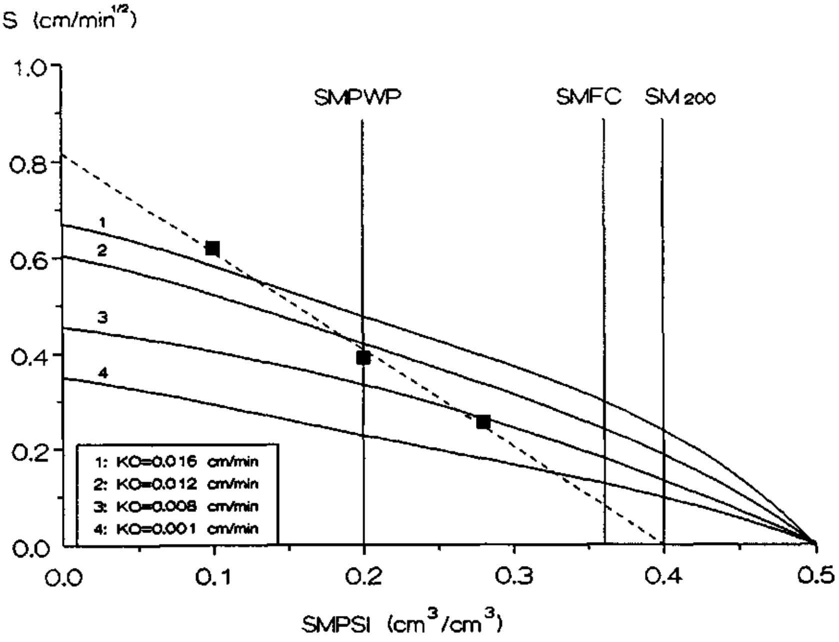


Fig. 3.23. Measured and simulated sorptivity values versus initial moisture content for a Vertic Xerochrept of the Nikea (Larissa) area. For further explanation, see Fig. 3.22 and text.

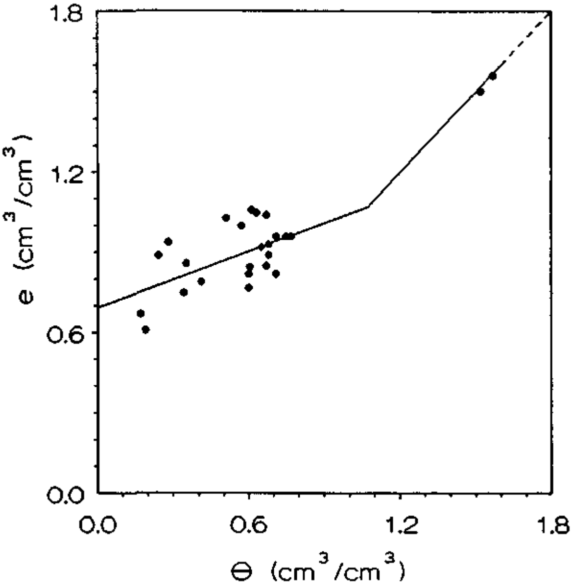


Fig. 3.24. The shrinkage characteristic of an Entic Chromoxerert in the Peneios alluvial plain. (Θ=moisture ratio in cm^3 water per cm^3 solid phase; e=void ratio (in cm^3 voids per cm^3 solid phase).

denotes porosity. These transformations involve (Philip, 1969):

$$\Theta = SMPSI*(1+e) \qquad (3.95)$$

$$e = (p_s/b_p)-1 \qquad (3.96)$$

where b_p is the volumetric mass of dry bulk soil (g cm^{-3}), and p_s is the volumetric mass of the solid phase (±2.65 g cm^{-3}).

The shrinkage characteristic of Fig. 3.24 refers to the surface soil. It is constructed from data collected in the period April-September under field conditions, which explains the high variability. Nevertheless, the ranges of consolidation and residual shrinkage and the approximate air entry value can be distinguished.

The suction range over which a rigid soil remains water-saturated can be found from the SMPSI-PSI characteristic: it is the trajectum over which d(SMPSI)/d(PSI)=0. In case of a swelling soil, the air-entry point cannot be established this way. Air-entry in soils P5a and Pcl seems to occur around PSI-values of 145 and 200 cm respectively (Figs. 3.22 & 3.23), at which points sorptivities (absorbtion forces) drop to about zero. Fig. 3.21 shows that simulated the sorptivity for the rigid soil P6a drops to zero at PSI=10 cm, that is the air-entry point. For the vertic soils, values of 145 to 200 cm are not excessively high if one considers the effect of the soil load at field conditions (Stroosnijder, 1976); these values correspond with moisture contents slightly above field capacity. This explains the very low sorptivity values of vertic soils, which were at field capacity when examined in spring.

The simulated S-SMPSI relations in the above figures are used only to demonstrate trends, as they are based on an unrealistic (constant) SMO-value. The pattern depicted in Fig. 3.25 below, constructed for soil Pcl on an hypothetical basis, is probably more realistic.

In summary, the limited information available seems to indicate that Vertic soils in the study area exhibit a behaviour that has elements of both rigid and swelling soils. Short time infiltration proceeds as in rigid soils with a dominance of sorptivity in the beginning and of gravitational forces later on. Under field conditions, macropore flow may not be neglected,

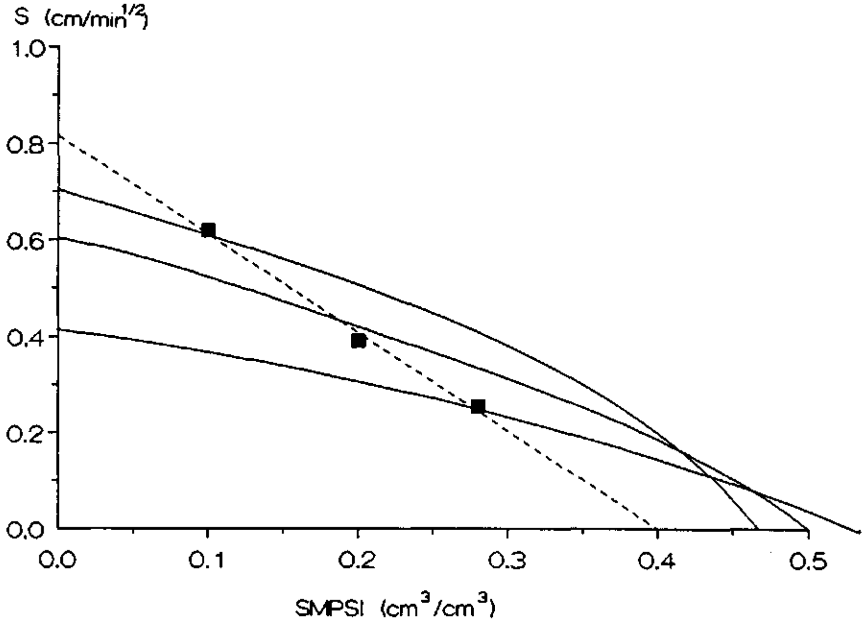


Fig. 3.25. Relation between sorptivity (S) and initial moisture content (SMPSI) for soil Pcl (Fig. 3.24). (■ measured S-values; solid lines represent hypothetical S-SMPSI relations for various matrix configurations and corresponding "essential" conductivities; the dashed line represents the equation used in the model).

as this supplements the (not necessarily very low) conductivity of such soils. A term such as "essential" conductivity might be used to denote the overall water intake through the soil surface. At higher moisture contents or after prolonged wetting, (slow) re-orientation of the matrix configuration results in a decreased "essential" conductivity and a rapid drop in sorptive forces. Apparently, the increase in flow inside aggregates is outweighed by the decrease in macropore flow. Air-entry points are reached at PSI-values slightly below the field capacities of these soils.

The sorptivity of the studied soils might for all practical purposes be approximated with the linear formula (3.90) substituting SM_{150} value for SMO. SM_{150} is read from measured moisture characteristics. The equivalent permeability assumes that KTR is equal to approximately KTR=2*A. Next, TPONDING is approximated with formula (3.94) as for rigid soils.

Strongly swelling soils

Strongly swelling Vertisols showed the highest and the lowest infiltration capacities in the study area. Fig. 3.26 demonstrates this for a Larissa Entic Chromoxerert under different moisture regimes (ponded infiltration data). At the end of winter, the surface of Vertisols is thoroughly wetted, the soils are swollen, and infiltration is practically nil. Oppositely, in dry Vertisols, large amounts of water can infiltrate before the soils swell.

Raw infiltration data from the ISMC, Larissa, show the failure of the Philip formula in predicting infiltration in Vertisols, except for soils rich in organic matter, viz. the Typic Chromoxererts of the Nikea area, under moist conditions. Instead, by plotting I vs. $t^{1/2}$, an S-type curve results (Fig. 3.26), which is typical for Vertisols of the Peneios alluvial plain

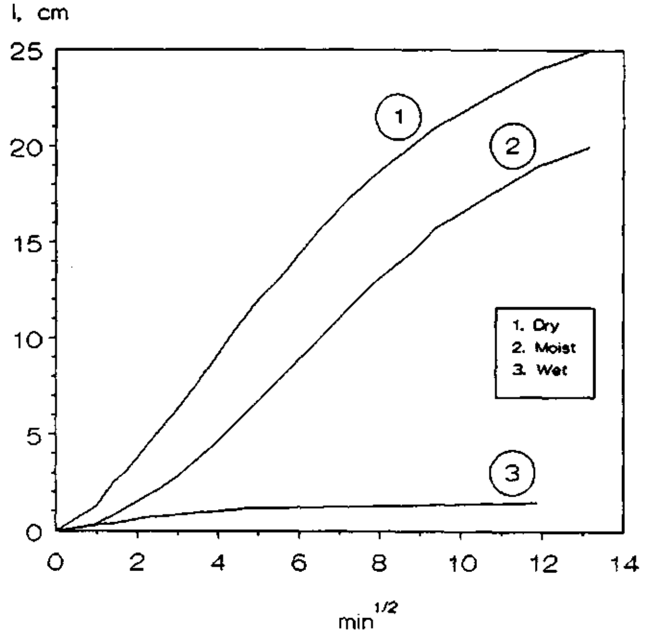


Fig. 3.26. Observed cumulative infiltration (I) versus $t^{1/2}$ in a strongly swelling Entic Chromoxerert under different initial moisture conditions. The experiments were conducted in the same location.

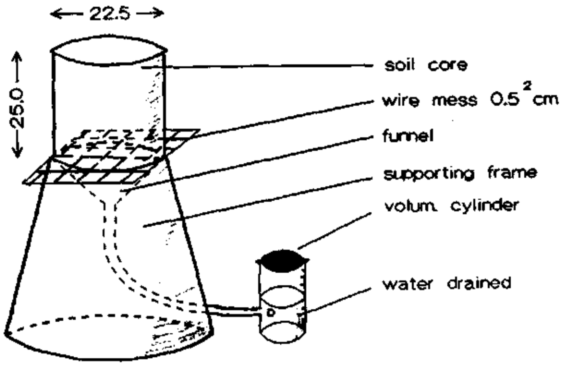


Fig. 3.27. Simple construction used for observing bypass flow.

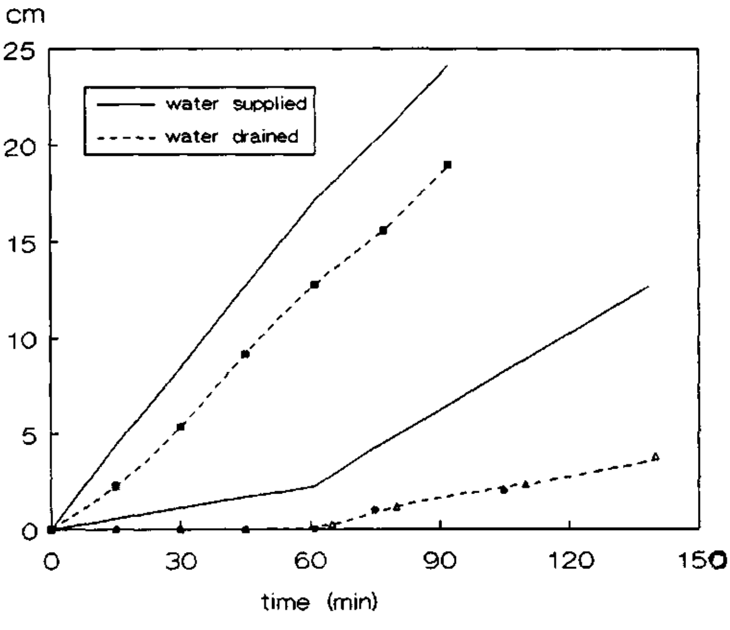


Fig. 3.28. Accumulated water supply and bypass flow until ponding of an Entic Chromoxerert under field moisture conditions for various rain intensities.

(Entic Chromoxererts) and the Karla basin (Typic and Entic Chromoxererts). In very wet soils, a straight S-$t^{1/2}$ relation indicates zero permeability, but in this case, gravitational forces are probably compensated by the soil load with depth (Philip & Smiles, 1969; Stroosnijder, 1976). The decrease of the slope of the curve at prolonged infiltration is attributed to consolidation of the topsoil, which is caused by the swelling of the wetted deeper layers. Full swelling of the surface soil ($dI/dt^{1/2} \rightarrow 0$) might occur after some 30 minutes (wet) to more than 3 hours (dry) depending on the cracking pattern of the soil.

Vertisols have extremely low conductivities and irrigation management of these soils is based on bypass flow. To gain some elementary knowledge on bypass flow and on the speed of re-orientation, some wetting experiments were carried out under more natural conditions using large undisturbed soil cores (Bouma *et al.*, 1981). The cores were carved out *in situ* in an Entic Chromoxerert on the Peneios alluvial plain. The soil was cultivated with alfalfa. The simple construction used is schematically shown in Fig. 3.27. Two cores were placed in the field, and sprinkling irrigation (via a travelling gun) supplied 2.2 cm water per hour Bypass flow started 45 min after irrigation. During the next 15 min, half of the supplied water was drained out of the cores. At that time, the application rate increased to 8 cm h^{-1}. Bypass flow increased drastically in both soils. When the soils were ponded with 1 cm of water after 105 and 140 minutes, irrigation stopped.

The experiment was repeated with a moist sample (pF=2.7) which was taken to the laboratory and subjected to a rain intensity of 17 cm h^{-1}. Bypass flow started instantaneously. After 92 minutes the surface started to pond and irrigation stopped. During the last 15 minutes, 97% of the supplied water was drained out of the core. These results, which can be viewed only as indications, are schematically presented in Fig. 3.28 and suggest the following:

(i) At field moisture conditions, any quantity of water can flow through the cracks of a strongly swelling soil before the soil surface consolidates, and

(ii) the time to consolidation seems not very much affected by the supply rate of water.

The first point is in agreement with experience gained in the field and with recent data on bypass flow in Greek Vertisols (Kosmas *et al.*, in prep.). Field practice has taught that fewer applications but high application rates are required on Vertisols. Cotton tolerates long intervals between irrigations. It is therefore not surprising that most of irrigated Vertisols in Larissa area are under cotton (viz. Karla area, p.112).

Vertisols in the Larissa area belong to only a few Soil Series. Therefore, it was hoped that an empirical relation between the soil moisture content and the time to surface consolidation could be found. Considering that the time to surface consolidation is not much affected by the application rate, the effective irrigation and/or rainfall could perhaps be approximated. However, records of initial moisture contents are not available in the Institute.

The time to surface consolidation of sprinkling-irrigated Vertisols is set here to 120 minutes, unless the soil moisture content is above field capacity. In that case, ponding is considered instantaneous. In the case of drip-irrigation, ponding does not occur. With these assumptions, a maximum of 4-4.5 cm water per application can be supplied with the highest sprinkling rates in the area (2-2.2 cm h^{-1}). It will be shown in Chapter 5, that potential yields of cotton are possible, if this amount of water is applied every 12-15 days.

3.3.6 Discussion

It was discussed in Section 3.2 that the dynamic description of infiltration requires time resolutions of the order of seconds. The failure of simplified models operating on a daily basis is therefore certain. Including detailed models in larger crop-growth models that consider periods of 120-150 days and more would increase computing costs to unrealistically high figures. An improvement of existing simplified models might be the automatic regulation of the time interval during the first hours after a shower or irrigation.

As an alternative, the time to ponding was introduced in this study. This time can be analytically calculated from sorptivity, S, and transmission zone conductivity (final permeability), KTR, and used for assessing effective irrigation or rainfall depth. Sorptivity can be approximated from its standard value, SO, and the soil moisture content, SMPSI; final permeability is approximated from measured permeability values, A.

This approach is applicable in the study area. It was demonstrated that the Philip model describes infiltration satisfactorily in all but strongly swelling soils. Experimental results help to approximate the infiltration parameters required. However, the modest number of experiments and the inevitable variability of the results limit the basic information to only the major soil units in the Larissa area. Indicative values are presented for each of the pilot areas (viz. Tables 2.9, 2.13 and 2.18).

In Table 3.6, 38 i_b rates (ISMC records) of Alfisols on the Pleistocene terrace are grouped for different textures of topsoil (Soil Types) and cultivations. It can be seen that orchards and fallow fields have very low basic infiltration rates, i_b=0.6 cm min^{-1}. In orchards, the rings are installed between rows, where the soils are compacted by machinery. In fallow fields, the topsoils of Alfisols are hard and massive. The rest of the (ploughed) soils show a considerable variation in i_b rates for the same Soil Types. Table 3.7 presents the calculated relation between i_b (found as explained in 3.3.2) and sorptivity and demonstrates the effects of different moisture conditions. Ploughed soils have higher i_b-rates, in excess of 2.4 cm/hour, corresponding to sorptivity values equal to or greater than 0.9 cm min$^{-1/2}$ (Table 3.7). Note the gap between the maximum sorptivity value of cropped arable soil and that of ploughed (prepared) soil. Apparently the sorptivity value of 0.6 cm min$^{-1/2}$ (underscored in Table 3.7) refers to a cropped soil which was close to wilting point because average sorptivity values range from 0.30 to 0.40 cm min$^{-1/2}$ in this area.

In the existing permeability maps, this variation is neglected because all cropped soils of Table 3.6 belong to the same infiltration class "moderately slow" (see Table 3.3). Large areas with Mollisols, Alfisols, Inceptisols and Vertisols in the Larissa area belong to this class. Lumping these soils together is not realistic, because the different infiltration capacities are associated with considerable differences in management requirements and production potential. As a result, the existing permeability maps can only serve to distinguish between major kinds of land use, such as arable crops vs. small gardening, pasture, etc.

Consider for example some typical soils of two different areas, viz. an Alfisol on the Pleistocene terrace (soil 1; KTR=0.003 cm min^{-1} and A=0.002 cm min^{-1}) and a Mollisol in the Nikea valley system (soil 2; KTR=0.03 cm min^{-1}and A=0.015 cm min^{-1}). Assume that the momentary sorptivity amounts to S=0.4 cm min$^{-1/2}$ for both soils. These combinations of S and A values would result in ponded infiltration with i_b rates of 1.2 cm h^{-1}, for soil 1, and 2 cm h^{-1} for soil 2. In this scenario, irrigation applied at the rate of 2 cm h^{-1}, viz. with large sprinklers, travelling guns, etc., would cause surface ponding once the soils have received 2.6 cm (soil 1; Fig. 3.29) and 6.66 cm water (soil 2). These figures represent the effective

Table 3.6. Basic infiltration rates (i_b) of Alfisols on the Pleistocene terrace for different land uses and Soil Types.

Land use	i_b (cm/hour)	Soil Type			Total
		3	4	5	
Orchards+ fallow	0.6	6	5	4	15
	0.6 - 1.1	4	4	2	10
Arable	1.2 - 1.4	5	1	-	6
crops	1.5 - 1.8	1	2	-	3
	1.9 - 2.3	-	-	-	0
Subtotal		10	7	2	19
Ploughed land	2.4	-	2	-	2
	3.0 - 3.6	2	-	-	2
Subtotal		2	2	0	4
TOTAL		18	14	6	38

(Source of data: Institute of Soil Mapping and Classification, Larissa)

Table 3.7. Values of sorptivity (S) at different basic infiltration rates (i_b) in Alfisols on the Pleistocene terrace.

i_b (cm/hour)	<=0.6	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
S (cm/min$^{0.5}$)	<=0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1

irrigation depths per application. Under this management, soil 2 appears to be far more productive than soil 1, although both soils are within the same infiltration category.

This is indeed the practice: maize is rare on the Alfisols of the Pleistocene terrace, and cotton yields may be much lower than yields in the Nikea area if irrigated with large sprinklers. This is illustrated in Fig. 3.29, where the amount of water infiltrated to the time of ponding is presented for the cropped soils of Table 3.6, calculated for 3 irrigation intensities, viz. 1.7, 2.0 and 2.2 cm/hour (the first and the third are the average and maximum intensities associated with travelling gun systems). If one considers that maize requires about 6-7 cm of water per 7-10 days in the peak season (cotton requires less water and tolerates longer intervals between applications), the applied irrigation rates are still rather low.

The use of empirical formulas is the only option for analyzing swelling soils, because conceptual models are still lacking for these soils. Under field conditions, most clay soils exhibit swelling properties. These soils have a very low infiltration capacity when moist, due to the reduced macropore flow. However, their permeability is disproportionably higher when they are dry. It is difficult to describe infiltration in strongly swelling soils because the soil moisture content and the matrix configuration change over time, and most theories lack sufficient validation. A grossly simplified hypothesis is used here, based on general indications.

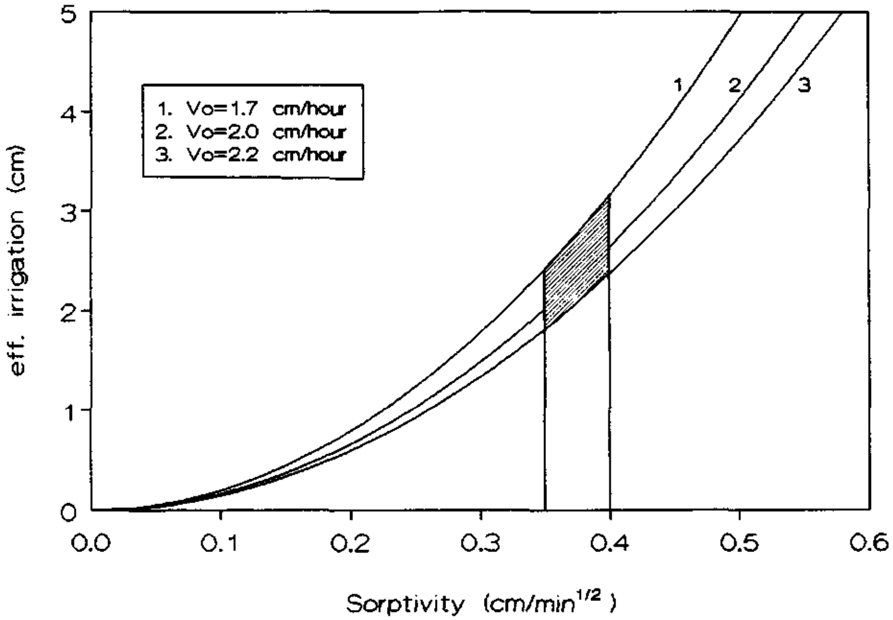


Fig. 3.29. Effective irrigation, i.e. quantity of water supplied until surface ponding, as determined by sorptivity and irrigation (rainfall) intensity, VO, in Alfisols on the Pleistocene terrace. The shaded polygon includes average values confirmed in the field practice. A KTR value of 0.003 cm/min has been applied.

4 FIELD EXPERIMENTATION

Maize experiments
Cotton experiments
Wheat experiments

4.1 Maize experiments

4.1.1 Materials and methods

The crop production model was tested in a number of field experiments in Larissa and Thessaloniki, involving the maize hybrids ARIS and PIONEER 3165-DONA.

The first two experiments were carried out in 1987, with maximum fertilization, frequent irrigation and total pest/disease control. In the experiments of 1988, fertilization and weed control were also optimum, whereas the effect of water stress on potential production was studied in a number of different irrigation schemes. The experiments are described in some detail hereafter:

Experiment 1 was situated on a flat (slope=0.5%), sticky, light clay soil of the Experimental Farm of the Higher Agricultural School, Larissa (TEI-STEG) (Appendix A.4). The site (0.24 ha) was disked and harrowed on the day of sowing. A basal dressing of 1,250 kg Ammonium Phosphate (20-10-0) and 360 kg diluted Superphosphate (0-20-0) per hectare was applied before sowing. The maize hybrid ARIS was sown in rows 75 cm apart with two plant distances: 15 cm (treatment A) and 29 cm (treatment B) corresponding with plant densities of about 85,000 and 45,000 plants per ha, respectively. The sowing date was May 7th, 1987. Three weeks after emergence, the site received an additional fertilizer input of 450 kg Ammonium Nitrate (33.5-0-0) per ha, bringing the total nutrient input at 400 kg N/ha and 200 kg P/ha (two control plots of totally 720 m^2 were left unfertilized). A randomized plot design was used with 3 replicates: each plot was 6x6m=36 m^2. Irrigation was applied using an automatic sprinkling system (travelling gun). The crop was irrigated 12 times; it received net water inputs of 4 cm per application on the following dates: 12/5, 26/5, 5/6, 19/6, 26/6, 3/7, 11/7, 17/7, 24/7, 31/7, 8/8, 20/8 and 28/8/1987. The dates of 50% emergence, flowering (tasselling), silking and maturity were recorded. The occurrence of a black layer on 50% of the kernels was used as an indication that the crop had fully matured (Rench & Shaw, 1971). The heat requirements for emergence, flowering and maturity were calculated by interpreting records on emergence, flowering and maturity of an earlier planting of cv. ARIS (on April 14th). The crop was harvested on the following dates: 10/6, 25/6, 15/7, 30/7, 20/8, 3/9 and 18/9/1987. For the first two harvests, 2 strips of 2 meters were taken from each replicate. Later, the size of the harvested strips was reduced, with sample weights of no more than 300-400 g per replicate and per treatment. Larger samples were taken again during the final harvest. Leaf blades, leaf sheaths, stalks and cobs+husks were harvested separately. Measuring the areas of 20 leaf blades from each replicate with a planometer and correlating leaf length and width with leaf surface gave an approximate leaf area. Then, the total leaf area of the crop was calculated from the measured lengths and widths of all leaves in the sample. All samples were dried at 90°C until constant weight. Combining the leaf area and dry leaf weight produced an indication of the momentary Specific Leaf Area (m^2 leaf/kg dry leaf mass). The physical and chemical soil data (texture, bulk density, intake rate, organic matter content, pH, $CaCO_3$, P-Olsen, exch. K, etc.) were measured in the laboratory of TEI/STEG. pF-curves were measured at the Department of Soil Science & Geology, WAU. Climatological data (daily maximum and minimum air temperatures, sunshine duration, precipitation, air humidity and wind speed) were recorded at the Larissa Airport at a distance of 1 km from the experimental site. Plant samples (including the control) were analyzed for total Nitrogen and Phosphorus at the Department of Soil Science & Plant Nutrition, WAU, The Netherlands.

Experiment 2 was done on flat, loamy sand on the Karagiannis farm, 25 km SW of the city of Thessaloniki (Vrachia). The site was fertilized with 500 kg N per hectare (500 kg of 8-16-24 plus 400 kg urea per hectare before sowing and the rest in two applications with 33.5-0-0), and with 80 kg P and 120 kg K per hectare. The maize hybrid PIONEER 3165-DONA was sown on April 23rd, in rows 80 cm apart with 6.5 plants/m, corresponding with approx. 80,000 plants per hectare. The ground-water depth ranged between 130 and 155 cm below the surface. Consequently, the crop was irrigated only 6 times, viz. on 17/6, 3/7, 15/7, 27/7, 7/8 and 18/8/1987. Furrow irrigation was used with net water inputs of about 80 mm per application, except for the first application of 120 mm. Under this scheme, the crop received enough water for maximum production. The design used was the same as in experiment 1, with 3 replicates, each consisting of 4 rows of 3.2 meters wide and 4 meters long. The crop was harvested on the following dates: 28/5, 19/6, 17/7, 31/7, 21/8, 4/9 and 21/9/1987. The daily maximum and minimum temperatures were recorded on-site; the rest of the climatological data (see experiment 1) refer to the city of Thessaloniki and were obtained from the National Meteorological Service.

Experiment 3 was done in 1988; it was situated at the same site as experiment 1. Before sowing, a basal dressing of 900 kg Ammonium Phosphate (20-10-0) per hectare was applied. The maize hybrid ARIS was sown on May 3rd, 1988, in rows 80 cm apart with a plant density of approx. 70,000 plants per hectare. Three weeks after emergence, the site received an additional dressing of 780 kg Ammonium Nitrate (34-0-0) per ha, bringing the total fertilization input at 445 kg N/ha and 90 kg P/ha with the exception of two control plots (the same plots as in 1987). Drip irrigation was applied with the laterals placed every second row, and the emitters (internal spiral-line distributors, placed 1 meter apart) dripping at a constant (low) discharge of 4 lt/hour or 0.25 cm/hour. A randomized block design was used with 4 treatments and 3 replicates. The treatments are:

- *treatment K:* normal irrigation; a net total of 386 mm irrigation water was applied from sowing to silking, and 395 mm from silking to maturity.
- *treatment A:* dry throughout; only 134 mm of water were applied for establishment.
- *treatment Y:* the "wet treatment"; with a total effective irrigation water input of 860 mm from sowing to silking and 420 mm from silking to maturity to ensure potential production.
- *treatment PY:* same as Y until silking, dry thereafter; only 55 mm of water were applied between silking to maturity.

Fig. 4.1.14 presents the water inputs in the four irrigation treatments. The exact dates and quantities of water per application are specified in Appendix C.

The crop was harvested 6 times, viz. on the following dates: 2/6, 23/6, 11/7, 28/7, 10/8 and 23/8/1988. The sampling procedure was as in experiment 1; the sampled matter was divided by plant organ, and leaf area measurements were done as in the foregoing experiments. The soil moisture content was frequently recorded (gravimetrically). The daily maximum and minimum air temperatures, sunshine duration, precipitation, air humidity and wind speed data (at the Larissa Airport) were supplied by the National Meteorological Service. Plant samples (including the control) were analyzed for total Nitrogen, Phosphorus and Potassium in Wageningen.

Experiment 4 was laid out on Vrachia (Thessaloniki) loamy sand on April 28th, 1988. The maize cv. P.3165-DONA was sown to 80,000 plants per hectare (see also experiment 2). The site received a basal application of 360 kg N, 80 kg P and 120 kg K per hectare (500 kg of 8-16-24 plus 400 kg urea per hectare and the rest with ammonium nitrate, 33.5-0-0). The ground-water table was within the control section only in the beginning of the growing period. Due to lack of water in the area, only two irrigations (furrow) were given, viz. on June 20th and July 6th, with 7 cm effective water depth per application. The growth of the crop was recorded on 12/7 and 17/8, and the final grain production was measured on 6/9/88. The daily maximum and minimum temperatures were recorded on-site; the rest of the climatological data (see experiment 2) refer to the city of Thessaloniki and were obtained through the National Meteorological Service. The heat requirements for emergence, flowering and maturing of maize were calculated with the help of data from an additional number of plantings of cv. ARIS, PIONEER 3183 and P.3165-DONA in neighbouring parcels in 1987 and 1988.

Finally, the results of a maize (cv. ARIS) experiment in Aliartos (Greece) in the summer of 1988 were kindly provided by the staff of the Dept. of Soil Science & Agric. Chemistry of the Agricultural University of Athens, for validation purposes.

4.1.2 Results and discussion

Development of the crop

Normally, the heat requirements from planting or emergence to flowering are established by summation of daily effective temperatures, calculated by subtracting a base (or threshold) temperature from the daily mean. The superiority of this method over the calendar-day method has been shown in numerous works. There is no agreement on the best method to compute threshold and ceiling temperatures (Mederski *et al.*, 1973). Suggested base temperatures for maize vary from 6°C (Bloc & Gouet, 1977) to 10°C (Andrew *et al.*, 1956; Cross & Zuber, 1972). Calculated heat requirements are corrected on the basis of ceiling temperatures (Gilmore & Rogers, 1958: effective degrees) or excess temperatures above the ceiling temperatures (Gross & Zuber, 1972), etc. Derieux & Bonhomme (1981) tested various published methods for calculating heat requirements (Tollenaar, 1979; Brown, 1969; Blacklow, 1972; Coelho, 1978; Arnold, 1975). For practical use, they recommended to take into account the accumulated daily (Tmax-10) temperature over the period from emergence to silking. Some of the methods published will be tested under Greek conditions.

The maximum, minimum and mean air temperatures (10-day averages) recorded during the experiment period in Larissa (1987) are presented in Figure 4.1.1. The Figure shows that the sowing-emergence period of cv. ARIS was one week if sowing took place on 14 April. With sowing on May 7th, the sowing-emergence period was 13 days, despite higher temperatures. This conflicts with the notion that the sowing-emergence period shortens with delayed planting (Marley & Ayres, 1972; Miedema, 1987). High temperatures may indirectly affect germination, because increased evaporation causes unsuitable moisture conditions for germination. This could be an explanation of the weak temperature effect on the length of the sowing-emergence period, found by Derieux & Bonhomme (1981), and it is certainly of importance in the case of late planting in Larissa. With the experimental site irrigated on May

12th, 50% germination was recorded on May 20th, 8 days after the irrigation. Experience in the area teaches that late sowing often leads to total failure. The length of the sowing-emergence period cannot be accurately predicted on the basis of temperature data only, although it is generally true that germination takes place between 7 and 10 days after sowing, if the temperature and moisture conditions are favourable.

The period from emergence to flowering ranged from 56 to 74 days, depending on the sowing date (Fig. 4.1.1); the interval from flowering to maturity, however, appeared unaffected, i.e. from 56 to 57 days. The emergence, flowering (tasselling) and maturity of a number of maize plantings in 1987 and 1988 are summarized in Table 4.1.1.

Table 4.1.1. Emergence (E), flowering (F) and maturity (M) dates of some maize plantings in 1987 and 1988.

Cultivar	Location	Emergence date	Flowering date	Maturity date	E-F days	F-M days	E-M days
cv. ARIS	Larissa	22/4/87	5/7/87	30/8/87	74	56	130
cv. ARIS	Larissa	20/5/87	15/7/87	10/9/87	56	57	113
cv. ARIS	Larissa	10/5/88	4/7/88	26/8/88	55	53	108
cv. ARIS	Thessaloniki	8/5/88	5/7/88	n.a.	54	n.a.	
cv. P.3165	Thessaloniki	4/5/87	19/7/87	18/9/87	76	61	137
cv. P.3165	Thessaloniki	9/5/88	10/7/88	3/9/88	62	54	116
cv. P.3183	Thessaloniki	4/5/87	14/7/87	9/9/87	72	57	129
cv. P.3183	Thessaloniki	9/5/88	8/7/88	n.a.	60	n.a.	

It appears that the growing period of cv. ARIS was about 120 days in Larissa in 1987 and about 110 days in 1988. Figure 4.1.2 suggests that this is caused by higher temperatures in 1988, especially during the heat wave in early July. The growth cycle of P.3165 (grown in Thessaloniki) exceeded that of cv. ARIS (grown in Larissa) by 8 days in 1988; this difference was more than 2 weeks in 1987. The calculated emergence-maturity periods of the cvs. ARIS and P.DONA are 120 and 130 days, respectively, if 1987 is taken as a (more or less) representative year. The Institute of Cereal Crops (Sfakianakis & Katsandonis, 1985) maintains that the growing cycle of cv. P.DONA is 10 days longer than that of cv. ARIS.

The accumulated heat units over the periods from emergence to flowering and from flowering to maturity were calculated for four plantings of cv. ARIS (Table 4.1.1), and with the following methods:

1. $[0.5^*(\mathrm{Tmax}+\mathrm{Tmin})]-\mathrm{Th}$, where Th is the threshold temperature 6,7,..,12°C and
   (a) Tmax, Tmin are the daily maximum and minimum temperatures respectively (°C),
   (b) as above but with a ceiling temperature in the range 26-32°C for the Tmax.
2. $\mathrm{Tmax}-\mathrm{Th}$, where Th is the threshold temperature 6,7,..,.12°C and
   Tmax is the maximum temperature with a ceiling in the range 26-40°C.
3. USA methods: Growing Degree Days (GDD; Gilmore & Rogers, 1958; Arnold,1975)
   $\mathrm{GDD}=0.5^*(\mathrm{Tmax}+\mathrm{Tmin})-10$, where
   (a) $\mathrm{Tmax}=30$ when $\mathrm{Tmax}>30°\mathrm{C}$ and $\mathrm{Tmin}=10°\mathrm{C}$ when $\mathrm{Tmin}<10°\mathrm{C}$,
   (b) $\mathrm{Tmax}=30-(\mathrm{Tmax}-30)$ when $\mathrm{Tmax}>30°\mathrm{C}$ and $\mathrm{Tmin}=10°\mathrm{C}$ when $\mathrm{Tmin}<10°\mathrm{C}$.
4. Ontario Corn Heat Units (CHU; Brown, 1969), with
   $\mathrm{CHU}=0.5^*[3.33(\mathrm{Tmax}-10)-0.084(\mathrm{Tmax}-10)^2+1.85(\mathrm{Tmin}-4.4)]$,
   with $\mathrm{Tmin}=4.4°\mathrm{C}$ if $\mathrm{Tmin}<4.4°\mathrm{C}$.

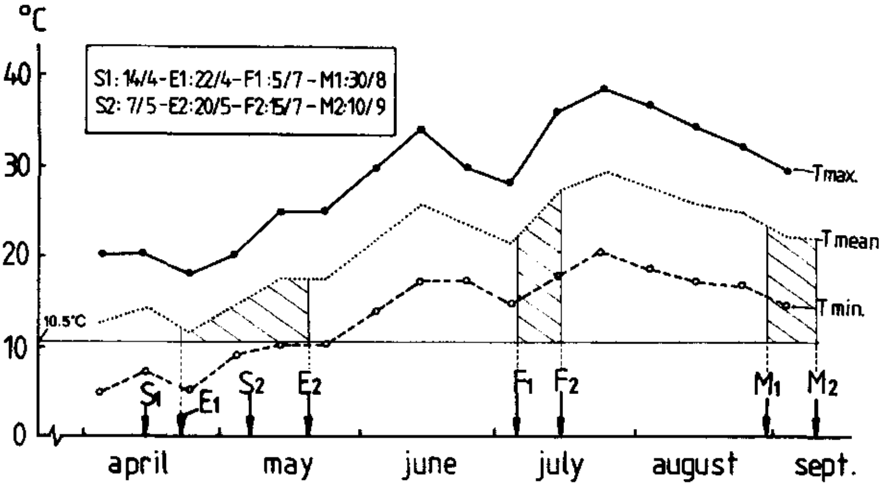


Fig. 4.1.1. Maximum, minimum and mean 10-days-average air temperatures in Larissa during the experimental period April-September 1987. Flowering (F) and maturity (M) dates of two plantings of maize cv. ARIS as affected by date of sowing (S)/emergence (E).

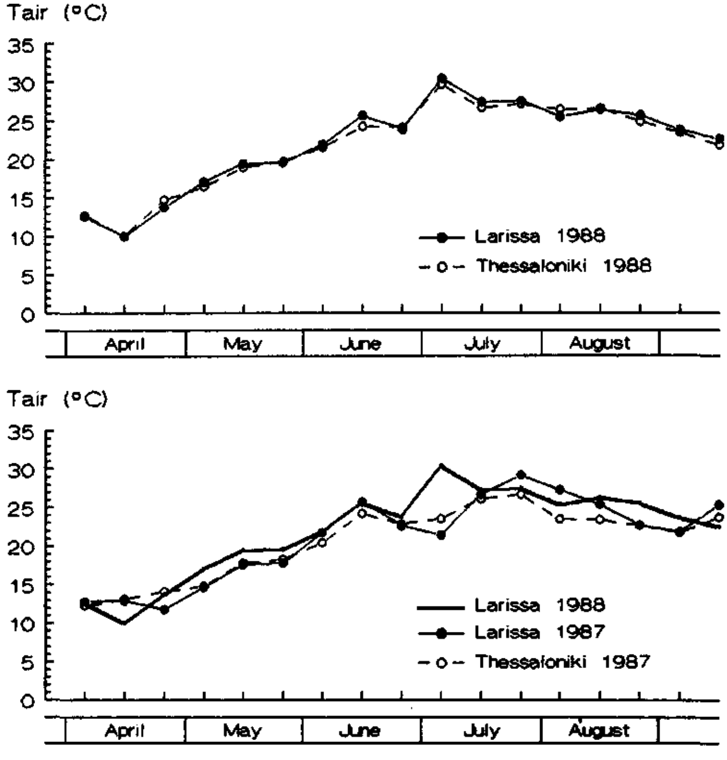


Fig. 4.1.2. 10-days-average air temperatures in Larissa and Thessaloniki.

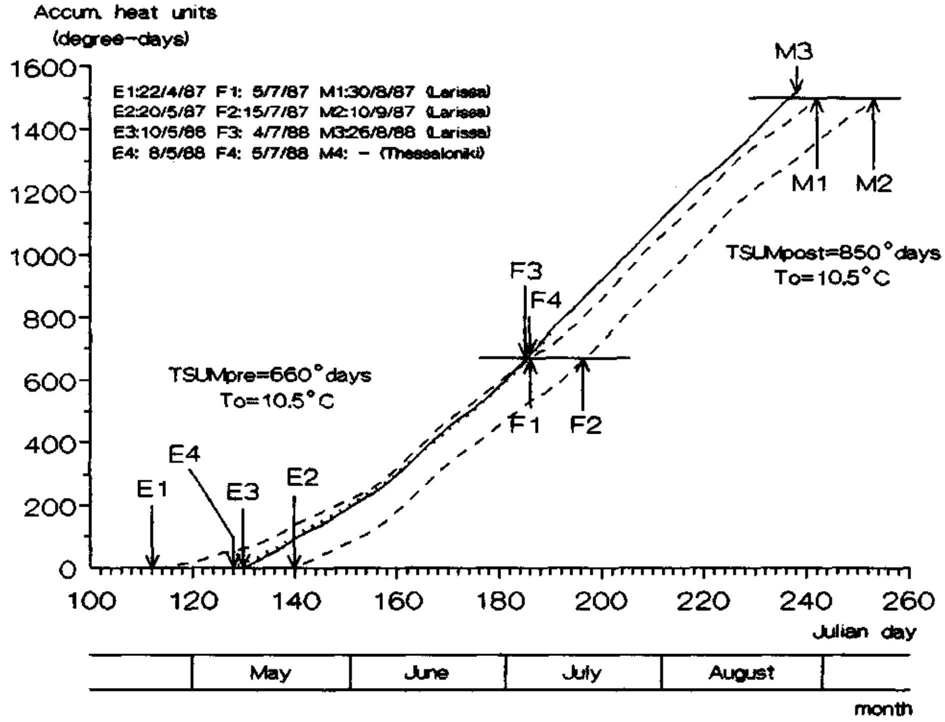


Fig. 4.1.3. Accumulated heat units during the growing season of four plantings of maize cv. ARIS in Larissa in 1987 and 1988, and in Thessaloniki in 1988. (E=emergence, F=tasselling, M=maturity; TSUMpre and TSUMpost are accumulated heat units required from emergence to flowering and from flowering to maturity, respectively).

The minimum coefficient of variation (CV) was obtained (for both periods) using the following formula:

$$\text{TSUM} = [0.5*(\text{Tmax}+\text{Tmin})-\text{Th}], \tag{4.1}$$

where TSUM is the accumulated heat units (°Cdays); Tmax and Tmin are the maximum and minimum temperatures, respectively; and Th is the threshold temperature equal to 10.5°C.

This formula suggests that the cv. ARIS needs 660 degree-days for flowering (TSUMpre= =660, CV=1.1%); the heat requirements of the cultivars PIONEER 3165 and P.3183 are: TSUMpre=780 and 730 °Cdays, respectively. TSUMpost, viz. the heat requirements from flowering to maturity, is 850 degree-days for both cvs. ARIS (CV=1.9%) and PIONEER (see Table 4.1.2).

Table 4.1.2. Heat units above 10.5°C required from emergence to flowering (tasselling) (TSUMpre) and from flowering to maturity (TSUMpost) for three maize cultivars.

Cultivar	TSUMpre (°Cdays)	TSUMpost (°Cdays)	TSUMtotal (°Cdays)
cv. ARIS	660	850	1510
cv. P.3183	730	850	1580
cv. P.3165	780	850	1630

The value of 10.5°C is higher than the threshold-temperature values suggested for European sites. This may be explained by the higher summer temperatures in the Greek lowlands (Durand, 1969).

The superiority in predicting flowering and maturity times based on the heat units method is apparent from Fig. 4.1.3, where the accumulated heat units are plotted for four plantings of cv. ARIS in Larissa and Thessaloniki, in 1987 and 1988. The accumulated heat units are calculated for each planting starting from the actual day of emergence; the days of emergence (E), flowering (tasselling) (F) and maturity (M) are indicated on the graphs. Note that the levels of 660°Cdays and 660+850=1510 °Cdays are also indicated and agree well with the accumulated heat units at flowering and maturity, respectively. Curves 1 and 2 refer to the 2 plantings in Larissa in 1987. Crop 2 emerged 28 days later but flowered only 10 days later. The maturation is delayed by 10 days in both cases; the curves 1 and 2 run almost parallel. Likewise, lines 3 and 4 run parallel although they represent different locations, viz. Larissa and Thessaloniki, in 1988. This may be explained by the average air temperature of Larissa and Thessaloniki, which were much alike in 1988 (see Fig. 4.1.2). As 1988 was warmer than the previous year (Fig. 4.1.2), curves 3 and 4 are steeper, and the flowering-maturity periods are shorter (53 vs. 56-57 days), resulting in earlier maturation.

The values established for the heat requirements during emergence to flowering and flowering to maturity (TSUMpre and TSUMpost, respectively) suggest that the rate of development of the studied maize cultivars is invariant during these periods. The development during those periods is assumed linear. Recalling the discussion in Section 3.1, the development stage of the crop (DVS) at any time can be estimated as follows:

```
IF Ta >=Th THEN TACT=TACT(old)+(Ta-Th)                                  (3.33)
IF TACT/TSUMpre<1  THEN DVS=0.5*(TACT/TSUMpre)                          (3.34a)
IF TACT/TSUMpre>=1 THEN DVS=0.5+0.5*[(TACT-TSUMpre)/TSUMpost] (3.34b)
```

where

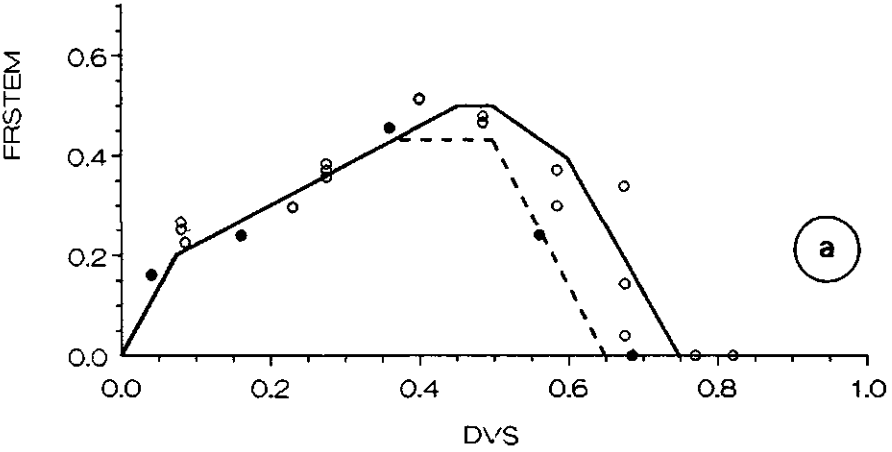
Ta	is the average air temperature = (Tmax+Tmin)/2 (°C),
Th	is the threshold temperature (10.5°C),
TACT	is the total accum. heat sum above Th (°C-days).

Note that DVS=0.5 at flowering and DVS=1 at maturity.

Assimilates partitioning

The partitioning of newly formed assimilates from the leaves to the various plant organs changes continuously during development. Recall that patterns of phenological development vary from year to year, mainly due to different weather conditions. As explained in Section 3.1, the partitioning of the assimilates to the various plant organs is accounted for with a crop-organ-specific partitioning fraction, FR(organ), which is a function of the DVS. The basic processes governing dry matter partitioning are still poorly understood (van Heemst, 1988).

The increments in dry matter mass were analyzed by interpreting the total dry-matter increase between two successive harvests as a reflection of assimilate partitioning to the various plant parts. This procedure yields unambiguous results only as long as plant parts do not die, unless all dead material is collected (van Heemst, 1986). This is a practical impossibility.



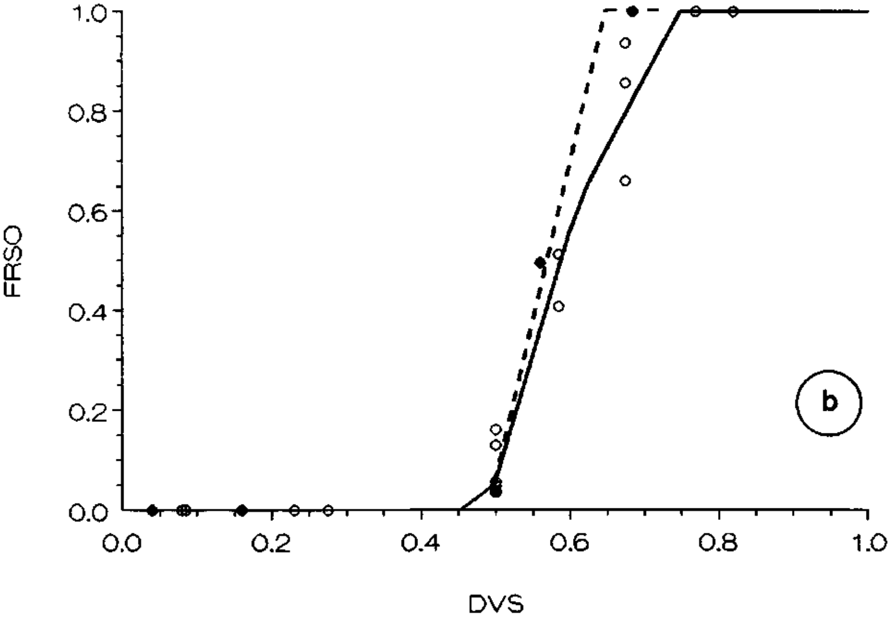


Fig. 4.1.4. (Continued).

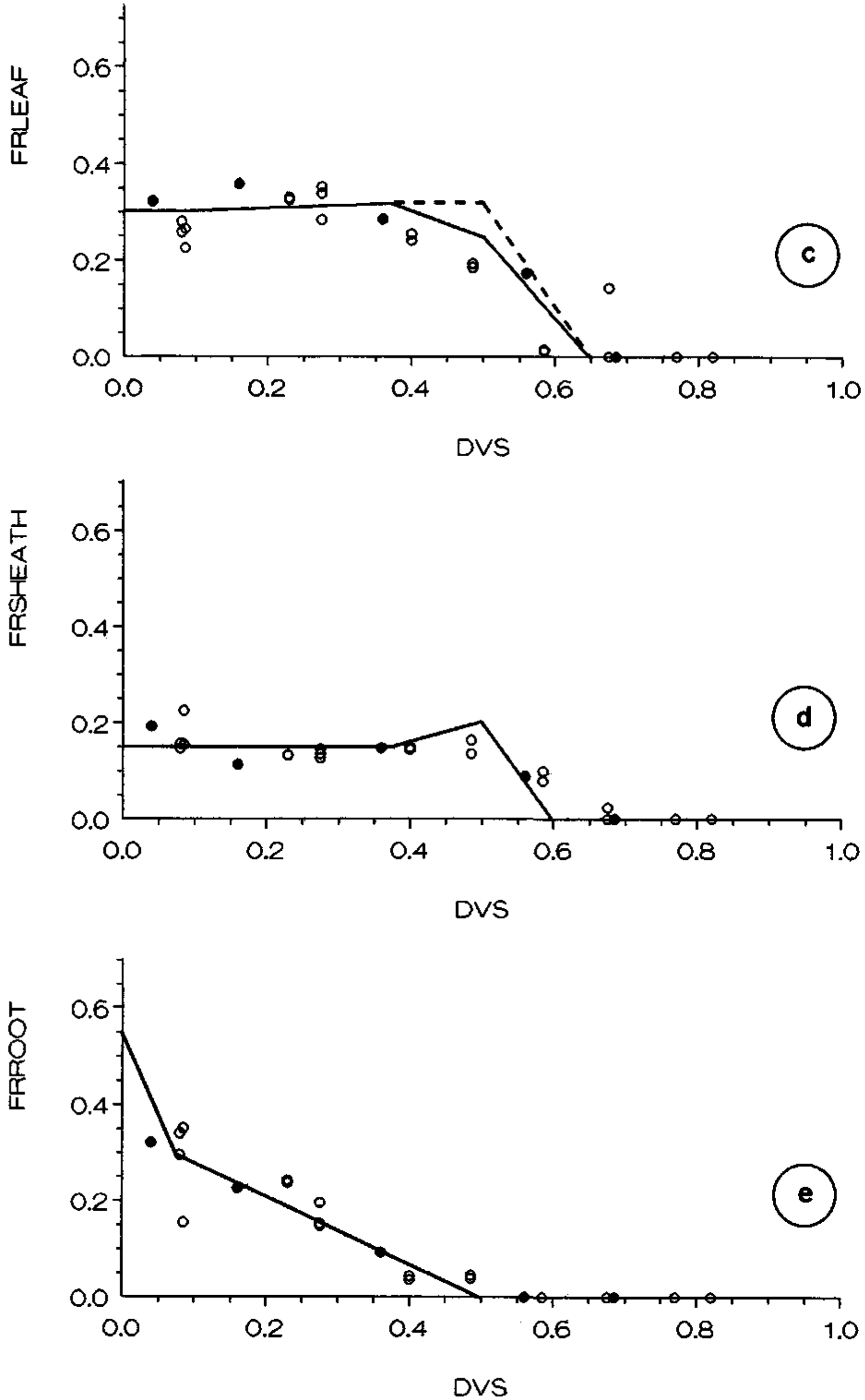


Fig. 4.1.4. Relation between the measured fraction of total dry matter increase invested in the various plant organs, FR(organ), and the development stage (DVS) of maize. (o—o cv. ARIS; ●---● cv. P.3165-DONA).

For that reason but also because it was no longer possible to collect the roots of each harvested replicate 6-8 weeks after emergence, two assumptions had to be made:

- no decrease in dry weight of any plant organ takes place after anthesis;
- root dry weight is at its maximum at the moment of anthesis, when it amounts to some 1,000 kg/ha. The latter value is based on published information in other maize cultivars.

With distribution factors related to the development stage of the crop, the FR(organ) could be calculated for periods between two consecutive harvests, halfway between the harvesting dates.

The results for both cv. ARIS and P.3165-DONA are presented in Figure 4.1.4a-e. For the latter cultivar, only the results of the simple experiment in 1987 are included, because only two intermediate harvests of the crop took place in 1988. There is no significant difference in FR(organ) between cv. ARIS plants with different plant densities (viz. 8.5 and 4.5 pl/m^2; experiment 1) and between irrigation treatments (experiment 3). It follows that all data-points can be used to fit the FR(organ)-DVS curves of Fig. 4.1.4. These curves are eye-fitted and are used as such to feed the crop growth model.

There is no evidence that different FR(organ)-DVS relations apply for the two maize cultivars until DVS=0.4, however, when FR(stem) of cv. ARIS exceeds that of P.3165 (Fig. 4.1.4). This is easily noticeable in the field: ARIS plants have (one, and rarely more) extra tillers (locally called brother stems), growing until some weeks after tasselling. Pioneer plants have only one shoot. P.3165 stems are at least 50 cm taller than ARIS-stems, e.g. 270 cm vs. 220 cm, and have at least 2 leaves more, typically 19 vs. 17 leaves in ARIS. Stem development ceases earlier in PIONEER and is followed by the formation of storage organs.

Specific Leaf Area

Leaf growth is of paramount importance for the interception of irradiance and for photosynthesis; it varies with the quantity of assimilates invested in the production of leaves and the ratio of the leaf area produced per unit of dry-leaf matter. The Specific Leaf Area (SLA in m^2/kg), or its opposite the Specific Leaf Weight (SLW=1/SLA), is a morphological plant characteristic; its value changes as a function of environmental conditions and age of the crop.

Many authors demonstrated that inverse proportionality exists between SLA and light intensity (Butt, 1968; Cooper, 1966; Pears & Lee, 1969; Cooper, 1966; Blackman, 1955; Meyling, 1973). Chatterton (1972) found diurnal fluctuations in experiments with maize and alfalfa; the fact that SLA is also affected by temperature at high levels of light was shown by Blackman (1955) and Meyling (1973): the maize leaves become thicker at lower temperatures but not much longer and this results in a decrease in fresh and dry SLA (Brower *et al.*, 1973). This phenomenon has been attributed to a lower conversion rate of primary photosynthates to structural leaf material, with accumulation of soluble carbohydrates in the leaves. Additionally, the rate of the leaf area expansion may be reduced under low temperatures (Grobbelaar, 1963; Klimendorst & Brower, 1970).

The Figures 4.1.5, 4.1.6 and 4.1.7 show that the overall SLA of maize decreases in the course of the growing period. Sibma (1987) studied the SLA of maize plants at different altitudes and found that both thickening of the existing leaves and formation of thicker new leaves account for this effect. Average SLA values under Greek and Dutch circumstances are plotted for different years in Figure 4.1.5. It appears that the initial SLA values under Greek circumstances are by 10-20 m^2/kg dry matter less than the values found in The Netherlands.

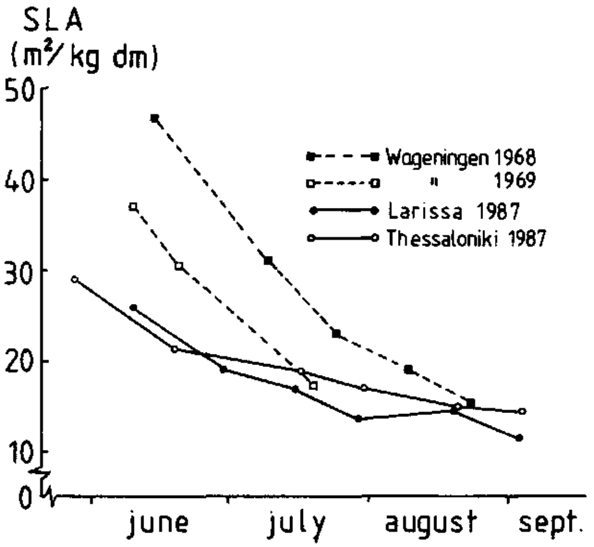


Fig. 4.1.5. Change of the specific leaf area (SLA) of maize with time. [Data for Wageningen from Sibma (1987), adapted].

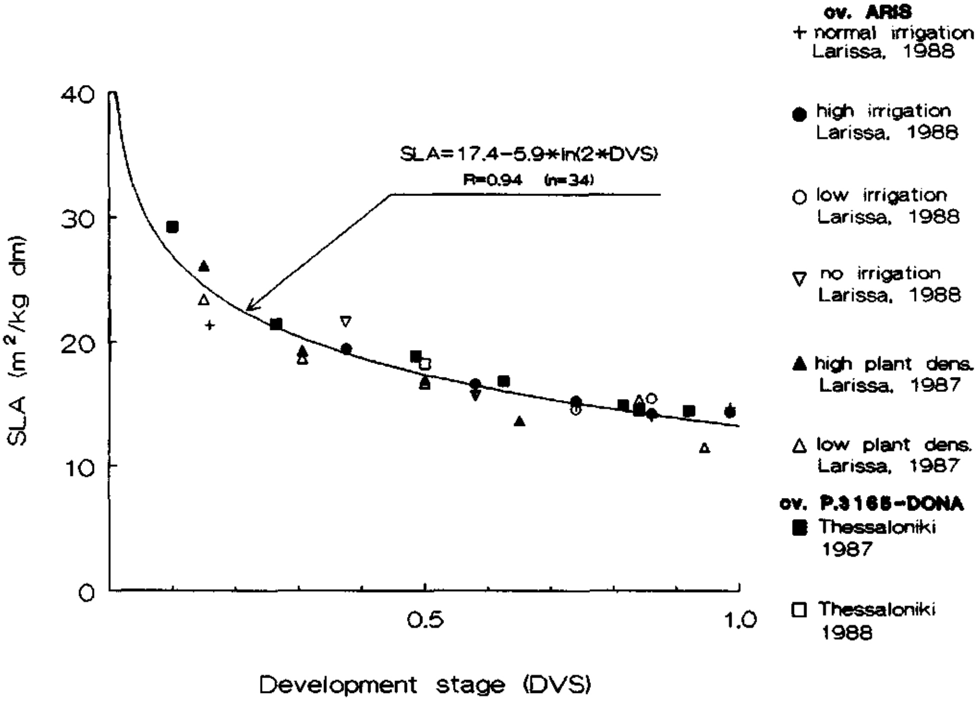


Fig. 4.1.6. The specific leaf area (SLA) of maize at various development stages (DVS) in 1987 and 1988. (For details about the various treatments see text).

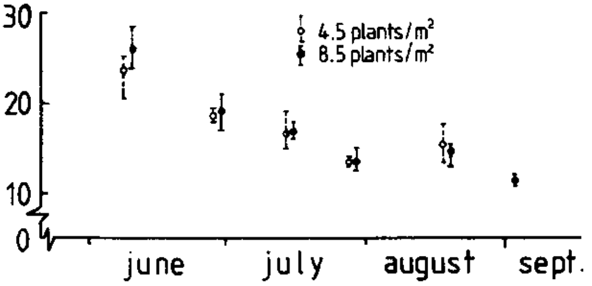


Fig. 4.1.7. The specific leaf area (SLA, in m^2/kg dm) of maize cv. ARIS at different plant densities (4.5 and 8.5 pl/m^2), in Larissa, 1987. (Vertical lines represent existing variation).

This may be associated with higher light intensities in Greece at the beginning of the growing season. No more conclusions can be drawn from Figure 4.1.5 because the SLA values indicated do not all refer to the same development stage. In Figure 4.1.6, the overall (average) SLA of the crop is plotted versus DVS values, calculated for the experiments in Larissa and Thessaloniki. The Figure shows that SLA is highly correlated with DVS independent of the cultivar, soil, location and plant density. SLA can be approximated with the following (empirical) logarithmic relation:

$$SLA = 17.4 - 5.9 * \ln(2*DVS) \quad (m^2/kg) \qquad (4.2)$$
$R=0.94$, $n=34$

Note DVS=0.5 at flowering and DVS=1 at maturity.

The correlation coefficient suggests that estimating DVS-values from the accumulated heat units, separately for the two periods emergence-flowering and flowering-maturity is accurate.

Figure 4.1.7 shows the overall SLA-values of maize cv. ARIS over time, for two plant densities of 4.5 and 8.5 pl/m^2. The same Figure also shows the deviations from the mean values. Sibma (1987) did find interaction between the SLA-DVS relationship and the plant density, but only for extreme plant densities, viz. 40 pl/m^2, with increased mutual shading, especially during late development stages.

Leaf morphology-leaf area index

As mentioned, leaf areas were determined by measuring the areas of a number of leaf blades from each replicate with a planometer. This method is very accurate but time consuming. The good correlation between leaf length/width and the leaf-surface area permitted to estimate the latter from the measured lengths and widths of all leaves in the sample. The leaf area and the dry leaf weight were subsequently used to calculate the Specific Leaf Area. Figure 4.1.8a demonstrates that the leaf surface area (E, in cm^2) can be accurately estimated for cv. ARIS from the product of the length times width of the leaf blades according to a linear relation:

$$E = 0.7795 * (L*W) - 4.168 \quad (R=0.996, n=221) \qquad (4.3)$$

where L and W are respectively the length and the width of the leaf blade (both in cm).

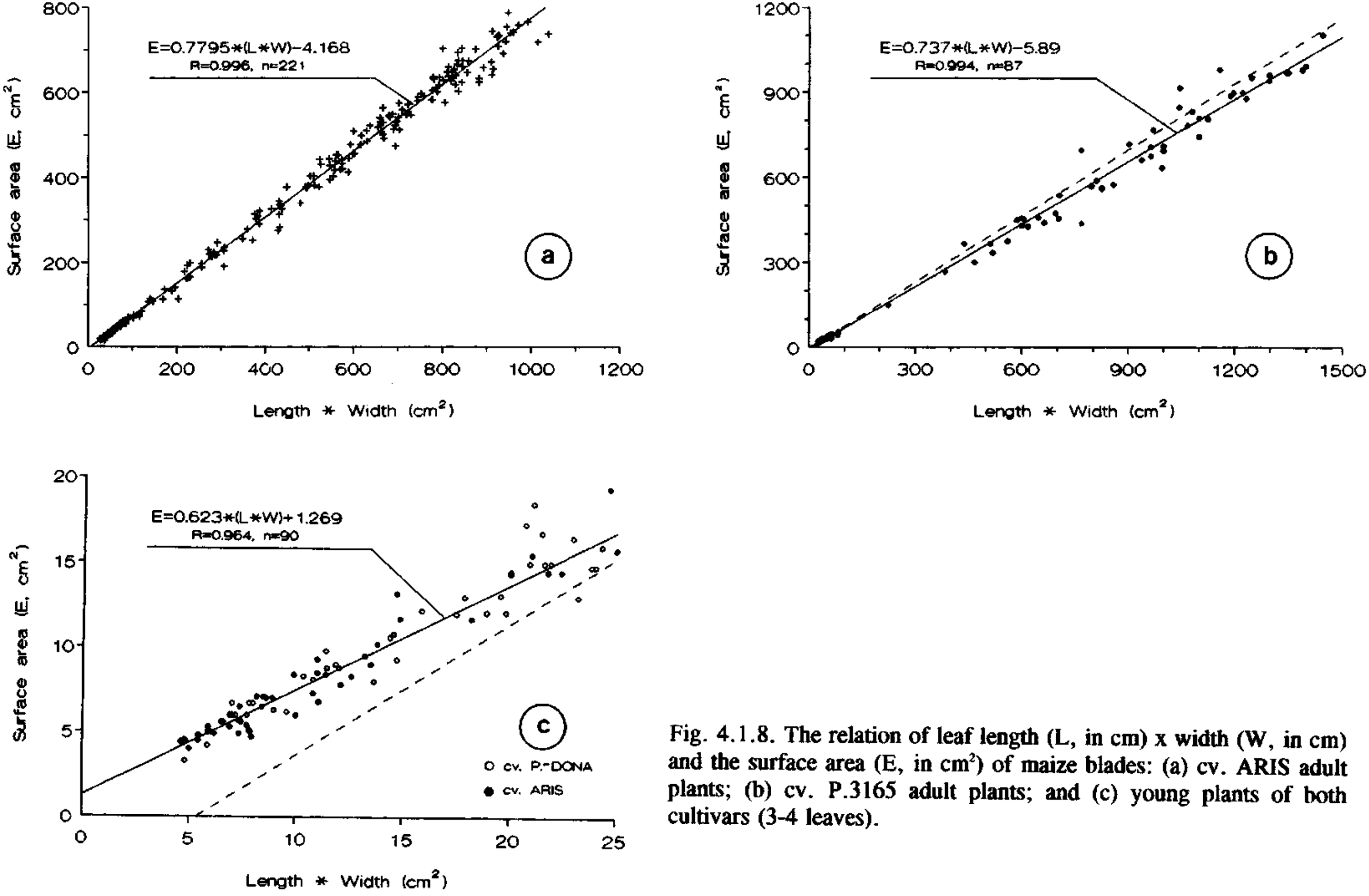


Fig. 4.1.8. The relation of leaf length (L, in cm) x width (W, in cm) and the surface area (E, in cm^2) of maize blades: (a) cv. ARIS adult plants; (b) cv. P.3165 adult plants; and (c) young plants of both cultivars (3-4 leaves).

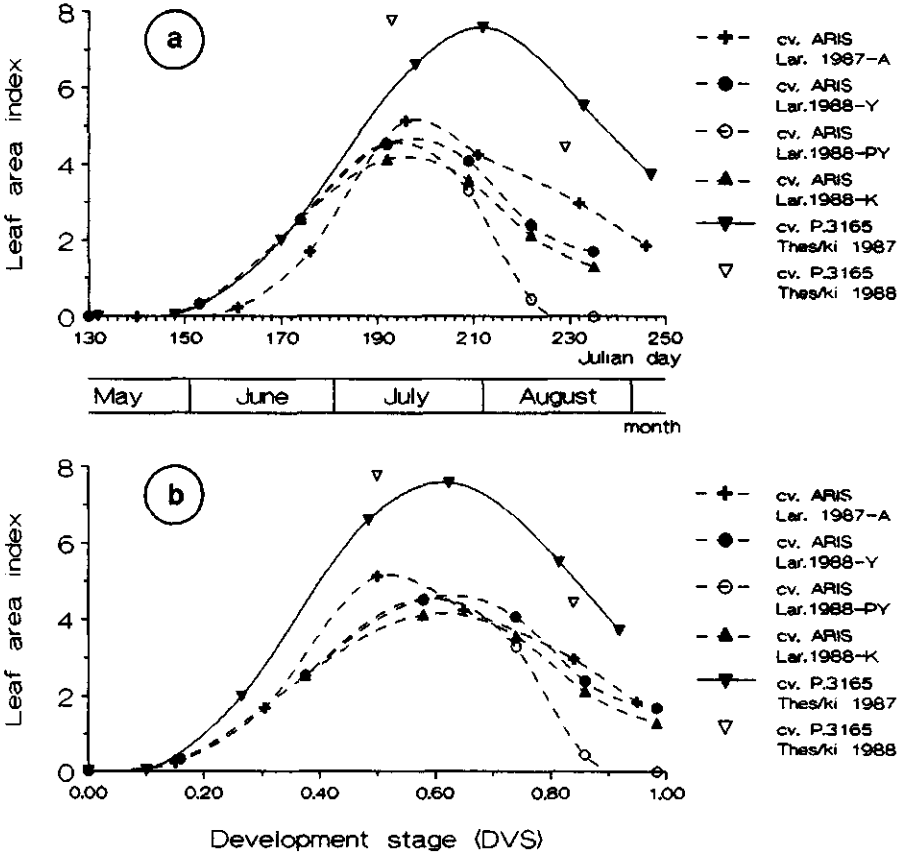


Fig. 4.1.9. The leaf area index as a function of time (a) and development stage (b), in various maize experiments with cv. ARIS and P.3165-DONA. (For details on the treatments see text).

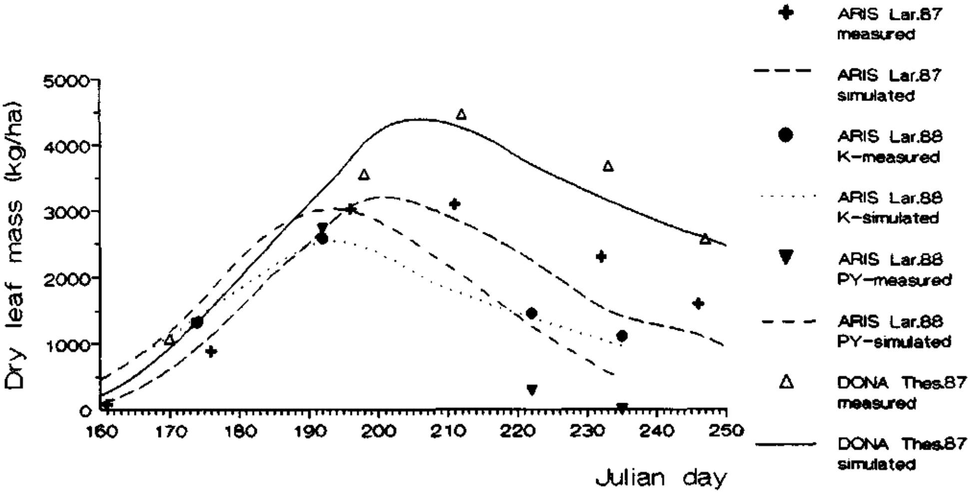


Fig. 4.1.10. The dry leaf mass (kg/ha) of maize over time.

Figure 4.1.8b suggests a slightly different relation to apply for cv. P.3165 plants. Both relations underestimate the surface area of the first 3-4 leaves, which have a more oval shape. This is apparent from Fig. 4.1.8c, where the dashed line represents adult cv. ARIS plants (Fig. 4.1.8a), whereas the solid line is suggested for all maize cultivars with 4 leaves or less.

Figure 4.1.9(a) shows, for ARIS and PIONEER cultivars, how the leaf area index changes with time; Fig. 4.1.9b relates this change to the development stage (DVS). It is clear that the LAI of cv. ARIS ranges from 4.2 to 5.2 at maximum leaf growth and is less than the LAI of the American cultivar which exceeds 7. Note also (Fig. 4.1.9b) that the LAI is maximum at tasselling or somewhat later (DVS=0.5-0.6). Assimilates partitioning to the leaves is zero at DVS>=0.65. Later, LAI decreases drastically due to dying off of senescent leaves, especially under dry conditions. As demonstrated in Fig. 4.1.9, all leaves were dry at the end of August, unless the crop was irrigated after flowering (treatment PY).

There is no strict correlation between the LAI and the dry matter production unless it concerns crops growing under controlled (weather) conditions. Maize cv. P.3165, for example, has a longer growing cycle and normally a higher LAI than cv. ARIS. It actually produced a higher yield in 1987, under optimum moisture conditions, but not in (dry) 1988, even though the crop still had a higher LAI (Fig. 4.1.9). Cv. ARIS grown in Larissa in 1987 (8.5 pl/m^2), had a higher LAI than on the same field in 1988 (7 pl/m^2). Yet, the final yield in 1987 was less than in 1988.

Dying rate of leaves

Figure 4.1.10 shows how the dry leaf weight changes over time in a number of field experiments with cv. ARIS in Larissa and cv. PIONEER 3165-DONA in Thessaloniki.

Be aware that all leaves were counted in the living dry weight in 1987, wrongly including leaf blades which were wholly or partially dry at advanced development stages. This overestimation was avoided in 1988, when yellow leaves were not counted. This resulted in an underestimation in treatment PY (dry after silking), in which the greater part of all leaves were yellow in the beginning of August. Such experimental errors did not occur in Thessaloniki, as all leaf blades of cv. P.3165 were green even at maturity.

In the latest versions of dynamic crop-growth models such as WOFOST and QLE, dying off of leaves is described using a leaf-tissue lifespan value (LLS). The value of LLS is temperature-dependent; a certain number of thermal units must be accumulated above the threshold temperature, before leaf tissue starts to die. In the testing stage of the present approach, a counter was activated which made it possible to decrease the calculated DWIL(leaf) value by the weight of all leaves formed LLS intervals (days) earlier:

IF TACTLLS>=TSUMLLS THEN K=K+1, and (4.4)
DWIL = DWIL(PRESENT)-DWIL(K) (4.5)

where

TACTLLS is the momentary temperature sum of the leaf mass (°C-days),
TSUMLLS is the heat requirement for a full leaf lifespan (°C-days),
DWIL is the dry weight increase of leaves (kg $ha^{-1}d^{-1}$), and
K is the counter for the intervals (days) in which the leaves were formed.

Various TSUMLLS values were tested, but simulated dry-leaf weights were either too high (high TSUMLLS values) or too low (low TSUMLLS values). Field observations in Larissa made clear that some of leaves of cv. ARIS were shed 4-6 weeks after their appearance, whereas other leaves died but did not fall. The values of TSUMLLS suggested in the literature, viz. 870-1000 °C-days, might be too high. It is an implicit error of this approach that the accumulated dry weight of the dead leaves is masked by the growth of new leaves; the net increase in leaf dry matter is measured and used to approximate the partitioning fraction, FRLEAF. An additional problem is caused by the fact that the dying rate of leaves is co-determined by the moisture status. In treatment PY (i.e. dry after silking), an extra loss of 1.5 tons of leaf matter per hectare was recorded within 30 days if compared with the fully irrigated treatment Y. In addition, water stress is associated with a higher canopy temperature. The problem is solved by assuming a steady dying rate (LDR) once the canopy has reached a particular temperature sum (accumulated °C-days above the threshold temperature of 10.5°C). The dying rate changes under water stress (expressed by the correction factor CFW) to the same degree for all maize cultivars. Trial runs suggested that measured and simulated results have the smallest variation if a constant, low dying rate is adopted which applies under optimum moisture conditions and increases exponentially with increasing water stress:

$$\text{IF TACTLLS} >= \text{TSUMLLS THEN DWIL} = \text{DWIL} - \text{LDR} \quad (\text{kg ha}^{-1}\text{d}^{-1}), \text{ and} \qquad (4.6)$$

$$\text{LDR} = 218 * \exp(-2.64 * \text{CFW}) \quad (\text{kg ha}^{-1}\text{d}^{-1}), \qquad (4.7)$$

where

TSUMLLS equals 1000°C-days

An example: Some 20 kg of dry leaf weight are lost per hectare each day if the canopy temperature sum is less than 1000°C-days and CFW is 1 (optimum water supply). If the canopy temperature sum exceeds 1000°C-days, about 170 kg/ha are lost each day if CFW= 0.1 (close to permanent wilting point). In the latter case, all leaves would die within some 20 days. The agreement between measured and simulated dry leaves weight (see Fig. 4.1.10) is considered acceptable for the present; a better agreement may be expected once the green (living) parts of the dying leaves are accounted for as living dry weight.

Growth rates and maintenance cost

The above-ground living dry weight figures realized in the various maize experiments are summarized in Fig. 4.1.11 and compared with curves of 350 and 450 kg ha^{-1}day^{-1}. The obtained growth rates of maize are quite high with the exception of the dry treatment of experiment 3: the plantings of cv. ARIS in 1988 (Larissa) and cv. P.3165 in 1987 (Thessaloniki) exceeded 400 kg ha^{-1}d^{-1}. A growth rate of slightly below 350 kg ha^{-1}day^{-1} was obtained in the experiment with the low plant density (4.5 pl/m^2). The lower growth rate is, in this case, attributed to less effective light interception. Assuming an average growth rate of 400 kg ha^{-1}day^{-1} for the post-anthesis period, and rapid kernel growth during 40 days, a dry-seed weight of 16 t/ha (equivalent to 18.5 t of economic product per hectare) may be attainable. Recall that the potential grain production is in this range under Greek conditions.

Early trials aimed at realizing the calculated (high) growth rates showed the crop-growth model to be very sensitive to the nominal maintenance respiration parameters. As discussed in Section 3.1, genetic values for relative respiration needs, R(organ), apply only at a crop-specific reference temperature Tref. Fig. 4.1.12 presents measured and simulated growth curves of 2 maize crops under near-optimum moisture conditions, viz. cv. ARIS grown in Larissa (1988) and PIONEER 3165 grown in Thessaloniki (1987). This Figure illustrates that

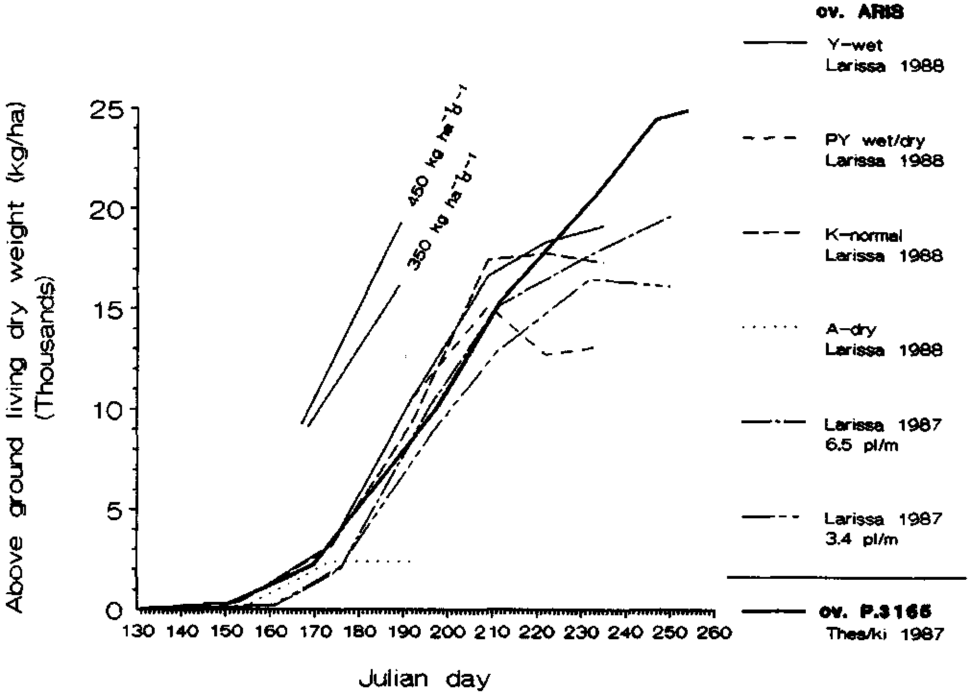


Fig. 4.1.11. Growth rates of maize cv. ARIS and P.3165 recorded in Larissa (1987 and 1988) and Thessaloniki (1987). Theoretical curves for 350 and 450 kg $ha^{-1}d^{-1}$ are added for comparison. The longer growing cycle in 1987 is also observable.

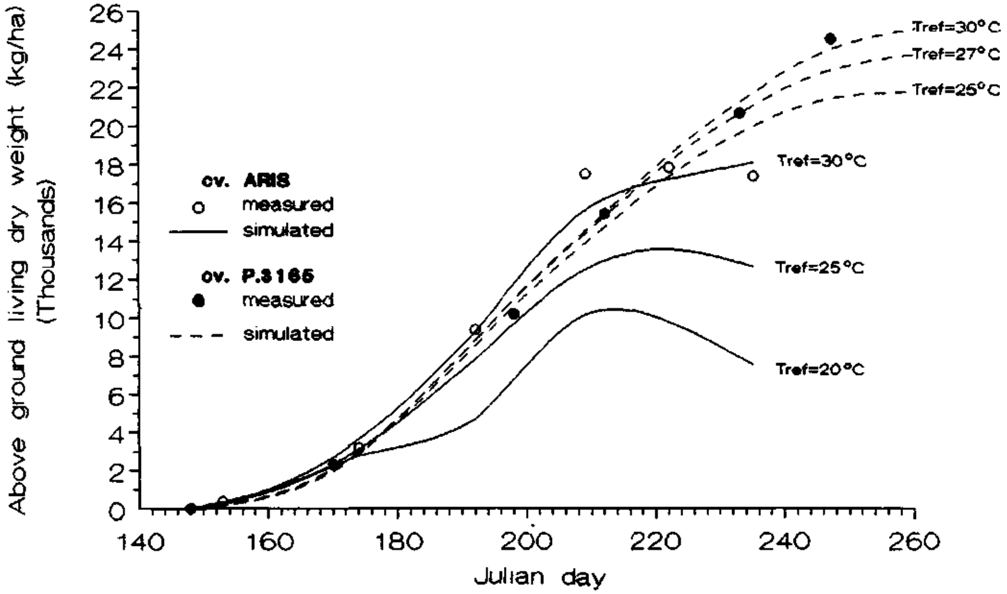


Fig. 4.1.12. Growth rates of maize cv. ARIS in Larissa (1988) and P.3165 in Thessaloniki (1987) and simulated growth rates obtained with different reference temperatures (Tref) for the maintenance respiration. The temperatures of the 2 locations can be seen in Fig. 4.1.2.

the most appropriate value for the reference temperature, Tref, is close to 30°C for both cases. Recently, it has been suggested to calculate Tref as a function of the temperature regime during the preceding 2-week period to account for the adaptation of the crop to the ambient temperature. However, this approach is not endorsed by Figure 4.1.12, especially if one considers that the temperatures in Thessaloniki in 1987 were lower than those in Larissa in 1988 (see Fig. 4.1.2).

The relative respiration rates (at Tref) themselves also had to be adjusted. Values of 0.0208 and 0.0116 kg $kg^{-1}d^{-1}$ are adopted for R(leaf) and R(stem), respectively. Note that the originally suggested R(leaf)-value (R(leaf)=0.03) leads to considerable underestimation of the production potential (see also Driessen & Konijn, 1992). In contrast to this, the value of R(St. org.) had to be increased to 0.0208 kg $kg^{-1}d^{-1}$, possibly necessitated by the relatively high concentration of nitrogenous compounds in the grain.

Translocation of previously stored dry matter

Fig. 4.1.13a-h shows how stem-, leaf- and sheath dry weights decrease at advanced development stages in all maize experiments; dry weight of the storage organs continues to increase even if the overall growth rates are low or even negative. This seems to justify the method for calculating the potential increments in dry organ weight (DWI), discussed in Section 3.1 (Eqn. 3.36). Note that some crop production models quantify DWI as the product of FR(organ) and the overall net assimilation rate. This approach yields a constant stem weight at advanced development stages and in a considerable underestimation of seed production. The higher final storage organ production realized in field experimentation is attributed to translocation of previously stored assimilates to the grain and is offset by adopting positive FR(SO) values before flowering (van Heemst, 1986).

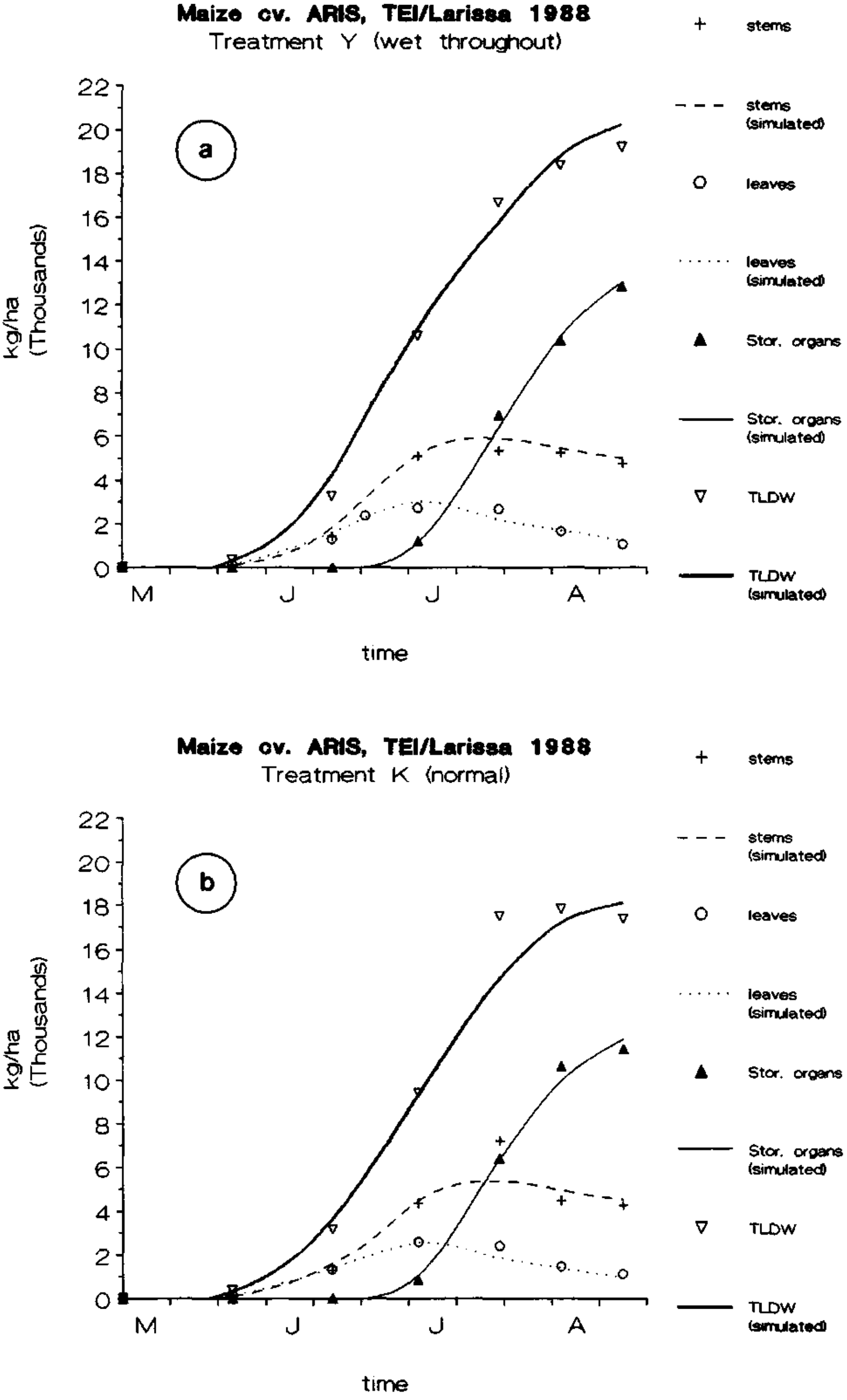
The results reported here do strongly suggest that the loss of stem dry matter coinciding with an increase in the dry grain increment does not imply that assimilates from earlier photosynthesis are translocated from the stem to the grain. Rather, dry matter is lost from the stem by respiration and is not replaced because the newly formed assimilates are preferentially directed to the grains.

Growth dynamics - calibration and validation aspects

The relation between water availability and growth rate was initially studied by manipulating the irrigation treatments, keeping all other factors optimal (experiment 3). Then, the data required for input and calibration of the crop production model were obtained. The Figs. 4.1.13a-h demonstrate that reasonable agreement exists between the observed and calculated (after calibration) growth curves for all experiments, especially with respect to the production of storage organs.

Experiment 3: Effects of the irrigation treatment on the growth and production of cv. ARIS in Larissa (1988).

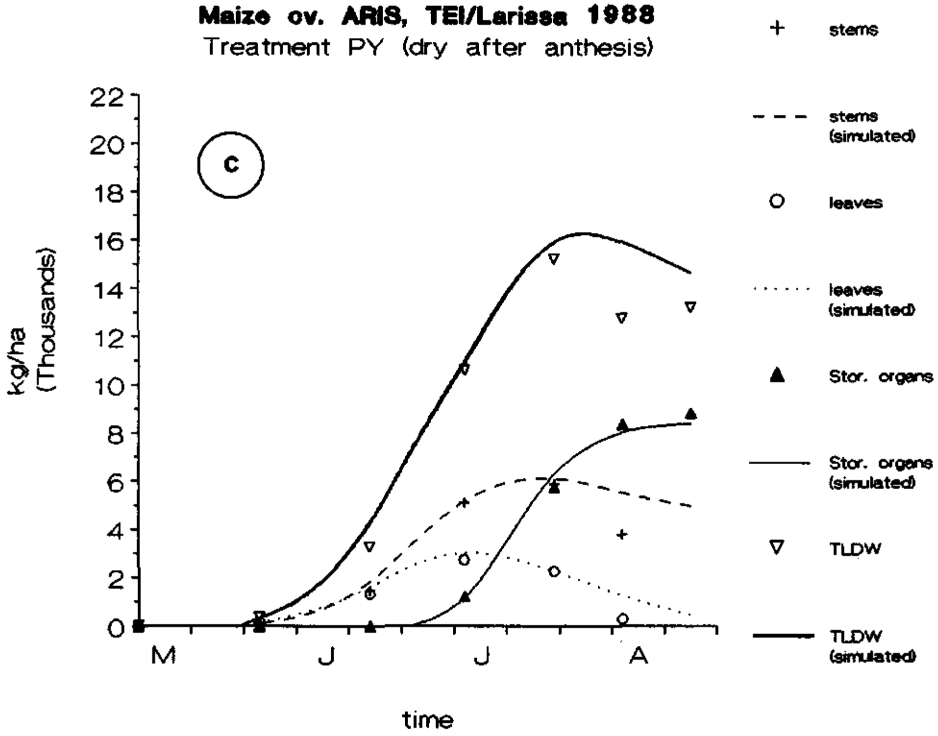
Fig. 4.1.14 presents the effective water depths applied per decade in 4 different irrigation treatments. As mentioned, the crop was harvested 6 times; the measured average values of dry matter are summarized in Table 4.1.3, and schematically presented and compared with simulated ones in Fig. 4.1.13a-d.



Maize cv. ARIS, TEI/Larissa 1988
Treatment Y (wet throughout)

Maize cv. ARIS, TEI/Larissa 1988
Treatment K (normal)

Fig. 4.1.13. (Continued).



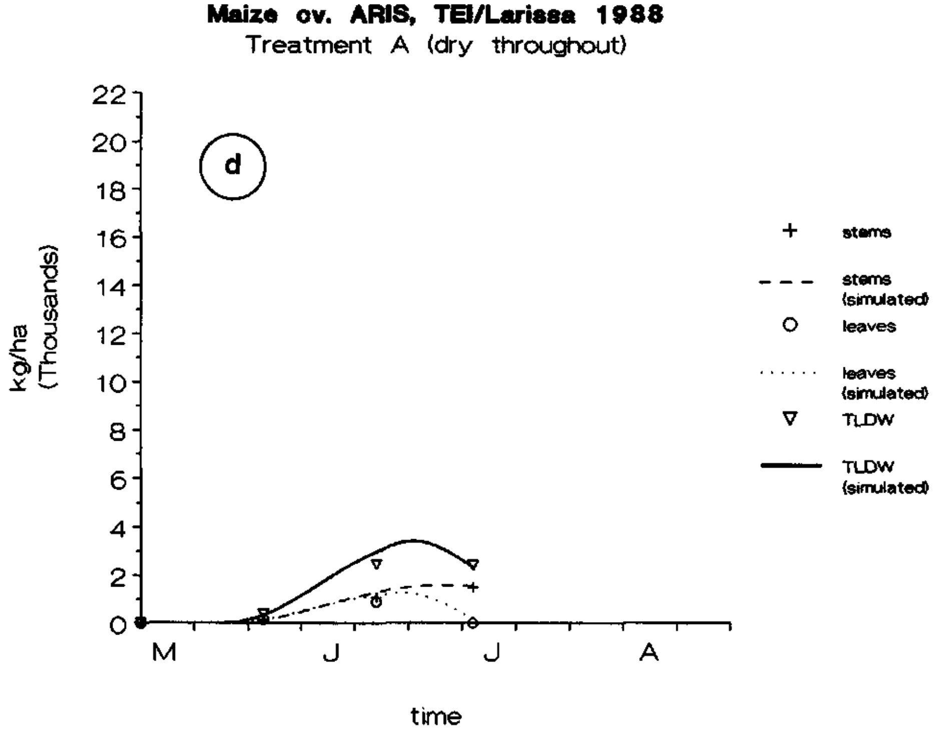
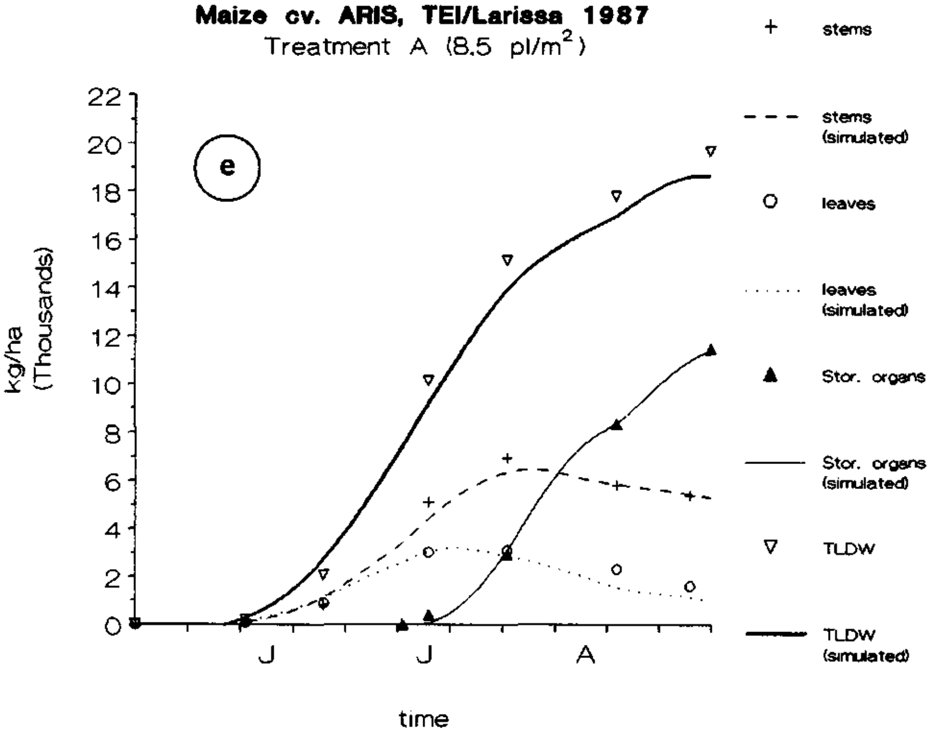


Fig. 4.1.13. (Continued).



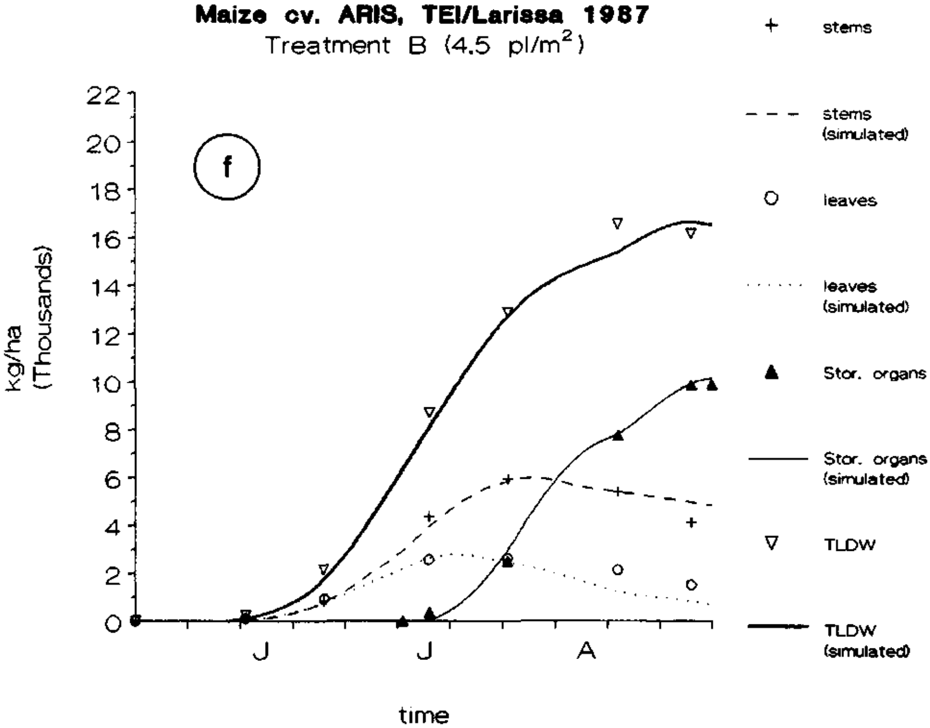


Fig. 4.1.13. (Continued).

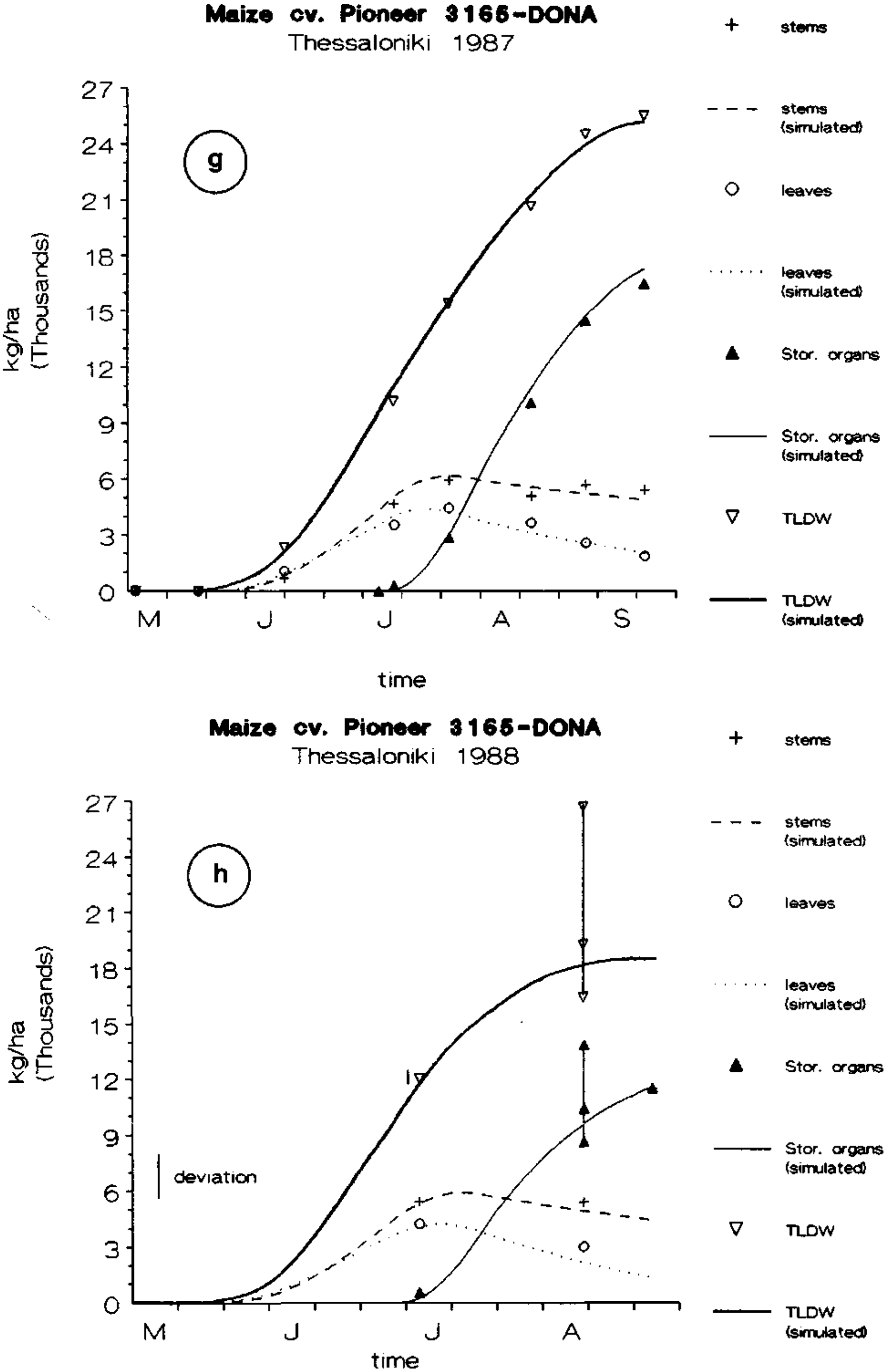


Fig. 4.1.13a-h. Average plant-organ dry weights recorded in subsequent harvests (markers), and calculated growth curves for the same organs (lines), in all maize experiments in Larissa (a-f) and Thessaloniki (g-h), in 1987 and 1988. (TLDW=total, above-ground, living dry weight; vertical lines in -h represent existing variation; for details on treatments see text).

The crop emerged on May 10th (Julian day=130), i.e. 7 days after sowing. A total of 134 mm (effective) water was applied in 3 applications, viz. 10/5(130), 20/5(140) and 10/6(161), to obtain a uniform seedling density and initial development for all treatments. No further irrigation was applied in the dry (A) treatment (see Fig. 4.1.14).
Until the second sampling, the normal treatment (K) received another 50 mm and the wet treatment (Y) another 139 mm of water.

The date of the second sampling, viz. on 23/6 (174), coincides with the start of linear growth (Fig. 4.1.13a-c). This point occurs 40-45 days after emergence in all experiments and corresponds with an approximate total dry biomass of 4 t/ha (including an approximate root dry weight of 700-1000 kg/ha). The growth rates to that point are about 135 kg ha^{-1}d^{-1} (above ground dry matter) in the Y- and K-treatments, but only 98 kg ha^{-1}d^{-1} in the dry treatment A, which produced 1 t/ha less biomass.

The third sampling took place on 11/7(192) and coincided with silking of the crop. Note that tasselling (DVS=0.5) occurred 1 week before silking, viz. on 4/7(185). At silking, about 9.5 t (treatment K) and 10.5 t (treatment Y) of above-ground dry matter were harvested per hectare. The irrigation applications between the two observations totalled 267 mm water for (Y) and 152 mm water for (K). This difference explains the observed higher growth rate of the Y-treatment, viz. 410 vs. 350 kg ha^{-1}d^{-1} for the K-treatment. The dry crop (A), apparently continued growing for some days after the second sampling at a rate of 90 kg ha^{-1}, and finally produced 4 t dm/ha; permanent wilting occurred before silking of the neighbouring plantings. The pronounced drought of treatment A is apparent from the calculated CFW (actual over maximum transpiration ratio; Fig. 4.1.15a).

The crop was sampled for the fourth time on 28/7(209). In this period, virtually no irrigation was applied in treatment PY (same as Y until silking), whereas the K and Y plantings received 300 mm of irrigation water. An increase of the growth rate of (K) to almost 500 kg ha^{-1}d^{-1} and a decrease of the growth rate of (Y) to 363 kg ha^{-1}d^{-1} (confidence 91%) suggest that Y-planting suffered from excess moisture. The calculated CFW ratios shown in Fig. 4.1.15b seem to confirm this; note that the upper soil was near saturation for many hours on days of irrigation. Fig. 4.1.13b suggests some overestimation of the stem dry weight in treatment K; the simulated data point to a value of 5,400 kg of stems per hectare, corresponding with a growth rate of 400 kg ha^{-1}d^{-1}. This is higher than the growth rate of the "wet" treatment. The stem weight of the PY-treatment exceeds that of treatment Y but the storage organ mass is less (see Fig. 4.1.13c and Table 4.1.3). Treatment PY had a relatively high growth rate of 312 kg ha^{-1}d^{-1} over the 17-days period. An even higher growth rate and a high production of stems occurred in the first week after silking (last irrigation with 50 mm). After silking, FR(stem) decreases rapidly in favour of the FR(SO) (see Figs. 4.1.4a&b). Figs. 4.1.15b&c illustrate that the growth rates of the PY-treatment were initially higher than those of the K-scenarios, which indicates that treatment K was affected by excess moisture too, though to a smaller extent than treatment (Y). The increasing drought in (PY) plants in the second week after silking (Fig. 4.1.15c) explains the low growth rates in the period of drastic increase of FR(SO) and the lower production of storage organs than in K- and Y-scenarios. Thus on 28/7, about 3,200 kg of dry grain were harvested for the Y- and K-treatments vs. 2,750 kg/ha for the PY-treatment. Dry husks were about 1,550 kg/ha for Y- and K-scenarios (average 22 g/cob) and about 1,350 kg/ha for the PY-treatments. This weight remained unchanged in the later samples implying that all later assimilates were allo-

Table 4.1.3. Averaged dry weights of the various plant organs (kg/ha) as measured for successive harvests of cv. ARIS grown in Larissa (1988) under various irrigation schedules.

a/a	Date(J.day)	Leaf	Sheath	Stem	S.O.	Seed	Husk	Rest	Total
	Treatment -Y								
1.	2/6/88(153)	156	85	124	0				365
2.	23/6/88(174)	1311	521	1431	0				3263
3.	11/7/88(192)	2725	1559	5101	1229				10614
4.	28/7/88(209)	2673	1704	5346	6967	3241	1604	2122	16690
5.	10/8/88(222)	1654	1110	5232	10393	6671	1600	(2122)	18389
6.	23/8/88(235)	1065	543	4751	12862	11258	1604	--	19221
	Treatment -PY (as -Y until 11/7/88)								
4.	28/7/88(209)	2254	1340	5863	5757	2757	1340	1660	15214
5.	10/8/88(222)	294	322	3780	8365	5485	1220	(1660)	12761
6.	23/8/88(235)	0	0	(3780)	8825	7485	1340	--	12605
	Treatment -K								
1.	2/6/88(153)	156	85	124	0				365
2.	23/6/88(174)	1323	536	1307	0				3166
3.	11/7/88(192)	2586	1608	4363	846				9403
4.	28/7/88(209)	2400	1472	7236!	6413	3171	1507	1735	17521
5.	10/8/88(222)	1466	1229	4492	10652	7408	1509	(1735)	17839
6.	23/8/88(235)	1118	570	4267	11451	9942	1509	--	17406
	Treatment -A								
1.	2/6/88(153)	156	85	124	0				365
2.	23/6/88(174)	895	463	1084	0				3263
3.	11/7/88(192)	1500(dry)	914	1493	0				3907
4.	28/7/88(209)	<------------ the crop was dry ---------------->							

(the values in brackets are estimated; ! marks possible outlier)

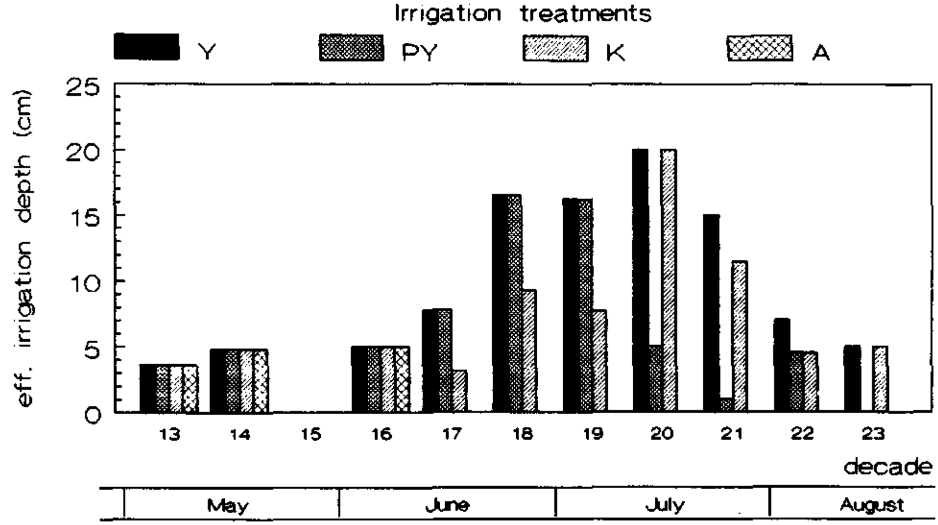


Fig. 4.1.14. Effective irrigation inputs per decade and per treatment during the experiment with maize cv. ARIS in Larissa, 1988.

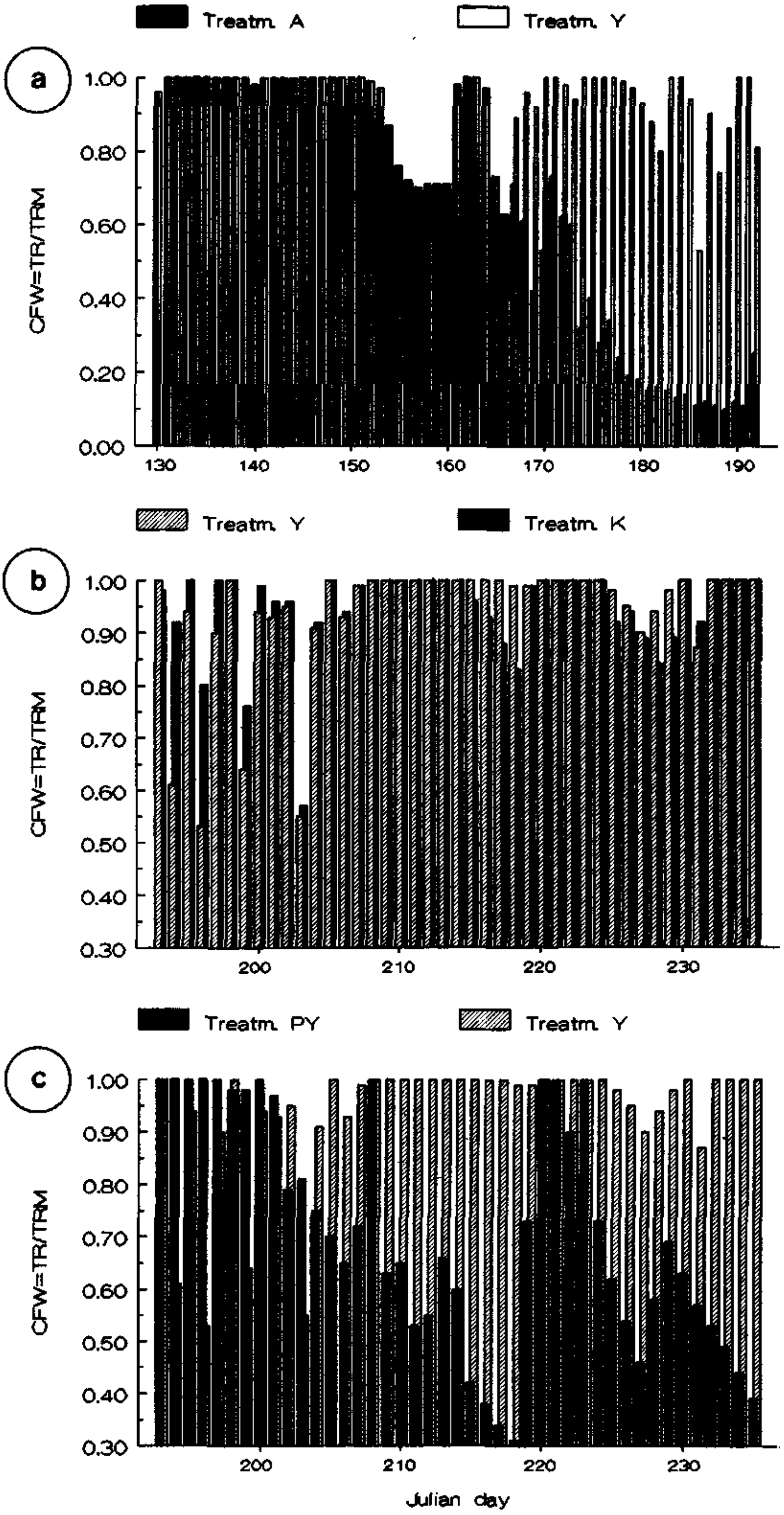


Fig. 4.1.15. CFW (=actual over potential crop transpiration) calculated during the growing period of maize cv. ARIS in Larissa, 1988: (a) emergence-silking period; (b)&(c) silking-maturity period. (Days of: emergence=130, silking=192, maturity=235; for details on treatments see text).

cated to the grain. Stress due to excess moisture is thought to occur between two soil moisture boundary values, viz. SMA and SMB (Section 3.2). These are soil constants, set here at 0.02 cm^3cm^{-3} (SMA) and 0.06 cm^3cm^{-3} (SMB).

During the next 13 days, planting (Y) received 2 irrigations to a total of 70 mm of water (the quantities of irrigation water were reduced with a view to the negative effects of high soil water contents). Each of K- and PY-treatments received 45 mm water, applied 3 days before the fifth sampling, i.e. on 10/8(222). Treatment PY suffered from pronounced drought which induced a negative growth rate (see Fig. 4.1.15c). Nonetheless, the grain weight continued to increase at a rate of 150 kg $ha^{-1}d^{-1}$. This rate is similar to the value calculated (Fig. 4.1.13c). This observation makes translocation of previously stored dry matter in the stems to the grain unlikely. The measured stem weight was less than the simulated value (see Fig. 4.1.13c), which may be due to increased respiration (not further considered here). As said, the dry weight of leaves was somewhat underestimated in the late samplings of PY (see Fig. 4.1.13c), because yellow leaves were excluded from the living dry-leaf weight. Table 4.1.3 and Fig. 4.1.13a-c confirm that the dying rate of leaves depends in part on water stress. The overall growth rate (above-ground d.m.) was about 230 kg $ha^{-1}d^{-1}$ in the rest treatments. The grain weight of K and Y crops increased by 100 kg $ha^{-1}d^{-1}$ more than that of the PY crop, to about 10.5 tons dry grain/ha (both Y and K treatments) versus 8.3 t/ha in treatment PY.

Other than originally planned, a last irrigation of 50 mm was applied to Y- and K-treatments on 18/8(230), as symptoms of water stress in the plants were evident (see also Fig. 4.1.15b). Apparently this application was rather late because 50% maturity was recorded some days later, on 23/8/88(235). The slightly lower water deficit in treatment Y (more water stored from previous irrigations, see Fig. 4.1.15b) but also the greater light interception at a slightly higher LAI in this period, resulted in more grain (confidence at 95% level), and more dry matter produced under this treatment. The dry grain production was 11,258 kg/ha for treatment Y and 9,942 kg/ha for treatment K, and only 7,485 kg/ha for treatment PY (Table 4.1.3). The harvested grain contains some 15 percent water, the economic maximum yield amounts to 13,250 kg/ha in treatment (Y), versus 11,700 kg/ha for treatment (K), still exceeding slightly the average yield of cv. ARIS in Larissa, in 1988.

Experiment 1: Growth of cv. ARIS under near optimal moisture conditions in Larissa.

As mentioned, maximum fertilization was applied in this experiment, and pests and diseases were kept under control. The plant densities were 85,000 pl/ha (treatment A) and 45,000 pl/ha (treatment B). The average plant density of maize in the Larissa area is 70,000 pl/ha. To assure near-optimal conditions of water availability, irrigation was applied at weekly intervals. A total of 13 irrigations was applied with 40 mm of effective water per application. The 12th irrigation was delayed by 5 days, on 20/8 instead of 15/8, because of a damaged deep-water pump.

Table 4.1.4 summarizes the average dry matter production of the various plant organs as recorded for 6 samplings in the growing period. The results of this experiment are divided in two categories: results required to feed the model and those needed for validation. The first category includes the specific leaf area (SLA), the assimilate partitioning fractions (FRorgan), the heat requirements between emergence and anthesis and from anthesis to maturity, which have already been discussed. The growth rates obtained in this experiment do not differ much from the values expected; the data served for model validation.

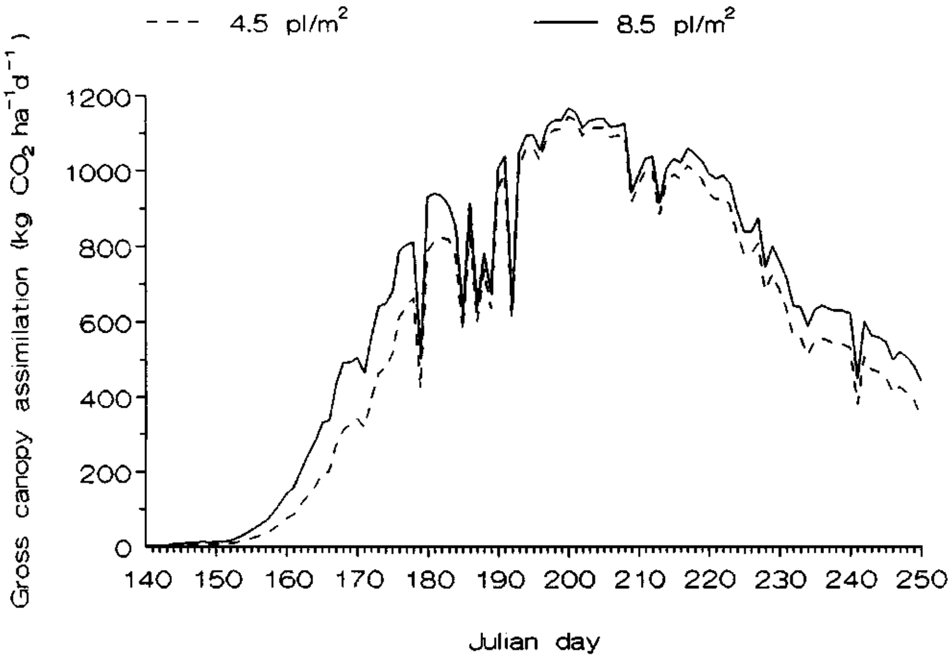


Fig. 4.1.16. Calculated gross canopy assimilation rate during the growing period of maize cv. ARIS in Larissa, 1987, for two plant densities.

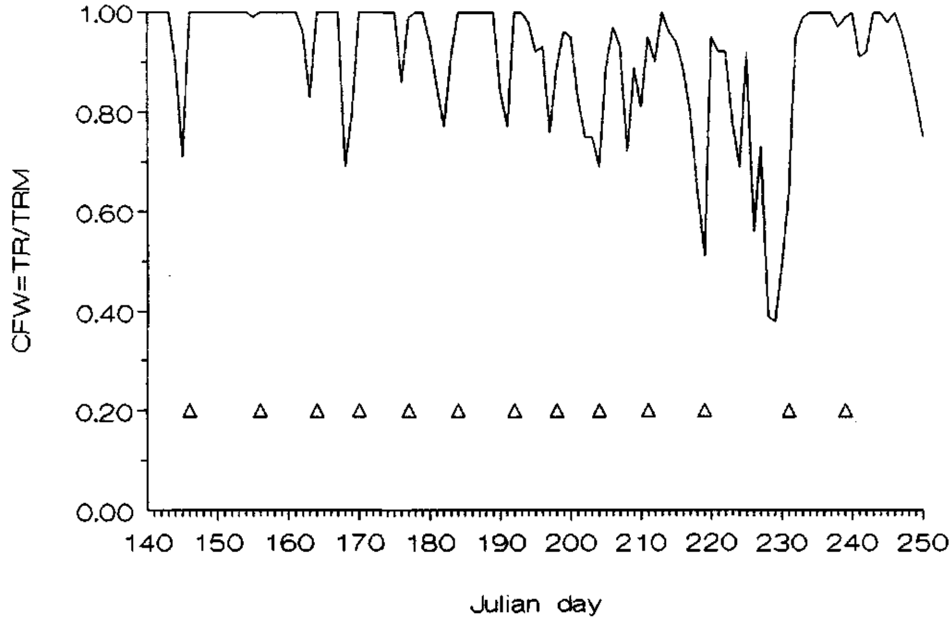


Fig. 4.1.17. CFW (=actual over maximum crop transpiration rate) calculated for maize cv. ARIS in Larissa, 1987 (treatment A). The triangles indicate individual irrigations (40 mm per application).

Fig. 4.1.13e shows the agreement between the actual and predicted dry matter productions under treatment A; note the excellent fit of the storage-organ values. For the calculations, the initial dry weight was set at 10 kg/ha. This value, used for the production calculations of experiment 3, is about half the actual seed weight, to account for maintenance losses in the sowing-emergence period. Fig. 4.1.13f demonstrates that the dry matter production measured in treatment B can be accurately predicted with the initial dry weight set at 5 kg/ha. The lower leaf dry weights simulated at advanced development stages (see Fig. 4.1.13e-f) refer to the living dry weight whereas measured values represent the total dry weight.

Table 4.1.4. Averaged dry weights of the various plant organs (kg/ha) as measured for successive harvests of cv. ARIS grown in Larissa (1987) under 2 different plant densities.

a/a	Date(J.day)	Leaf	Sheath	Stem	S.O.	Seed	Husk	Rest	Total
	Treatment A (8.5 pl/m^2)								
1.	10/6/87(161)	86	43	74	0				203
2.	25/6/87(176)	889	370	806	0				2065
3.	15/7/87(196)	3029	1621	5109	398				10157
4.	30/7/87(211)	3107	2122	6971	2955				15155
5.	20/8/87(232)	2314	1335	5803	8348				17800
6.	3/9/87(246)	1612	1238	5368	11464	9930	1553	--	19682
harvest	18/9/87				11466	9922	1544	--	
	Treatment B (4.5 pl/m^2)								
1.	10/6/87(161)	105	53	90	0				248
2.	25/6/87(176)	937	390	842	0				2169
3.	15/7/87(196)	2583	1383	4357	374				8697
4.	30/7/87(211)	2645	1806	5935	2516				12901
5.	20/8/87(232)	2155	1243	5403	7777				16578
6.	3/9/87(246)	1521	663	4109	9884	8395	1488	--	16177
harvest	18/9/87				9875	8390	1485	--	

If one compares the growth curves of Fig. 4.1.13-e and -f, it becomes apparent that the higher growth rates occurred in the initial and late development stages in treatment A (high plant density), whereas the growth rates were about the same in both treatments in the mid-season stage. Differences in the light interception are deemed responsible. Fig. 4.1.16 presents the gross canopy assimilation rates calculated for the 2 treatments, plotted versus time. Despite different LAI values in mid-season, the canopy is closed, and the assimilation rate is about the same in both treatments. The canopy is open in the initial and late stages, and differences in the leaf area cause differences in assimilation rate. The simulated data suggest slight differences in evapotranspiration but their effect is negligible, because the ratio of actual over maximum transpiration rate (CFW) remains almost the same for both plantings.

CFW is plotted versus time in Fig. 4.1.17. The days when irrigation was applied are indicated. Moisture availability appears to have been near-optimum except for the period between the 11th and 12th application, when a considerable water-deficit occurred. The resulting sharp decrease in the growth rates of both plantings is evident (Figs. 4.1.13e&f).

Such delays of irrigation are very common in practice and cause considerably lower than potential productions. It is believed that farmers in the Larissa area apply less than optimal doses of irrigation for two reasons (other than the shortage of water), i.e.:

(1) underestimation of the potential evapotranspiration rates, and

(2) the occurrence of surface ponding, long before the required irrigation water has infiltrated. This is especially the case when large sprinklers (high application rates) are used.

According to the irrigation schedule, net doses of 40 mm water were applied per week, or about 6 mm/day; this is broadly considered as the evaporative demand of maize grown in the study area. Fig. 4.1.17 confirms that CFW < 1 for most of the growing period. It is therefore believed that the potential evapotranspiration rates calculated for the area are slightly too low. The higher values calculated if the Penman formula is applied with daytime, rather than 24-hours weather data, are more appropriate to explain the different growth rates obtained in the field experiments. Fig. 4.1.18 shows the potential evapotranspiration rates calculated using 24-hours weather data as well as the rates of potential evapotranspiration and maximum transpiration based on daytime data. This particular example considers the 10-days period after anthesis in treatment A (dense planting). The maximum transpiration rates used here are similar to the average potential evapotranspiration rates. This may be a coincidence but might also indicate an underestimation of the evaporation component in calculations of the average potential evapotranspiration rate. The subject needs further investigation.

It has been mentioned that water stress occurred during the experiment of 1987. However, the irrigation depth per application could not be increased without initiating ponding and runoff. With a constant rainfall intensity of 20 mm/hour, runoff started some 2 hours after irrigation commenced. Experience in the area teaches that this is very often the reason of low yields on fertile soils that are irrigated with gun sprinklers. This prompted the author to do a more detailed study on the infiltration capacity of the soils in the area, with special attention to the time to ponding. The subject was treated in Sections 3.2 and 3.3.

Table 4.1.5. Yield (dry matter) figures of the maize cv. ARIS experiments in Larissa in 1987 and 1988.

Year	Treatm.	Stor. organs kg/ha	Stor. organs g/cob	Grain kg/ha	Grain g/cob	Husks kg/ha	Husks g/cob	seed/cob
1987	A	11466	135.8	9922	117.6	1544	18.3	0.865
1987	B	9875	290.4	8390	246.8	1485	43.6	0.850
1988	K	11451	166.6	9942	144.6	1509	21.9	0.868
1988	Y	12862	187.1	11258	163.8	1604	23.3	0.876
1988	PY	8825	128.4	7485	108.9	1340	19.5	0.848

Table 4.1.4 shows that the final dry seed production of treatment A amounted to 9,922 kg/ha, about 1.5 t/ha more than under treatment B. The production of treatment A is close to the production of the normal treatment (K) in experiment 1 (Table 4.1.5). Note that the final weight of the husks is about the same in both cases, viz. 1,509-1,544 kg/ha, and not much different than in treatment B, viz. 1,485 kg/ha. With plant density in the range 7-8.5 pl/m^2), the average (dry) husk weight per plant is 19-22 g vs. 44 g in the case of the low

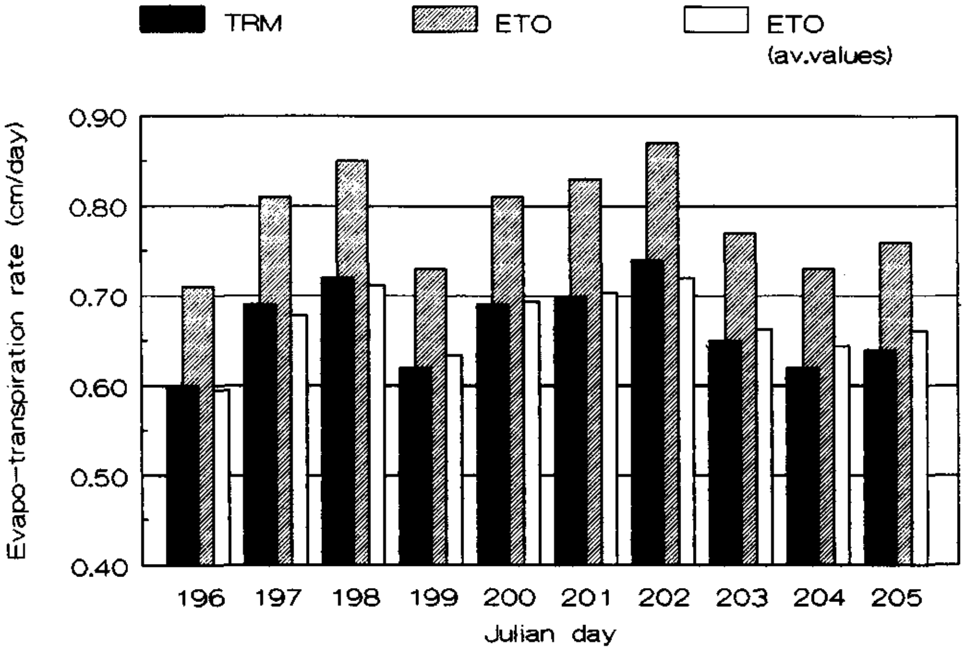


Fig. 4.1.18. Potential evapotranspiration (ETO) and maximum transpiration (TRM) rates calculated with day-time weather data, and potential evapotranspiration rate (ETO) calculated with 24-hours average values, during the first decade after tasselling of maize cv. ARIS in Larissa, 1987.

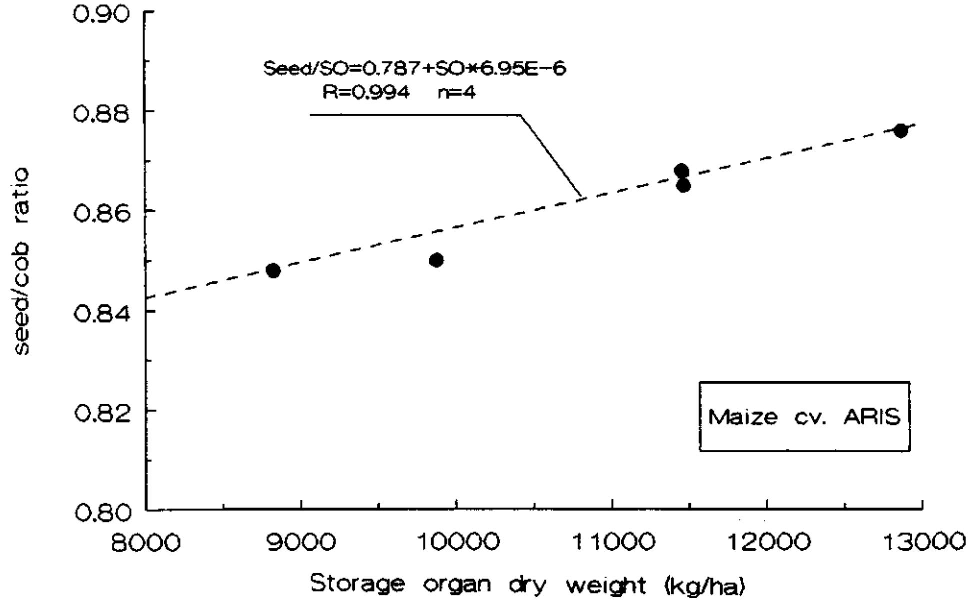


Fig. 4.1.19. The seed/cob ratio as a function of the dry storage organ (seed+husk) weight of maize cv. ARIS. The outlier is of the treatment with the low plant density.

plant density (4.5 pl/m^2). This means that the plant density (within the studied range) did not affect the "sink" potential much; the higher production of treatment A is a result of higher light interception in the canopy (higher values of LAI) and consequently a higher "source". The effect of these potentials will be discussed into more detail in Section 4.3 (wheat experiments).

The production calculations quantify the dry matter production and the production of dry storage organs. As the value of the (dry) seed/cob ratio is about the same as the ratio of dry over harvested grain weight (with 13-15% moisture in the grain), the final output of calculations is roughly the same as the economic yield. Fig. 4.1.19 suggests an accurate estimation of the economic yield:

$$Y = [SO * (0.787 + SO * 6.95\text{x}10^{-6})] / 0.85 \qquad (4.8)$$

where

Y	is the economic yield (kg/ha),
SO	is the dry weight of the storage organs (kg/ha), and
0.85	is the coefficient of the moisture content (here 15%)

Experiments 2 and 4: The growth of maize cv. PIONEER 3165-DONA in Thessaloniki, under near optimal conditions in 1987 (experiment 2) and under water-limited conditions in 1988 (experiment 4).

The experiments were particularly useful for validation of the model and for establishing the values of hybrid-specific data such as SLA, FR(organ), TSUM, etc. Optimum fertilization was applied in both experiments; the large variation in growth rates which occurred in the two years is attributed to differences in water availability.

Table 4.1.6 summarizes the (average) dry matter weights of the various plant organs sampled in the growing period. The growth curves (recorded and calculated above-ground dry matter) are presented in Figures 4.1.13g&h.

In 1987, the ground-water level fluctuated between 130 cm depth (at emergence) and 155 cm. The presence of this shallow water table explains the high yields claimed by the farmer. The near-optimum moisture supply permits high growth rates during a prolonged period (long-duration cultivar), and a high biomass production and yield (Figs. 4.1.11 and 4.1.13g). A grain production of 16 t/ha is very exceptional in Larissa, even for a skilled farmer, but such yields were normal for this particular farmer in Thessaloniki. Fig. 4.1.13g shows that the growth rate and dry matter production could be reasonably described, despite an overestimation of the final storage organ weight. This demonstrates once more the predictive value of dynamic crop-growth models in comparison with statistical or parametric approaches. Fig. 4.1.20 shows the fluctuations of the ground-water level. The low values observed occur after each of the six irrigation applications. Under Larissa conditions, 6 irrigations would have been too few, especially due to the low water-holding capacity of the loamy sand. The farmer, however, knew that more irrigation water would bring about negative effects. In hindsight, this is understandable; excess irrigation raises the ground-water table in the rootzone. The analyses of the 1987 planting confirm that a too shallow ground-water table builds up upon excessive irrigation.

Table 4.1.6. Average dry organ weight (kg/ha) in successive harvests of cv. PIONEER 3165-DONA in Thessaloniki in 1987 and 1988.

Experiment 2 (1987)

a/a	Date(J.day)	Leaf	Sheath	Stem	S.O.	Seed	Husk	Rest	Total
1.	28/5/87(148)	18	6	5	0				29
2.	19/6/87(170)	1080	342	713	0				2315
3.	17/7/87(198)	3570	1632	4692	306				10200
4.	31/7/87(212)	4479	2101	5962	2903				15445
5.	21/8/87(233)	3700	1739	5116	10150	6966	1678	1476	20705
6.	4/9/87(247)	2582	1748	5706	14506	10996	1915	1595	24542
7.	21/9/87(272)	1865	1721	5432	16541	13436	1786	1291	25541

Experiment 4 (1988)

a/a	Date(J.day)	Leaf	Sheath	Stem	S.O.	Seed	Husk+Rest	Total
1.	12/7/88(193)	4279	1762	5468	560			12070
2.	17/8/88(229)	3063	1369	5418	10991!	9202	1789	20841!
production harvest	6/9/88(249)				11538	9749	(1789)	

(the value in brackets is estimated; ! marks possible outlier)

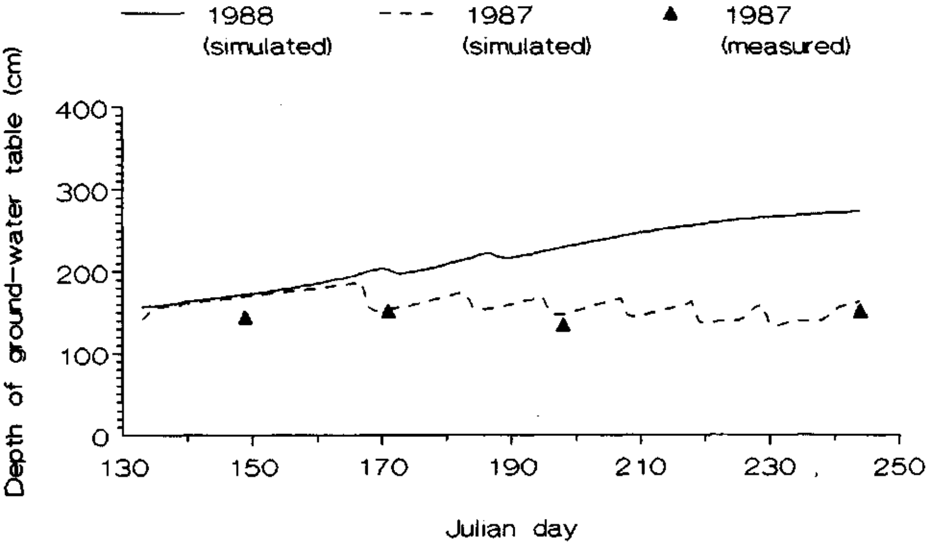


Fig. 4.1.20. The ground-water depths in Thessaloniki, in 1987 and 1988.

The summer of 1988 was warmer than that of 1987 (Fig. 4.1.2) and particularly dry for the Thessaloniki area. The ground-water table, still present in spring, sank below the control section later in the summer. Only two irrigations were possible due to a general lack of water in the area; these applications were scheduled for the most critical period (paragraph 4.1.1). Crop failure being expected, the 1988 experiment received little attention. Table 4.1.6 shows, however, that a dry grain production of 9,749 kg/ha (11.2 t economic yield/ha) was attained nonetheless. Simulation suggests that capillary rice provided (a considerable part of) the needed moisture to the deeper-growing roots, in spite of the deep ground-water table (see Fig. 4.1.20). The yield produced is similar to the yields of cv. ARIS obtained with full irrigation in Larissa in 1987 and 1988 (normal treatment). Despite the large variation in the second sampling of this experiment (CV=27% on above-ground dry weight; Fig. 4.1.13h), the simulated results are thought to describe the experiment satisfactorily.

The limited data do not permit to establish the seed/cob ratio accurately, as for cv. ARIS. The seed/cob ratio appears to be between 0.812 and 0.845. It is stressed, however, that the crop-performance in 1988 is an unusual one. P.3165 is a long-cycle cultivar with very high water needs and is mostly used in areas with shallow ground-water tables, such as the plains of Axios, Agrinion, etc.

4.2 Cotton experiments

4.2.1 Materials and methods

Experiment 5. The growth of the *Gossypium hirsutum* cv. Zeta-2 on the Larissa clay soil was studied at the Experimental farm of the Higher Agricultural School (T.E.I.) in 1987. Zeta-2 is of American origin (Acala), highly tolerant to *Verticillium* and extensively used in the Larissa plain. A 0.24 ha field, adjacent to the maize experiment, was prepared and fertilized with 750 kg Ammonium Phosphate (20-10-0) and 360 kg diluted Superphosphate (0-20-0) per hectare. A top dressing of 220 kg of Ammonium Nitrate (33.5-0-0) three weeks after emergence brought the total nutrient input at 224 kg N and 147 kg P per hectare. Two control plots of totally 750 m^2 remained unfertilized. The crop was sown on May 7th, 1987 with 95 cm between rows and intervals of 24 and 14 seeds/m. The resulting plant densities were approx. 120,000 and 60,000 pl/ha, respectively. Note that the recommended plant density for this cultivar is 10-12 pl/m^2 (Greek Cotton Organization). A random design was applied with three replicates and plot sizes of 36 m^2. Using an automatic travelling gun, the crop was irrigated 11 times. The effective irrigation depth was 4 cm/irrigation, applied on the following dates: 12/5, 26/5, 5/6, 19/6, 26/6, 3/7, 17/7, 24/7, 31/7, 8/8, 20/8 and 28/8/1987. The crop was partially defoliated at the end of August and before harvest. This is normal practice in the Larissa and Thessaloniki plains, and various chemicals for it are on the market. The dates of emergence, bud initiation and flowering, and the ripening index (ratio of ripe/total bolls) were recorded. The crop was harvested 7 times during the growing period, on the following dates: 12/6, 24/6, 16/7, 29/7, 19/8, 5/9 and 19/9/1987. The (seed) cotton was harvested on 10/10 and on 19/11/1987. Initially, 2 strips of 2 meters were harvested per replicate and per treatment, but the sampling size was reduced in later harvests. The plant material was divided in leaf blades, petioles, stems and storage organs, the latter including buds, flowers and bolls. The leaf area of a number of leaves was accurately measured by planometer and correlated with the linear dimensions of the cotton leaves. Based on this, the total leaf area of the crop was estimated from the measured dimensions of all leaves in the sample. The specific leaf area was determined on leaf-subsamples of known surface area. The dry weights of the plant parts were determined by drying every fraction at 90°C until constant weight. Weather data such as the daily temperature (max, min), air humidity, wind velocity, precipitation and sunshine duration, were recorded at the Larissa Airport (National Meteorological Service, E.M.Y.). At the end of the experiment, all plant samples (including the control) were analyzed for total N and P (Dept. of Soil Science and Plant Nutrition, WAU).

Experiment 6. The growth of the same cultivar (Zeta-2) under 3 different irrigation schemes was studied at the same site in 1988. The crop was sown on May 3rd in rows 95 cm apart with 26 seeds/m^2, resulting in an average plant density of 130,000 pl/ha upon establishment. A total fertilizer input of 215 kg N and 50 kg P per hectare (500 kg Ammonium Phosphate plus 340 kg Ammonium Nitrate per hectare) prevented nutrient stress. The same plots were left unfertilized as in 1987. Irrigation was applied by means of an automatic drip irrigation system as described for Experiment 3. The randomized block design used 3 treatments with 3 replicates:

- *treatment A*: "dry treatment"; 84 mm of irrigation water were applied before establishment (common in all treatments) and another 55 mm were applied on August 7th.

- *treatment K*: "normal treatment" (dry conditions until flowering and no water stress after flowering): The crop received 84 mm of irrigation water before establishment and a total of 60 mm applied on the dates June 17th and June 28th, 1988. After flowering, the crop was irrigated every 7-10 days and, until the beginning of September; it received a total of 500 mm irrigation water.

- *treatment Y*: "wet treatment" (frequent irrigation inputs to ensure constraint-free conditions): A total of 130 cm irrigation water was applied between sowing and the beginning of September, equally divided over the pre- and post-anthesis periods. Such wet conditions are unrealistic, not only in the study area but in all of Greece. TEI-agronomists expected low yields or even total failure of this treatment, which proved very important for the present study. (For the exact irrigation dates and water amounts per treatment, see Appendix C).

The growth of the crop was recorded 8 times, viz. on 3/6, 24/6, 6/7, 27/7, 11/8, 24/8, 6/9 and 21/9/1988. The crop was harvested on 14/10 and 7/11/88. The sampled dry matter was sorted into the various plant organs and the leaf area measurements were done as in the previous experiments. The dry storage organ mass was further split into bud+flowers and bolls with the latter consisting of seed cotton and husks. The seed cotton was weighed after oven-drying (to force the bolls to open). The so obtained total seed cotton should be distinguished from the "economical yield", which is only a part of it (the ripe bolls). The soil moisture content was controlled (gravimetric method), and weather data (daily max. and min. air temperatures, sunshine duration, precipitation, air humidity and wind speed) were collected from the National Meteorological Service. Plant samples (including the controls) were analyzed in Wageningen for total Nitrogen and Phosphorus at the end of the experiment.

Experiment 7. The growth of the Greek variety Sindos 80 on Vrachia soil was monitored at the Gigikostas farm over the period April-October 1987. This variety has a shorter growing cycle than Zeta-2. The accumulated heat units required until anthesis and from anthesis to maturity cannot be established from this one experiment. In view of the many uncertainties with regard to the crop specifications, the results of this 7th experiment will not be discussed in this document.

4.2.2 Results and discussion

Development of the crop

Sowing-emergence period:

It is common knowledge that cotton must be sown after the air temperature exceeds 14-15 °C, and that the higher the temperature the shorter the time of germination is under favourable soil moisture conditions (Cardwell, 1984; Doorenbos *et al.*, 1979; Marani & Amirav, 1970; Wanjura *et al.*, 1967; etc.). Low temperatures did not permit early sowing in 1987; eventually the crop was sown on May 7th despite the low air temperature of 12.5°C. The temperature rose to more than 15°C 5 days later, and 50% emergence was recorded on May 20th, when the accumulated heat units above the threshold temperature of 15°C reached 27°C-days. The sowing-to-emergence period was only 6 days in 1988, when sowing took place on May 4th and coincided with a sharp rise of the air temperature from 13.2°C to 21.9°C on May 10th. The maximum temperature reached 35°C. The accumulated heat units at emergence (May 10th, 1988) were 28°C-days. It is therefore assumed that 27-28°C-days is enough for cotton to germinate under optimum moisture conditions; the threshold temperature is set at 15°C. Optimum soil moisture conditions as in both these plantings might not always exist: prolonged wetness before (too) early sowing (viz. early in April) and slow germination (viz. 20-25 days) may lead to partial or total loss of the seed material (Galanopoulou, 1977). On the other hand, the high temperatures during sowing-germination may delay this period due to the drying out of the top-soil. In spite of the observed need of 28°C-days for germination, it is believed that the emergence period cannot be accurately predicted on the basis of temperature data only (under Greek circumstances). However, it is generally true that germination occurs 7 to 10 days after sowing under favourable temperature and moisture conditions.

Emergence-Flowering period:

As cotton is a continuously flowering crop, literature reports on flowering are quite diverse. The time of bud initiation, the appearance of first flowers and 50% flowering are among the commonest indicators used. The criteria of 1 flower/m^2 and 50% flowering are commonly used in Greece (Cotton and Industrial Plants Institute). In the present study, however, the day when the first flowers appear in most plants will be considered the "flowering time". This corresponds to about 10 flowers/m^2. At an average flowering rate of 0.3 flower/day per plant, this date is not more than 1 week later than flower initiation.

In 1987, flowering time was 63 days after germination, i.e. on July 22, for all treatments. The first flowers had appeared one week earlier, and the first buds 3 weeks earlier (June 27th). In 1988, flowering of the normal (K) treatment occurred 61 days after germination, i.e. on July 10th. Flowering was recorded 2 days earlier and two days later than the above date in the dry (A) and wet (Y) treatments. Note that the LAI was 1 for the dry, 1.5 for the normal and 2.5 for the wet treatments at flowering time. The accumulated heat units above the threshold temperature of 15°C (Mauney, 1966) amounted to 530°C-days at flowering for both plantings in 1987 and for the normal planting (K) in 1988. The comparatively small effect of other than temperature factors on the flowering time permits to use the value of TSUMpre = 530°C-days to predict the flowering date of Zeta-2 cotton. If compared with other Greek cotton varieties, Zeta-2 is a normal to late flowering variety, similar to cv. Acala as described by Galanopoulou (1984). The flowering time in 1988 could be predicted by using the approximated canopy temperature as described in Section 3.2. The value of TSUMpre had to be set to 840°C-days in this case, to account for the effect of warming up of the soil at low LAIs.

From flowering to maturity:

Cotton plants continue flowering as long as the temperature and the soil moisture status permit. Thus some weeks after flower initiation, one might find on the stand buds, flowers, and bolls in various stages of ripening. Therefore, it is difficult to establish the physiological end of the growth cycle, when, according to our setup, the plant is mature and DVS=1.0.

As with flowering, various maturation dates are suggested in the literature. The most commonly used maturation index in Greece is the "average maturation time", proposed already in 1955 (Christidis & Harrison). It is calculated from the harvested weight of seed cotton and the harvesting date. Various workers demonstrated the effect of air temperature on the maturation period of individual cotton bolls (Christidis, 1965; Ifoulis & Fasoulas, 1973, -1978); average maturation times of 150 varieties in Greece are summarized by Galanopoulou (1984). Ifoulis (1977) studied the relation between the temperature and the boll maturation period of 5 cotton varieties and described the boll maturation period as a function of the maximum and minimum air temperatures, their range, the day temperature and the night temperature. His data were processed in the present study, using various threshold values in the range 10-15°C, with or without ceiling temperatures. It was found that the boll maturation period can be predicted with high accuracy of about 1 day from the accumulated heat units above 10°C (no ceiling temperatures). The results are summarized in Table 4.2.1. The threshold temperature value of 10°C for predicting boll maturation agrees with the author's experimental results. It was indeed observed that bolls continued to mature -at lower rates- at temperatures between 15 and 10°C, even though the growth of cotton plants virtually ceased below 15°C.

Table 4.2.1. Accumulated heat units (°C-days) above 10°C required for boll maturation of some cotton varieties.

Variety		Year			
	1966	1967	1968	mean	C.V.
24-21	689	679	659	677	2.3%
4S-132/2b	731	729	686	715	3.6%
Acala 94b/1a	695	719	706	707	1.7%
4S-4b/1a	723	750	724	732	2.1%
Coker-65a/4	753	767	729	750	2.6%

Note that the data in the above Table are based on various flowering times and that the canopy temperature is not considered. Table 4.2.2 shows that the maturity index (r.i.) varied considerably among the different irrigation treatments in 1988. Note for example that some 94% of the bolls were open in the dry treatment (A) versus 44% in the normal (K) and only 13% in the wet treatment (Y) at the harvest of 6/9/88 (Table 4.2.2). Note also that despite the highest r.i. of the dry crop on Sept. 6th, the production of ripe bolls in the three treatments varies from K=26.7 bolls/m^2 to A=16.8 bolls/m^2 and Y=7.4 bolls/m^2.

Table 4.2.2. Number of cotton bolls and ripening index of *Gossypium hirsutum* cv. Zeta-2 in Larissa (1988) under various moisture conditions.

	Bolls / m^2				Ripening index			
	<-- Treatment -->			l.s.d.	<-- Treatment -->			l.s.d.
Harv.day	A	K	Y	(P=0.05)	A	K	Y	(P=0.05)
11/08/88	20.0	74.7	46.0	19.9***	0.00	0.00	0.00	-
24/08/88	14.4	47.4	37.9	14.4**	0.27	<0.1	<0.1	0.14**
6/09/88	17.9	60.7	57.2	20.5**	0.94	0.44	0.13	0.23***
21/09/88	25.9	78.6	38.2	23.1**	0.92	0.67	0.50	0.16**
14/10/88		79.4	44.7	n.s		0.80	0.74	n.s.

note: * P=0.05, ** P=0.01, *** P=0.001; A=dry, K=normal, Y=wet crop.

It appears that one must distinguish between the physical development of the crop as important for the partitioning of assimilates to the various plant organs, and the effect on the maturation of the cotton bolls. The observed boll maturation indexes (see Table 4.2.2) are plotted versus the sum of (Tcan-10) after flowering (viz. DVS=0.5) in Fig. 4.2.1. Tcan is the approximated daily canopy temperature (°C); the threshold temperature is set to 10°C. It can be seen that 96% of the variation in the maturation index can be explained when considering the canopy temperature. Fig. 4.2.1 shows that some 730°C-days are required for maturation of the first bolls. In the model, the momentary seed cotton mass is calculated as follows:

IF DVS>0.5 AND TCAN>=10 THEN TACTSO=TACTSO+TCAN-10 (4.9)
RIPE = DEFN (TACTSO) (4.10)
COTTON = SSO * 0.655 * RIPE (4.11)

where

DVS	is the development stage (DVS=0.5 at flowering),
TCAN	is the canopy temperature (°C),
TACTSO	stands for the accumulated heat units (°C-days) of the specific day after flowering,
0.655	is the experimentally found fraction of the storage organ mass which consists of seed cotton (see also Table 4.2.4),
RIPE	is the boll maturation index,
DEFN	represents the function in Figure 4.2.1,
SSO	is the total storage organ dry weight (kg/ha), and
COTTON	is the momentary seed cotton mass (in ripe bolls) (kg/ha)

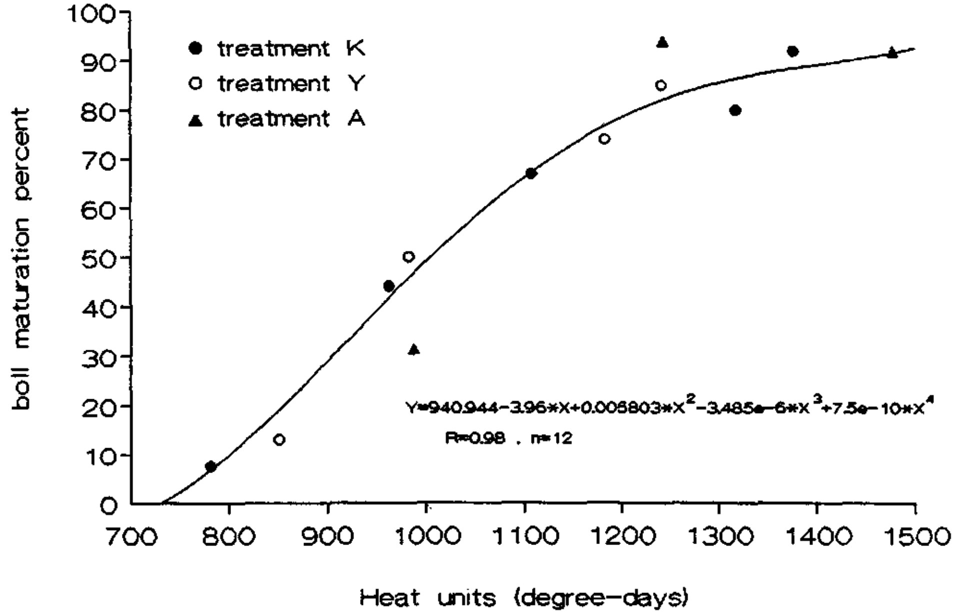


Fig. 4.2.1. Boll maturation index (%) of *Goss. hirsutum* cv. Zeta-2 as a function of the heat units (°C-days above 10°C) accumulated after flowering in Larissa in 1988.

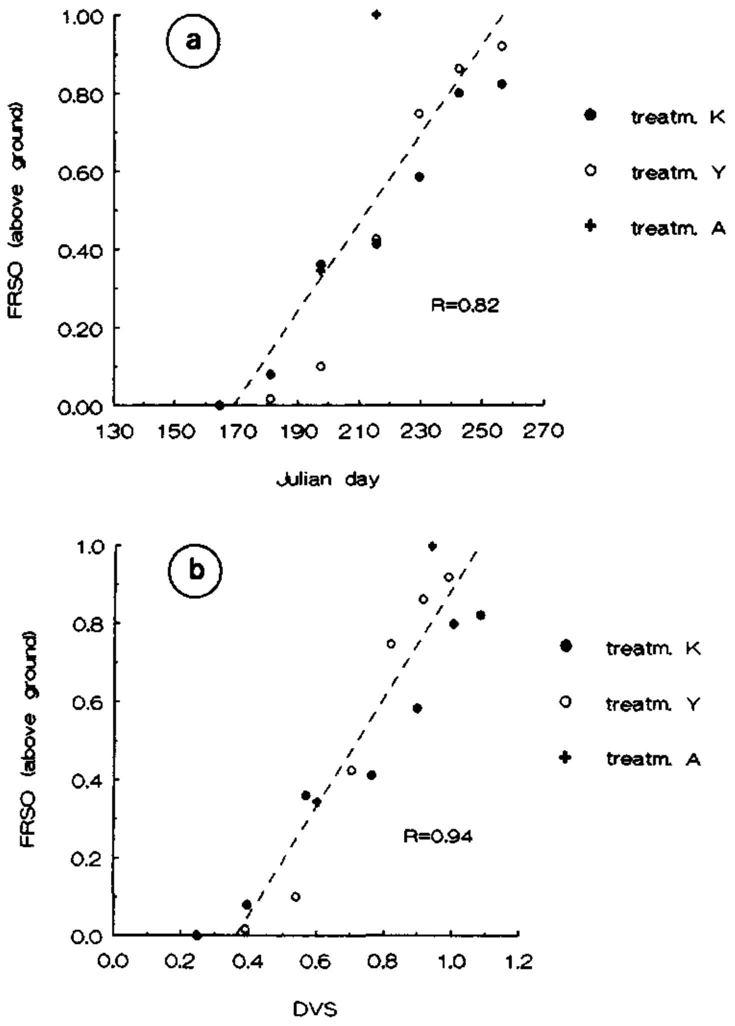


Fig. 4.2.2. Fraction of above-ground dry matter increase invested in storage organs (FRSO) versus time (a), and the development stage (DVS) (b), of *Goss. hirsutum* cv. Zeta-2 in Larissa (1988).

The threshold temperature of 15°C also applies after flowering. However, the end of the growing cycle was not reached in the experiments until the end of September, except for the dry crop (treatment A). Cotton is a continuously growing crop; flowering and boll development take place at the same time as stem elongation and leaf formation as long as weather conditions allow. As shown in the next paragraph, however, most assimilates are allocated to the storage organs after a certain development stage, and only a minor portion to the rest plant organs. This development stage is taken as the point of DVS = 1, to establish the assimilate partitioning fractions (FRorgan). The accumulated heat units (canopy temperature) above 15°C required from flowering to that point are 600°C-days.

The development from emergence to flowering and from flowering to maturity is assumed proportional with the daily effective temperature, and the development stage (DVS) of cotton at any time can be estimated as that of maize (Subsection 4.1.2-development of the crop).

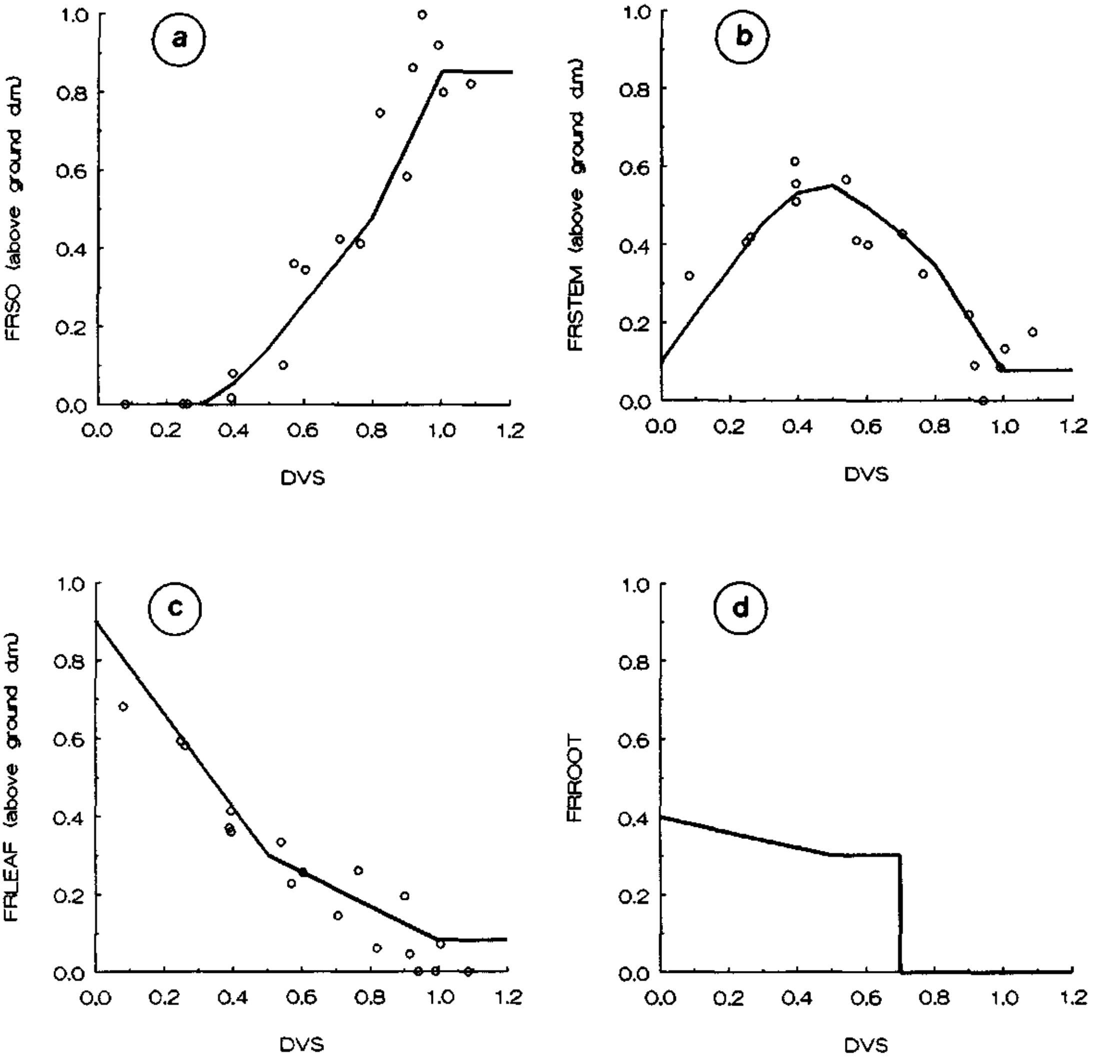


Fig. 4.2.3. Relation between the measured fraction of above-ground dry matter increase invested in the various plant organs [viz. storage organs (a; FRSO), stems & petioles (b; FRSTEM), leaves (c; FRLEAF)], and the development stage (DVS) of *Goss. hirsutum* cv. Zeta-2 (Larissa, 1988); and the approximated fraction of total dry matter increase invested in the roots (d; FRROOT) as a function of DVS. Markers represent measured values for all treatments. Curves are eye-fitted.

The distribution of dry matter

The partitioning of the gross assimilate production was approximated by calculating the total dry matter increase between two successive harvests and expressing the partitioning (FRorgan) over the various plant parts as the fraction of partial and total weight increases (see maize experiments). If FRorgan is plotted vs. time for each treatment of 1988, it becomes evident that FRLEAF starts from a high initial value and decreases with time. FRSTEM increases from an initially small value to a maximum value at flowering and decreases to a very small value. FRSO has a small positive value at flowering (the buds), and increases sharply to reach its maximum some time later in the season, viz. in early August in the dry (A) treatment vs. September in the K and Y treatments. Fig. 4.2.2 demonstrates that 20 percent more of the variation in the FRSO distribution ($R^2=0.94$ vs. 0.82) could be explained by using the canopy temperature in the DVS calculations. About the same applies to FRSTEM and FRLEAF. Using the canopy temperature is superior to the conventionally used mean daily temperature. Development may be shifted towards vegetative growth or towards reproductive growth. This explains much of the hitherto unpredictable (fluctuations of) vegetative- and storage organ growth of cotton.

The final result is presented in Fig. 4.2.3, where FR(organ) is plotted as a function of the DVS, based on data points from the three treatments. The adopted curves are used in the crop growth model. The FRROOT-DVS curve was constructed later, after calibration of the model, and represents the best fit between calculated and measured data. As said, the point at DVS=1 (Fig. 4.2.2) does not indicate physiological maturity, and therefore growth - unique for cotton- continues beyond this point. Most but not all assimilates are invested in the storage organs at DVS>1. Arbitrary values of FRSO=0.85 and FRSTEM=FRLEAF= =0.075 at DVS>1 gave the best fit of calculated and measured data. The negative growth of leaves or/and stems late in the crop cycle are explained by the necessity to meet the maintenance needs of the various plant parts.

Leaf area characteristics, Specific leaf area

Table 4.2.3 lists the mean specific leaf area values (SLA, in m^2 leaf/kg dry leaf), measured in the growing periods of 1987 and 1988. The numbers in parentheses indicate the leaf area index (LAI) at the time of measurement.

As Table 4.2.3 shows, the studied plant density did not affect SLA. Apparently, the widely spaced plants produced more leaves to finally attain a similar LAI as the densely spaced crop.

Mutual shading was about the same in both 1987 treatments, but this was not the case in 1988, when the differences in mutual shading were largely responsible for the fluctuation of the SLA-values reached under 3 irrigation treatments. Table 4.2.3 shows that the overall SLA of cotton decreases from an initially high value of 17.6 m^2/kg, as long LAI<1. Sibma (1987) observed for maize that this is caused by both thickening of the existing leaves and the formation of thicker new leaves. At LAI>1, however, the SLA tends to increase. The fact that SLA is inversely proportional to light intensity has already been discussed. One may therefore assume that shading results in the formation of much thinner leaves in the lower layers of the canopy, which increases the overall SLA. The effect of aging takes over at advanced development stages, and the SLA tends to decrease despite a slight increase of the LAI (see Table 4.2.3). In Figure 4.2.4, the average SLA of the crop is plotted as a function

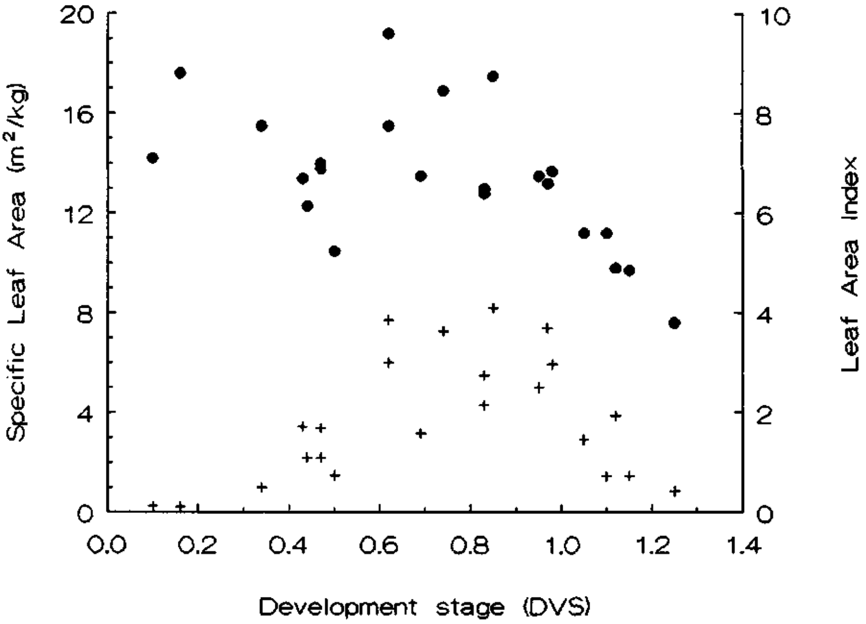


Fig. 4.2.4. Measured specific leaf area, SLA (●; left y-axis) versus the development stage (DVS) of *Goss. hirsutum* cv. Zeta-2 in Larissa (1988; all treatments). A poor negative linear relation between SLA and DVS exists ($r^2=0.54$). Mutual shading, as expressed by the leaf area index, LAI (+; right y-axis), explains a great deal of the remaining variation. Note that for same DVSs, higher LAI-values correspond to higher SLA-values (see also Fig. 4.2.5).

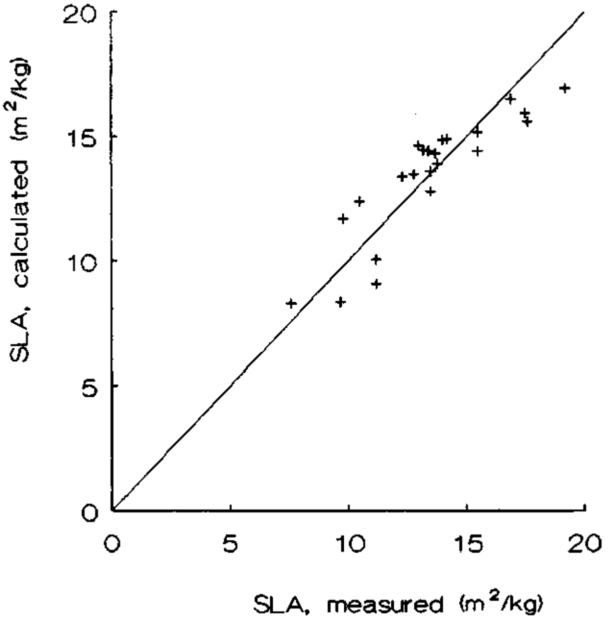


Fig. 4.2.5. Measured and calculated values of the specific leaf area of cotton (equation 4.12).

Table 4.2.3. Specific leaf area (SLA, in m^2/kg) of cotton cv. Zeta-2 grown in Larissa in 1987 and 1988. The values in parentheses represent the LAI at measurement time.

Year = 1 9 8 7

	Plant density		
harv.date	12pl/m^2	6pl/m^2	lst(P=0.05)
12/6/87	14.2 (0.12)	13.1 (0.08)	n.s.
16/7/87	14.0 (1.69)	13.8 (1.10)	n.s.
29/7/87	16.4 (3.05)	14.5 (2.97)	n.s.
19/8/87	13.0 (2.80)	13.3 (2.73)	n.s.
5/9/87	13.9 (2.46)	13.2 (2.57)	n.s.

Year = 1 9 8 8

	Irrigation treatment			
harv.date	A-dry	K-normal	Y-wet	lst(P=0.05)
3/6/88	<------ 17.6 (CV=7.9%); LAI=0.10 ------->			n.r.
24/6/88	14.9 (0.35)	16.2 (0.55)	15.3 (0.51)	n.s.
6/7/88	10.5 (0.75)	12.3 (1.10)	13.4 (1.72)	1.58**
27/7/88	11.2 (1.46)	13.5 (1.59)	19.2 (3.86)	4.05**
11/8/88	11.2 (0.72)	12.8 (2.15)	16.9 (3.64)	3.77*
24/8/88	9.7 (0.73)	13.2 (3.60)	17.5 (4.11)	4.64**
21/9/88	7.6 (0.42)	9.8 (1.94)	13.7 (2.97)	n.s.

(note: * P<0.05, ** P<0.025)

of the DVS (left y-axis) for the Larissa experiments. The LAI is indicated in the same Figure (right axis). Incorporation of the LAI improves the SLA-DVS relation by 44%. Apart from DVS and LAI, the air temperature (TA) was found to explain another 4% of the variation especially at early DVS. As DVS is a function of the (canopy) temperature here, it seems that bringing TA in the model would mean that the effect of temperature is counted twice. There is evidence, however, that the lower the temperature in early development stages cause the higher the value of SLA. See for example Table 4.2.3, where (mean) SLA was 13.5 m^2/kg on 12/6/87 vs. 17.6 m^2/kg on 3/6/88 (LAI=1 in both cases). This difference is significant (lsd=3.06 at 0.05 sign. level) and attributed to the difference in temperature, viz. 26°C on 12/6/87 vs. 20°C on 3/6/88. The effect of the temperature even outweighs that of aging; the values of DVS are 0.10 and 0.16 for the two dates, respectively. This effect of the temperature is not surprising as it reflects the greater role of assimilate production and allocation to the (thicker) leaves at high temperatures. This confirms the thermophilic character of this crop. The existing data suggest that the value of the SLA can be approximated with the following empirical formula:

$$SLA = 20.2 - 6.646*DVS - 0.192*TA + 1.5*LAI \quad (R=0.87^{***}) \qquad (4.12)$$

It should be noted that the average air temperature of the last 3 days is input in the above relation. The agreement between the measured SLA-values and those calculated with the above model is evident from Figure 4.2.5.

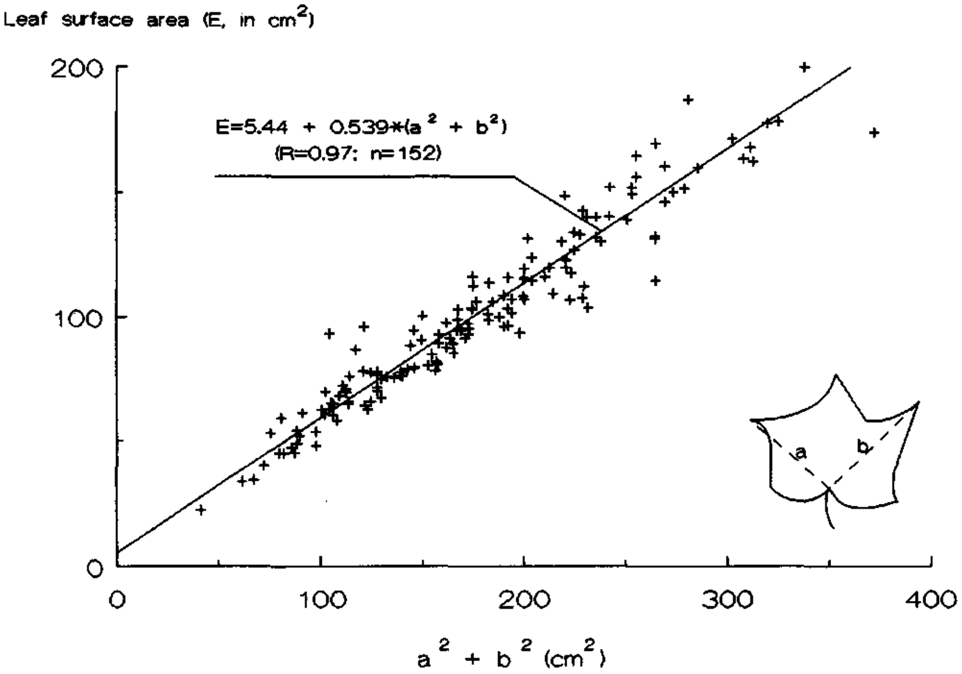


Fig. 4.2.6. The surface area of cotton leaf blades (E) as a function of the product of the squared side veins (a^2 x b^2).

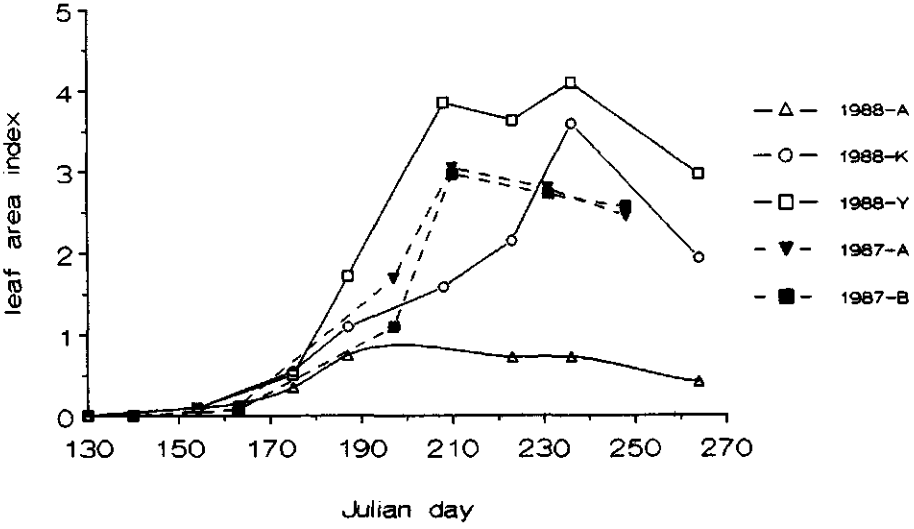


Fig. 4.2.7. The leaf area index as a function of time in various cotton experiments with cv. Zeta-2 in Larissa in 1987 and 1988. (For details on the treatments see text).

Recall that the SLA was determined by dividing the surface area of a number of leaves (measured by planometer) by their dry weight. The surface area can be estimated from the leaf dimensions. For cotton, a good correlation was found between the leaf surface area and the summed squared lengths of the side veins (see Fig. 4.2.6).

Figure 4.2.7 presents the Leaf Area Index over time for all plots. Note that rapid (leaf) growth occurred after mid-July in all cases. The maximum LAI (4.1) was attained in the wet (Y-) treatment of 1988. The drier conditions of planting K are responsible for the much lower value of LAI till the end of July. After flowering, the crop received appreciable inputs of irrigation water. Fig. 4.2.7 shows that the LAI-value can increase sharply even in advanced growth stages. Crop "A" grew under virtually dry conditions; its LAI never exceeded 1. In 1987, the LAI was significantly lower for low plant densities (B) than for the normal planting (A), until the middle of July. After that, the LAI increased to attain a similar value as crop A by the end of August. The slightly drier conditions but also the shorter period of vegetative growth in 1987 (10 days later germination) are deemed responsible for the lower LAI at the end of July 1987 than observed for the wet crop in 1988. Perhaps the LAI would have increased further if the crop had not been (partly) defoliated in mid-August. The LAI decreases in the advanced development stages in all plantings. However, no decrease in the dry leaf weight takes place until the beginning of September, so that the lower SLA-values at advanced development seem responsible for this decrease. The decrease of the dry leaf mass in September 1988 (Table 4.2.4) is due to the disability of the crop to meet its maintenance needs.

Note that an optimum LAI exists. For Greece, it seems to range from 2.5 to 3. At $LAI < 2.5$, much photosynthetic energy is lost to the ground, whereas development of crops with too luxuriant foliage produce low yields (or even failures) due to low temperatures early in fall. This was the reason of the defoliation in 1987. The matter will be further discussed in the next paragraph.

Growth dynamics

General observations on growth rates and maintenance cost

All obtained growth curves are summarized in Fig. 4.2.8. These curves show the above-ground, living dry matter. The growth rates ranged from 120 to 160 kg $ha^{-1}d^{-1}$, except for the rather low rates of the dry (A) planting of 1988. As apparent from Fig. 4.2.8, linear growth starts at the end of June to early July after about 1.5-2.0 tons biomass has been produced per hectare. It continues until the beginning of September when the temperature drops to 20°C or less. To reproduce the obtained growth rates, literature data on the maximum gross assimilation and on respiration rates were used. A maximum gross assimilation rate of 50 kg $CO_2 ha^{-1} hour^{-1}$ is suggested by Mutsaers (1982). For the conversion factors (Section 3.1) the values suggested by Penning de Vries & van Laar (1982) and by Penning de Vries *et al.* (1983) are used: ECLEAF=ECROOT=0.72, ECSTEM=0.69 and ECSO=0.61 (for storage organs). The relative maintenance respiration rates [R(organ)=0.01 $kgCH_2O\ kg^{-1}d^{-1}$] were calculated by the above authors from the biomass composition of stems, fibrous roots and storage organs of cotton. The values adopted here are slightly higher, i.e. R(stem)=0.0145, R(root)=0.0139, R(S.O.)=0.0164. The value used for the relative maintenance needs of the leaf mass is R(leaf)=0.0139, rather than 0.03 $kgCH_2O\ kg^{-1}d^{-1}$, as originally suggested. (The value of 0.03 kg $kg^{-1}d^{-1}$ appeared too high; see also maize experiments). A constant reference temperature (Tref) of 30°C is used here.

Table 4.2.4. Average dry matter per organ (kg/ha) in successive harvests of cotton cv. ZETA-2 grown in Larissa (1988) under different irrigation schemes.

Treatment -Y

a/a	Date(J.day)	Leaf	Petiol.	Stems	S.O.	Seed cotton total	ri.	avail	Total
1.	3/ 6/88(154)	51	5	20	0				75
2.	24/ 6/88(175)	334	57	162	0				553
3.	6/ 7/88(187)	1284	283	1121	33				2721
4.	27/ 7/88(208)	2013	549	2900	374				5836
5.	11/ 8/88(223)	2151	453	3438	1018	512	0	0	7060
6.	24/ 8/88(236)	2346	432	3257	2398	1398	8	116	8433
7.	6/ 9/88(249)	2568	433	3710	3482	2333	13	303	10199
8.	21/ 9/88(264)	2168	424	4369	3456	2264	50	1132	10417
9.	14/10/88(287)						74	2329*	
10.	7/11/88(315)						85		

(* field weight, moist.=10-15%; ri.=boll maturation percentage)

Treatment -K

a/a	Date(J.day)	Leaf	Petiol.	Stems	S.O.	Seed cotton total	ri.	avail	Total
1.	3/ 6/88(154)	51	5	20	0				75
2.	24/ 6/88(175)	341	59	165	0				565
3.	6/ 7/88(187)	894	179	743	71				1887
4.	27/ 7/88(208)	1178	228	1265	953				3626
5.	11/ 8/88(223)	1683	297	2094	1902	892	0	0	5976
6.	24/ 8/88(236)	2172	413	2820	2508	1487	7	109	7913
7.	6/ 9/88(249)	2442	337	2806	4319	3045	44	1340	9904
8.	21/ 9/88(264)	1975	304	2954	5290	3464	67	2321	10523
9.	14/10/88(287)						80	3055*	
10.	7/11/88(315)						92		

(* field weight, moist.=10-15%; ri.=boll maturation percentage)

Treatment -A

a/a	Date(J.day)	Leaf	Petiol.	Stems	S.O.	Seed cotton total	ri.	avail	Total
1.	3/ 6/88(154)	51	5	20	0				75
2.	24/ 6/88(175)	235	39	117	0				391
3.	6/ 7/88(187)	715	143	600	92				1550
4.	27/ 7/88(223)	644	117	626	622	369	0	0	2009
5.	24/ 8/88(236)	753	112	800	1092	836	31	263	2757
6.	6/ 9/88(249)	695	85	938	1013	739	94	695	2731
7.	21/ 9/88(264)	544	62	953	1424	981	92	903	2983

(ri.=boll maturation percentage)

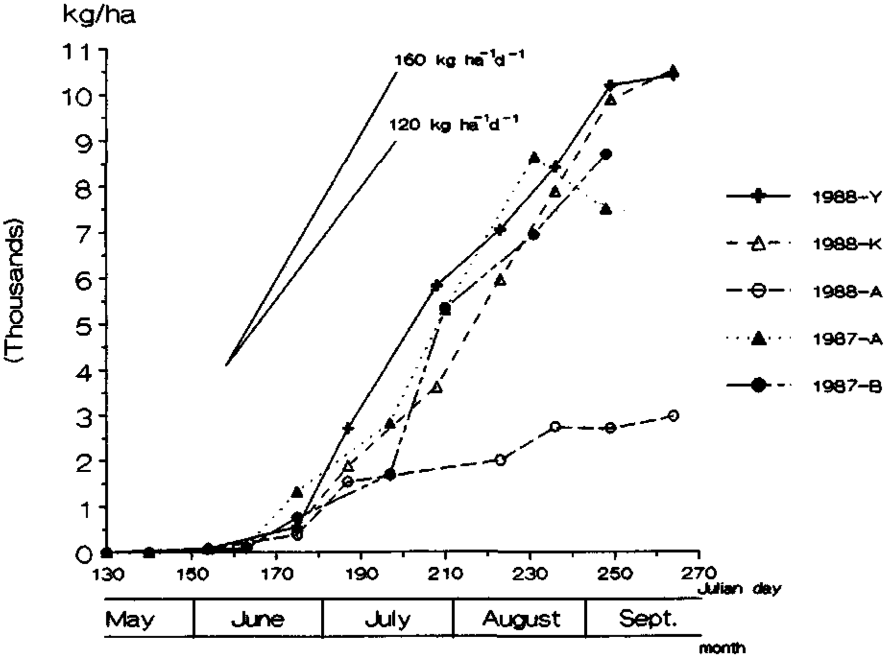


Fig. 4.2.8. Growth rates of *Goss. hirsutum* cv. Zeta-2 recorded in Larissa in 1987 and 1988. Theoretical curves for 160 and 120 kg $ha^{-1}d^{-1}$ are added for comparison. (For details on the treatments see text).

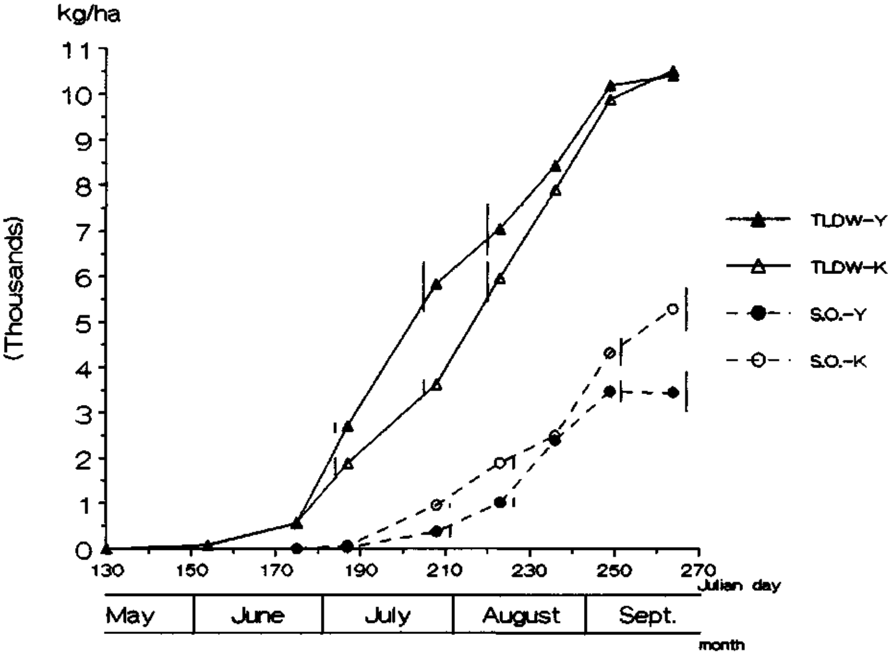


Fig. 4.2.9. Recorded total (above-ground) living dry weight (TLDW) and storage organ dry weight (S.O.) as compared for the "Y-wet" and the "K-normal" irrigation treatments of cotton cv. Zeta-2, in Larissa (1988). The vertical lines represent standard deviations.

The effect of temperature

Figs. 4.2.7 and 4.2.8 show that the same growth rates hold for a wide range of LAI-values, whereas in some cases, plantings with a lower LAI (viz. due to lower plant density, previous drought, etc.) had even higher growth rates than plantings with a luxuriant foliage. The dry planting (A) of 1988 is the proverbial exception.

Fig. 4.2.9 focuses on the wet (Y) and normal (K) plantings of 1988. The measured total (above ground) living dry weight (TLDW) and the dry storage organ weight (S.O.) are presented (the difference is the weight of leaves+stems). The K-crop grew under conditions of water stress until flowering; the Y-crop was frequently irrigated. The higher initial growth rates and TLDW of the Y-crop are not surprising. However, higher canopy temperatures in the stressed crop forced the plants towards reproductive growth resulting in a greater St.Org. production (mostly buds and flowers at this early stage), in spite of the lower growth rate. The effect of temperature was pronounced in late July and August. The normal (K) crop was frequently irrigated after flowering and exhibited similar or even higher growth rates than the Y-crop and a higher final production of storage organs. Note that the value of the LAI is only 1.6 vs. 3.8 in the Y treatment at the end of July, when rapid growth occurs in the K-planting, (see also Fig. 4.2.7). These results seem to confirm the importance attached to the effect of temperature for cotton growth in the Greek literature and the farmers' experience and advises. We have to accept that cotton in Greece grows under less than optimum conditions and the effect of temperature on growth should be further quantified.

Fig. 4.2.10 presents the air temperature during the post anthesis period of the Larissa (1988) crop and the calculated canopy temperature (Tcan) for the dry and wet plantings. Unfortunately the few Tcan records from the field do not suffice to validate the calculated values. Nonetheless, the temperature differences observed are largely explained. In the dry (A) crop ($LAI << 1$), Tcan is not much different than thermometer readings in the sun, whereas Tcan of the Y-crop was 1-4°C less than Tair after canopy closure, depending mainly on wind velocity and air humidity.

The maximum growth rate of the Y planting was 181 kg dm $ha^{-1}d^{-1}$ (Fig. 4.2.9) between the 2nd and 3rd harvests, viz. in the period 24/6(175)-6/7/88(187). Considering the average biomass in this period (see also Table 4.2.4) and an R(organ) value of 0.01, an approximate maintenance respiration of 16 kg CH_2O $ha^{-1}d^{-1}$ applies. The LAI ranged from 0.51 on 24/6 to 1.72 on 6/7. Taking an average LAI=1, calculations at PS-1 level (Section 3.1) produce a gross assimilation rate of 416 kg $CO_2 ha^{-1}d^{-1}$ for LAT=40°N, DAY=182, AMAX=50 kg $CO_2 ha^{-1}hour^{-1}$ and the average sunshine duration for the above period (10.5 hours vs. 14.8 hours max. sunshine duration). Accordingly, the potential growth rate is: $(416 * 30/44 - 16) * 0.69 = 185$ kg dm $ha^{-1}d^{-1}$, where 0.69 is the average value of the conversion efficiency. Comparison of calculated and obtained growth rates indicates that field conditions were optimum with respect to both water supply and temperatures. The average air temperature in this period was 27.1°C; the calculated Tcan fluctuated between 28.5°C and 30°C (see also Fig. 4.2.10). The fact that growth rates decrease later in the season is probably partly caused by the lower Tcan, the negative effect of which outweighs the positive effect of a higher LAI. This explains why in the period 6/7-27/8/88 the growth rate of the K-planting (with LAI=2.1) is at least equal to (if not greater than) that of the Y-planting (with LAI=3.7) (see Figs. 4.2.7, 4.2.9 and Table 4.2.4). In this period, both treatments enjoyed optimum water supply so that the effect of the temperature can be isolated:

In the period DAY=221-230, the sunshine duration ratio (SD) was 0.714; the water effic-

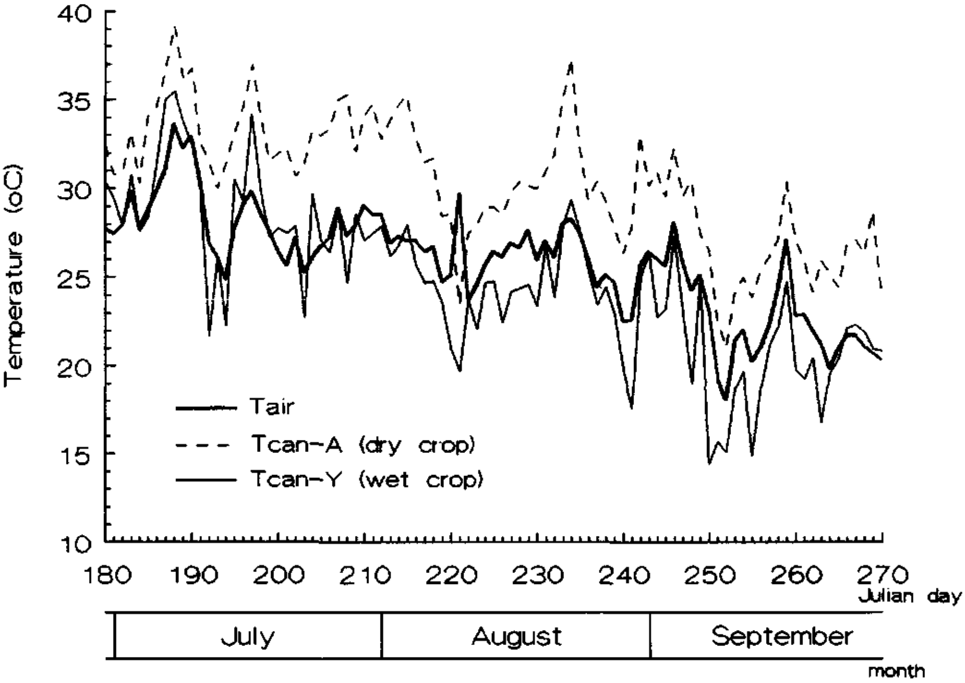


Fig. 4.2.10. Daily canopy temperature (Tcan; calculated) during the reproductive stage of the A (dry) and Y (wet) plantings of cotton cv. Zeta-2 in Larissa (1988). The mean daily air temperature (Tair) recorded for the same period is also included.

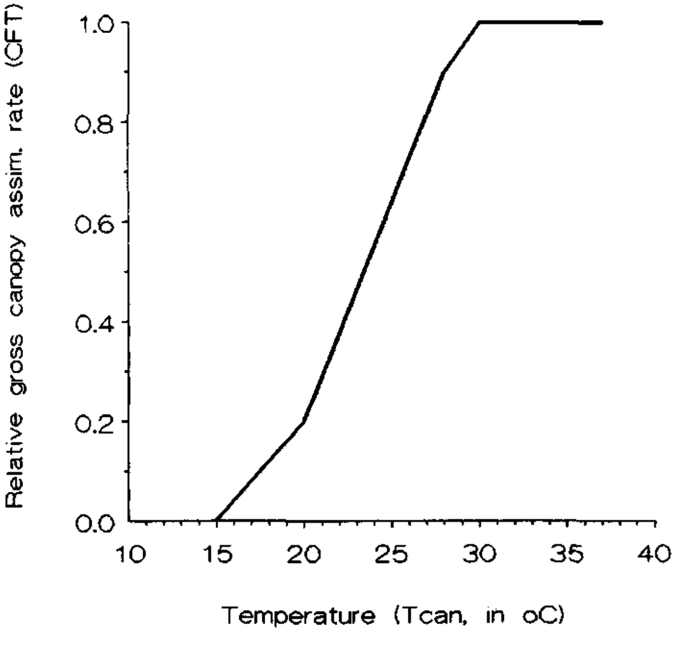


Fig. 4.2.11. The adopted relation between the relative gross canopy assimilation rate (temperature correction factor, CFT) and the (canopy) temperature of cotton.

iency factor (CFW) was 1; the calculated total maintenance cost of the existing biomass (Table 4.2.4) is around 60 and 70 kg CH_2O $ha^{-1}d^{-1}$ for the K and Y plantings, respectively. The calculated potential gross assimilation rates for DAY=223 (LAT=40°N, AMAX=50 kg $CO_2ha^{-1}hour^{-1}$, DAYL=13.6 hours) are 628 and 798 kg $CO_2ha^{-1}d^{-1}$, resulting in growth rates of 254 and 327 kg dm $ha^{-1}d^{-1}$, for LAI-values of 2.1 and 3.7, respectively. These rates exceed the ones actually obtained (Fig. 4.2.10), apparently due to the lower temperature in this period (Tair=25.4°C). However, the growth rate of the K-planting was at least that of the Y-crop. A growth rate of 150 kg dm $ha^{-1}d^{-1}$ would occur for both plantings if the gross canopy assimilation had been 408 kg $CO_2ha^{-1}d^{-1}$ and 424 kg $CO_2ha^{-1}d^{-1}$ for K (with LAI=2.1) and Y (with LAI=3.7) plantings. A temperature correction factor (CFT) of 408/628=0.65 and 424/798=0.53 would apply for the K and Y plantings, respectively. The average Tcan values calculated for the same 10-day period are 23.4°C for treatment Y (see also Fig. 4.2.10) and 25.7°C for treatment K. Based on the experimental results and considering the facts mentioned above, the pronounced effect of the temperature in the 20-30°C-range was expressed in a temperature-correction factor CFT for the gross canopy assimilation. The CFT-T relation, adopted after calibration of the model, is presented in Fig. 4.2.11. Though in contradiction with earlier authors who consider assimilation to be hardly influenced by temperature in the 25-35°C-range (Bierhuizen & Slatyer, 1964; El-Sharkawy & Hesketh, 1965; Thoughton & Slatyer, 1969), this relation appears to be confirmed by recent publications signalling exponential growth between 20-30°C which ceases below 12-15°C (Hearn, 1969; Gutierrez *et al.*, 1975) or beyond 40°C. Mutsaers (1982), summarizing the results of other authors (viz. McKinion *et al.*, 1975, etc.), notes the prompt response of cotton growth to temperature fluctuations and concludes that a linear response curve would be a quite reasonable approximation between 12 and 32°C.

Any effort to simulate cotton growth should take the canopy temperature into account. Firstly, temperature affects development. Low canopy temperature may induce a dramatic shift towards vegetative growth. Temperature affects the growth rate itself, the rate of assimilation, and the fractions of all assimilates allocated to the different plant organs. It controls the boll-maturation period and it controls the specific leaf area, viz. the actively photosynthetic area per unit of dry leaf mass produced.

The effect of water supply

Fig. 4.2.9 demonstrates that optimum supply of water before anthesis results in a luxuriant foliage but delays reproduction growth (Tables 4.2.2 and 4.2.4 and Fig. 4.2.9). Mild drought before anthesis is generally desirable. After anthesis, however, drought depresses the formation and filling of storage organs. Severe drought before anthesis results in a too low LAI, and even if irrigation is applied later on, the crop is not able to recover (see A-treatment, Figs. 4.2.8 and 4.2.14c). Note that the permanent wilting point was not reached in the dry treatment, despite the severe drought.

The growth rates obtained in the different irrigation treatments served model calibration. It appeared, however, that the maximum evaporation rate was somewhat over-estimated, especially for the dry treatment. This is due to the incapacity of the simplified model to assess mulch formation in a topsoil which is exposed in the dry-hot summer (viz. LAI<1). This could be done with the detailed model (see Section 3.2) but computing time and costs are prohibitive. Identification of a more useful empirical formula deserves further research.

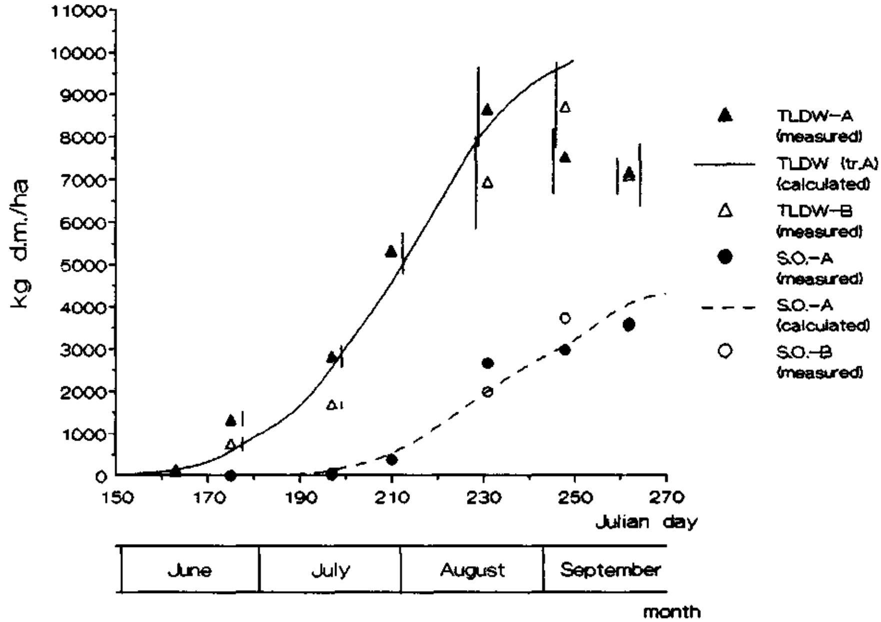


Fig. 4.2.12. Total (above-ground) living dry weight (TLDW) and storage organ dry weight (S.O.) versus time, as measured for the two treatments of cotton cv. Zeta-2, in Larissa in 1987 (markers). The vertical lines represent standard deviations. The calculated curves (lines) for planting A (normal population) are included for comparison. (Note: treatment A: 12 pl/m^2; treatment B: 6 pl/m^2).

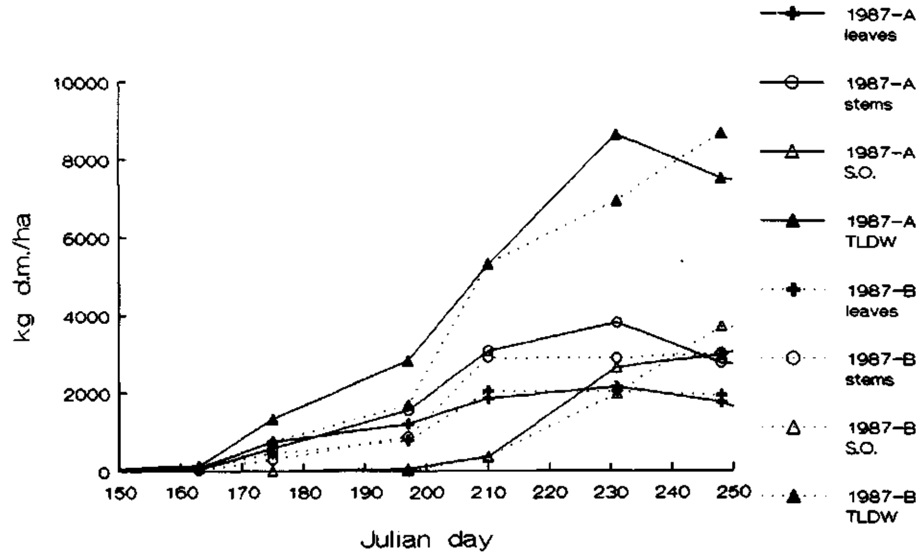


Fig. 4.2.13. Average dry matter production of leaves, stems(+petioles) and storage organs (S.O.), as recorded in the two population treatments of cotton cv. Zeta-2 in Larissa (1987).

The effect of plant density

As with moisture supply, plant density affects the canopy temperature. Fig. 4.2.12 shows a similar pattern in the plantings of 1987: growth and biomass production of treatment A (12 pl/m^2) exceeded those of treatment B (6 pl/m^2) until the middle of July. At the harvest on 16/7/87, the LAI-values were 1.7 and 1.1, respectively. After flowering, however, conditions of less competition in treatment B brought about higher growth rates so that no significant difference in biomass production was observed after mid-August. As shown in Fig. 4.2.7, the LAI was about the same for all treatments after the end of July. Both treatments received ample irrigation and grew under (near) optimal moisture conditions. Due to the expected too high vegetative growth, the crops were partly defoliated in middle August and before harvest. This caused highly variable results (Figs. 4.2.12 and 4.2.13). Yet, there is no doubt that, within a certain plant density range, less competition results in higher growth rates of the widely spaced plants, so that the initial difference in biomass and storage organ production becomes much less later on. There is strong evidence, however, that the permissible plant density is pretty wide for cotton, due to its sympodial growth. The growth of two individual plants which grew 2 meters apart, fully irrigated and fertilized was monitored for both biomass and storage organ production. The foliage covered the entire space between the two plants and a total of 195 bolls were produced (110 and 85) in late September. Note that the maximum production obtained in the normal (K) planting of 1988 was 79 bolls/m^2 (Table 4.2.2). It is believed that the canopy temperature plays a major role, in combination with moisture and nutrients supply, in the performance of crops at various plant densities. The effect of lower canopy temperatures on the growth of dense plantings may be explained as follows:

- dense stands have a greater leaf mass and leaf area index, and show earlier canopy closure, but this does not affect the final yield. The superiority of a dense planting is apparent when weather diminishes the vegetative growth or in late plantings viz. end of April-middle May (Galanopoulou, 1977).

The present study confirms that delayed growth of a dense, well watered and fertilized crop during the (occasionally) wet-cool end of the summer may result in a rather low yield. Reduced vegetative growth induced by drier conditions, etc., is a precondition for higher yields in dense stands.

- high rainfall may have a negative effect on the yield of dense stands (Hearn & Hughes, 1975).

High transpiration rates in a dry, hot and windy environment depress the already low canopy temperature of a too dense crop resulting in a late beginning of the reproductive stage and the boll maturation period. If much rain falls during the early vegetative stages, a luxuriant growth and premature canopy closure will take place, especially in dense stands.

- lateness in dense stands is reported by Eaton (1955) and correlated with the level of the first fruiting branch. This relation was studied also by Low *et al.* (1969). Galanopoulou (1977) reports that the average maturation date occurred 3 days later in dense stands. She deems the effect of plant density on earliness less prominent than the effect of the sowing date.

Some authors predicted a shorter boll maturation period in dense stands (Baker, 1973), due to the crop's morphology, viz. less bolls per plant but homogeneously distributed on the main

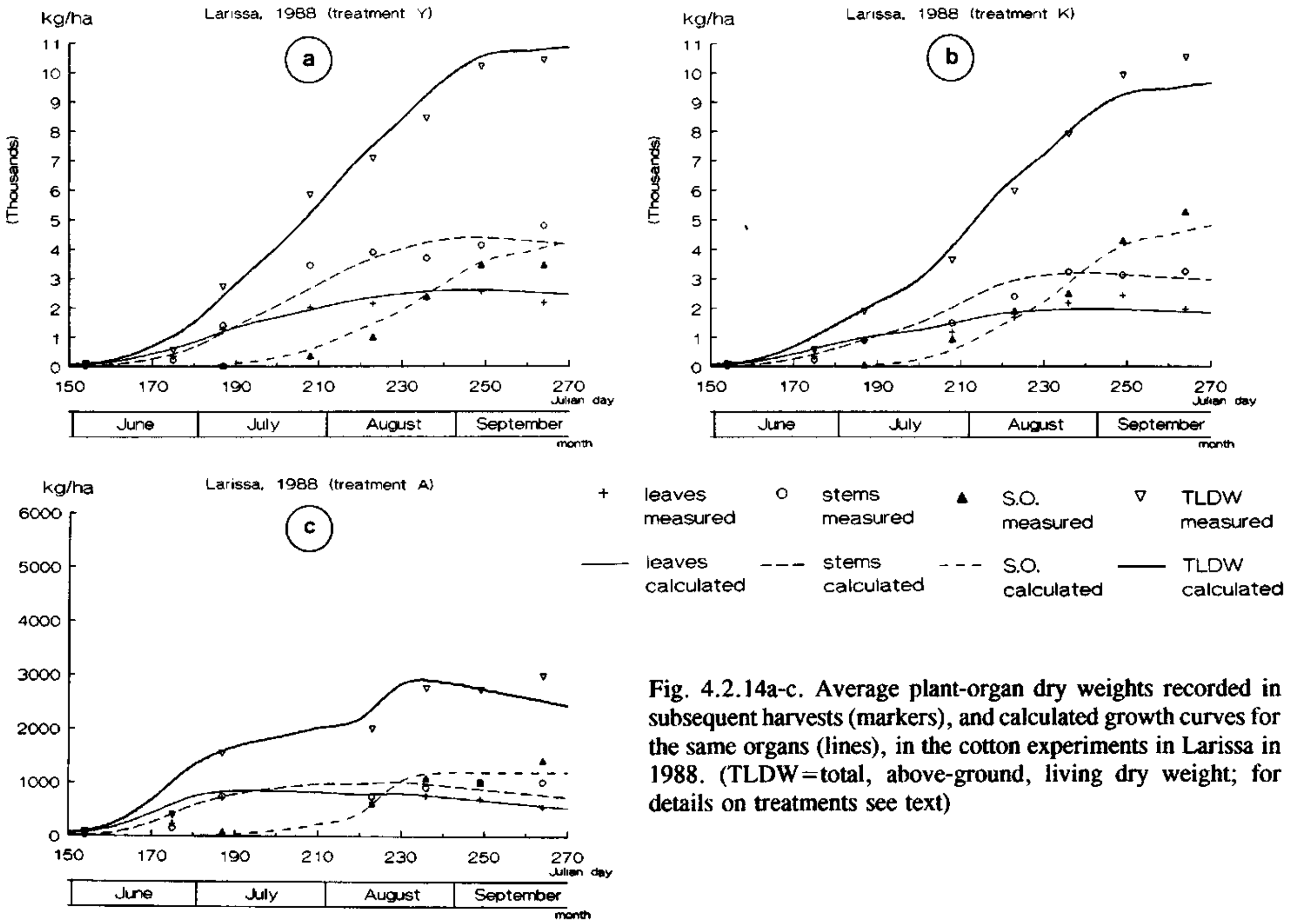


Fig. 4.2.14a-c. Average plant-organ dry weights recorded in subsequent harvests (markers), and calculated growth curves for the same organs (lines), in the cotton experiments in Larissa in 1988. (TLDW=total, above-ground, living dry weight; for details on treatments see text)

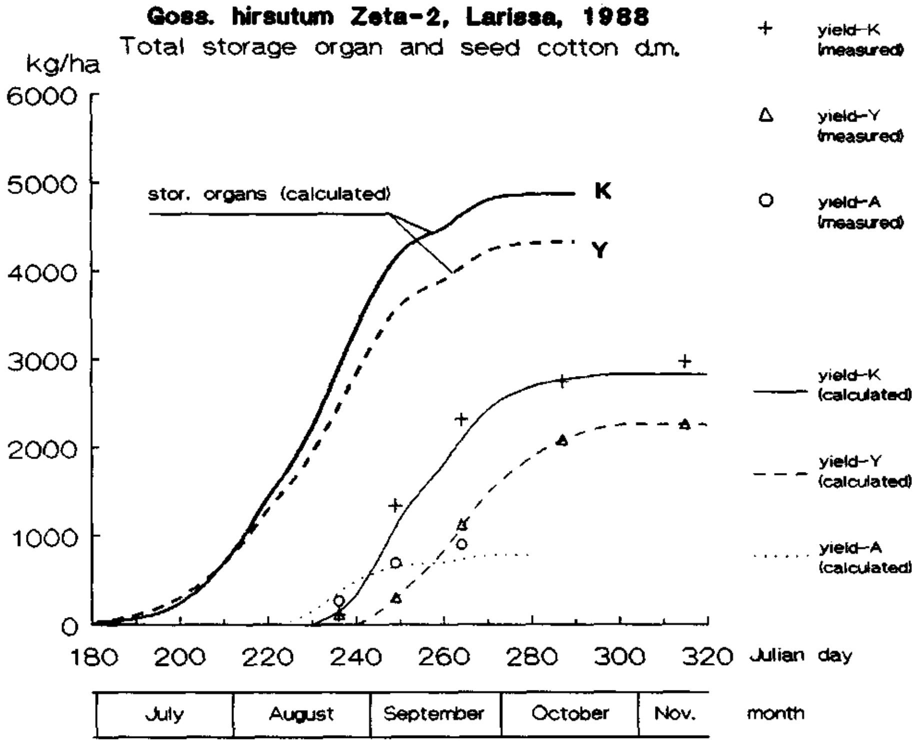


Fig. 4.2.15. Measured and calculated dry yield (seed+lint) of cotton cv. Zeta-2 in the 3 irrigation treatments in Larissa (1988). The calculated total storage-organ dry weights of the K and Y treatments are included for comparison (treatm. K=normal; Y=wet; A=dry; for more details see text).

stem and more effectively intercepting the sun-rays. This could however not be confirmed in practice (Baker, 1976; Galanopoulou, 1977). The experimentally obtained yield of the dense planting (A, 12 pl/m^2) in Larissa (1987) was higher than the yield of treatment B (6 pl/m^2), viz. 1,973 kg/ha dry seed cotton (A) vs. 1,565 kg/ha (B). Despite the significant difference (viz. lsd(0.05)=155 kg/ha) the effect of the defoliation is not known (see also Fig. 4.2.12), and no conclusion can be drawn.

Validation

The average growth curves for the three plantings of 1988 are schematically presented and compared with calculated curves in Fig. 4.2.14. The values represent the dry weights of plant organs. The storage organ weight includes the weights of bolls, flowers and buds. The good agreement between measured and calculated values for all treatments before flowering justifies the general methodology. Moreover, with the introduction of the canopy temperature, it could be explained that the initially luxuriant growth (stems+leaves) is not (always) coupled with a high storage organ production. Figs. 4.2.14-a&b demonstrate that the storage organ production of the normal (K) treatment exceeded the production of the wet (Y) treatment throughout the post anthesis period. This is caused by higher temperatures. The treatment also showed a shift of the reproductive stage of the crop earlier. A good fit is also obtained for the dry planting (Fig. 4.2.14c). Note that the permanent wilting point was not reached despite the pronounced drought in the summer, and the crop responded to only one irrigation in early August with an increased rate of storage-organ production. The good agreement between the measured and calculated dry mass of stems and leaves demonstrates that the present calculation of the DVS is a useful approach.

Fig. 4.2.12 shows that the observed growth rates of vegetative matter and storage organs can be reasonably explained for the normal treatment A (viz. 12 pl/m^2) until defoliation. The large variability of the measured values after defoliation prohibit validation. It seems, however, that defoliation at this stage may depress boll formation slightly but this would influence the final yield only if a long, dry autumn would allow maturation of all bolls formed. This is probably not the case here, because the final dry yield (seed cotton) is almost identical with the calculated value, viz. 2,587 vs. 2,520 kg/ha.

The predicted and obtained dry yields of the three plantings of 1988 are compared in Fig. 4.2.15. The calculated storage organ production is also included as a reference of the maturation period. The match of the predicted and observed yields is satisfactory. Two more remarks:

- the final maturation index of the Y-planting [viz. yield/(SO*0.655)] is less than that of the K treatment, and both are less than 1. This confirms the importance of the temperature late in autumn, with regard to the maturation of the bolls formed in the season.
- the date of 50% maturation in the three treatments follows the order A < K < Y from early to late. Fig. 4.2.15 demonstrates that this date cannot be correlated with the cotton yield; the yield of the earliest planting was by far lower than the yield of the other two.

4.3 Wheat experiments

4.3.1 Introduction

Wheat is Larissa's most important food crop. It grows under rainfed conditions from November to June and produces an average yield of 3 tons and a maximum yield of 6 tons per hectare (Institute of Cereal Crops- I.C.C., 1985). The Institute recommends applications of 100-150 kg Nitrogen and 30-40 kg Phosphorus per hectare for good yields.

Early runs of the crop growth model used crop data as cited in literature and indicated yield potentials in excess of 10 t/ha. Such yield levels were at the time beyond imagination. Some farmers in Farsala claimed yields as high as 8 t/ha obtained in previous years, but these claims were doubted by agronomists. It was therefore attempted to reach the potential production of wheat in the study area in a field experiment in 1988-89. Growth was studied in a fully irrigated planting (wet treatment-Y) and compared with the growth of a rainfed crop (normal treatment-K). Irrigation was applied by means of an automatic drip irrigation system. Drip irrigation is never applied to wheat, neither in practice nor in field experiments. For the present study, however, drip irrigation was the only possibility because sprinkling may lead to lodging, even at low application intensities, and sprinkling in May entails the danger of diseases. Moreover, drip irrigation is superior with respect to the uniformity and the precision of the application. Note that surface irrigation is not practicable in the Larissa area. Both treatments were fully fertilized. The wet planting received extra N and P.

Triticum turgitum durum cv. Mexicali was sown on Larissa clay soil in 6 rows per meter, on November 30th, 1988. This is a short variety selected from MEXICO 75 (G-015361) and introduced by the I.C.C. in 1981 (I.C.C., 1985). At present, the cultivar is widely used in the Larissa area and also in other parts of (southern) Greece. A basal dressing of 500 kg Ammonium Phosphate (20-10-0) per hectare was applied before sowing. The site received an additional fertilizer application of 300 kg Ammonium Nitrate (35.5-0-0). A second dressing of 625 kg Ammonium Nitrate per hectare was applied to the wet treatment (Y) on April 12th, 1989. This brings the total nutrient input to 50 kg P/ha for both treatments, and 250 and 460 kg N per hectare for the normal and wet treatments, respectively. Two plots of the wet planting scenario did not receive the heavy top-dressing (viz. Y-control or Yc hereafter). A randomized plot design was used with three replicates: each plot measured 4x4=16 m^2. On April 4th, 1989, viz. 9 days before anthesis, a (drip) irrigation system was installed with a constant discharge rate of 2 mm/hour. Until 5/5/89, the wet planting (Y) received a total of 162 mm water, given in 9 applications: 12/4(24 mm), 13/4(12 mm), 22/4(22 mm), 24/4(12 mm), 25/4(8mm), 26/4(12 mm), 27/4(12 mm), 8/5(30 mm) and 9/5/1989(30 mm). The dates of 50% emergence, flowering and maturity were recorded. As in the case of maize, the occurrence of a black layer on 50% of the kernels was taken as an indication of the maturation time (Rench & Shaw, 1971). The crop was harvested on the following dates: 30/3, 12/4, 25/4, 11/5 and 31/5. The final yield was collected on 14/6/1989. Subsamples of the harvested material were divided into leaf blades, stems, cobs+husks and roots. All fractions were dried at 90°C until constant weight. The surface area of a number of leaf blades from each replicate was measured by planometer. The specific leaf area was calculated and combined with the measured dry leaf weight to approximate the leaf area index. Plant samples were analyzed for their Nitrogen and Phosphorus contents at the

Department of Soil Science and Plant Nutrition, WAU, The Netherlands. Daily weather data during the growth cycle were obtained from the Larissa Airport (National Meteorological Service).

The growth of the same variety was also studied on the experimental farm of the Agricultural University of Athens in 1991. The site is situated in Spata (Attica), 25 km east of Athens. The crop was sown on gently sloping (north-east, 3 percent), slightly gravelly, light clay soil, already in November 1990. The work, however, started in middle March and continued while field work in Spata focused on rainfall-erosion and desertification aspects (MEDALUS-EPOCH, EEC Project of the Athens Agric. University). Therefore this experiment received little attention: the exact sowing and emergence dates have not been recorded, and fertilization was sub-optimal. Moreover, the weather data were recorded at the Spata Airport, which has a different microclimate, especially with respect to precipitation and wind force and direction. An automatic meteorological station was installed on the site in April 1991. The crop was harvested 6 times: on 14/3, 3/4, 16/4, 6/5, 22/5 and 12/6/91. The harvested material was divided into leaf blades, stems and storage organs and oven-dried (90°C) until constant weight in the Laboratory of Soil Science (Agric. Univ. Athens). Flowering and maturation dates were recorded, and the assimilate partitioning factors were established. The exceptionally rainy winter and spring of 1991 explains the high yield obtained by this rainfed crop.

4.3.2 Results and discussion

Weather data

The recorded temperature and rainfall data deviated considerably from the average values in both wheat experiments. The weather data are summarized in Table 4.3.1. Mean daily data can be found in Appendix B.

A cold, dry winter occurred in Larissa in 1988-89. Lower than average maximum and minimum temperatures were recorded, especially in November and December 1988 (Table 4.3.1). The lowest average minimum temperature normally occurs in Larissa in January (0.7°C) (Table 4.3.1). However, Tmin was below zero in both December 1988 and January 1989, viz. -1.3 and -2.5, respectively. The lowest temperature was recorded on December 20th, viz. -17.5°C. Rainfall in the period January-May 1989 was less than average. January and February 1989 were very dry. However, showers in November and December brought the total precipitation in the growing period close to the average value.

The growing season 1990-91 was exceptionally rainy. Table 4.3.1 shows that the total rainfall in Spata was 616 mm in the period November-May (average is less than 400 mm). Some 246 mm of rain fell in April and May, critical for wheat. Recall that 200 mm (about 40 mm rain and 160 mm irrigation water) were required during the same months of 1989 for potential production in Larissa. The temperature in Spata was also lower than average in the growing period 1990-91.

Development of the wheat crop

The rains of November 1988 prohibited early sowing in Larissa. Finally the crop was sown on 30/11 after a 4-days dry spell. Fifty percent emergence occurred on 11/12, after a total of 100°C-days had accumulated. This agrees with results of Bauer *et al.* (1984).

Table 4.3.1. Monthly climatological data during the growing period of wheat in Larissa and Spata (in parentheses 30-years average data).

Month	Ta (°C)	PREC (mm)	n/N	RH	WIND (m/s)
LARISSA 1988/89					
November	6.6 (11.8)	122.7 (53.5)	0.421	0.80	1.4
December	2.8 (6.7)	97.0 (63.4)	0.372	0.87	1.1
January	3.4 (5.2)	1.9 (41.6)	0.513	0.79	0.7
February	7.1 (7.1)	5.3 (38.8)	0.522	0.71	1.5
March	11.0 (9.6)	35.0 (42.0)	0.472	0.75	1.5
April	15.0 (14.3)	11.1 (32.3)	0.665	0.63	1.5
May	17.5 (19.8)	29.5 (41.5)	0.547	0.64	1.9
		302.5(313.1)			
SPATA 1990/91					
November	15.5 (14.7)	52.8 (56)	0.445	0.73	2.6
December	10.5 (11.0)	158.1 (71)	0.313	0.75	2.4
January	7.2 (9.3)	36.6 (62)	0.458	0.75	2.8
February	8.0 (9.9)	40.9 (37)	0.314	0.75	3.8
March	10.6 (11.3)	81.5 (37)	0.435	0.76	3.1
April	12.3 (15.3)	196.5 (23)	0.434	0.75	3.4
May	16.0 (20.0)	49.9 (23)	0.555	0.70	3.3
		616.3(309)			

Legend: Ta=mean daily temperature, PREC=precipitation, n/N=sunshine duration ratio, i.e. actual/maximum sunshine hours, RH=air humidity.
Spata station is rather new and 30-year average data do not exist; thus the data for Athens are indicated in parentheses. (Data source: Nat. Met. Serv., Min. of Defence).

Crop development was delayed due to the very low winter temperatures in Larissa. The crop was still exceptionally short (30 cm) at the end of March; 50% anthesis was recorded on April 19th, 140 days after germination (100% anthesis occurred on 21/4/89). Despite the somewhat lower than normal temperatures in Spata in 1991, 50% anthesis occurred already on March 3rd, 1991. Anthesis is normally expected to occur earlier in Spata (Athens) than in Larissa due to the higher winter temperatures (Table 4.3.1). Assuming a threshold temperature of 0°C and a mean daily temperature Ta=(Tmax+Tmin)/2, i.e. 964°C-days were accumulated before anthesis in Larissa. Wheat is a long-day plant. For periods with highly variable day length (viz. December vs. May), the process temperature (TPR, °C) takes the day length into account in the calculation of the temperature for development (see Eqn. 4.13). After this refinement, the TSUMpre was finally set to 920°C-days. Evidence of a threshold temperature (Th) higher than 0°C (as suggested by some authors) was not found.

In Larissa, physiological maturity was recorded 48 days after anthesis, viz. on 6/6/1989. This is rather late, considering that the harvest of wheat normally starts in mid-June. The irrigated plants were still green at maturation, in contrast with the rainfed crop which was rather dry at the harvest on 31/5. Actually, the growth of the (rainfed) plants may cease long before physiological maturity in dry years. In Spata, maturation was recorded on 28/5, viz. 55 days after flowering. TSUMpost is almost identical for the Spata and Larissa plantings and amounts to 800°C-days. After refinement of the process temperature calculation, TSUMpost had to be set to 860°C-days (Th=0°C).

In summary, the flowering and maturation dates of wheat are predicted here as follows:

TPR = [(DAYL*Tmax + (24-DAYL)*Tmin] / 24 (4.13)
IF TPR > = Th THEN TACT=TACT+(TPR-Th) (4.14)
IF TACT/TSUMpre <1 THEN DVS=0.5*(TACT/TSUMpre) (3.34a)
IF TACT/TSUMpre> =1 THEN DVS=0.5+0.5*[(TACT-TSUMpre)/TSUMpost] (3.34b)

where TPR is the process temperature for development (°C), DAYL is the day length (hours), TACT is the total accumulated heat sum above the threshold temperature (°C-days), Th is the threshold temperature (°C), TSUMpre & TSUMpost are the total accumulated heat sum above the threshold temperature at anthesis and maturity, respectively (°C-days), and DVS is the development stage of the crop. Note that DVS=0.5 at flowering and DVS=1 at maturity.

(Specific) Leaf area and leaf morphology

The specific leaf area (SLA) is an important crop characteristic that changes with time and environmental conditions. The importance of SLA in the present approach has been discussed in previous sections. Literature on the SLA of wheat is limited. Van Heemst (1988) mentions that the SLA of some wheat cultivars studied by Aase (1978) had a constant value of 20 m^2/kg. Fisher *et al.* (1981) reported that SLA of single leaves varied with time from 22 to 13 m^2/kg across 48 irrigated spring wheat genotypes. In Larissa, the overall SLA of cv. Mexicali was also found to vary over time. SLA decreased from an initially high value (31 m^2/kg) to about 15 m^2/kg some days before maturation. Fig. 4.3.1 demonstrates that the overall SLA values of both rainfed and irrigated plantings (Larissa, 1988-89) depend largely on the degree of development (DVS). Recall from Subsection 4.1.2 (paragraph on SLA), that a logarithmic relationship between SLA and DVS was also found for the studied maize cultivars. As in maize, the leaves of wheat will become thicker at advanced development stages and/or new, thicker leaves are formed. There is no evidence of different SLA-values in the two treatments. However, the available data are limited and the subject deserves further study. The relationship depicted in Fig. 4.3.1 is used in the present version of the crop-growth model for DVS>0.32. The value of SLA is unknown for DVS<0.32; a substitute value of SLA=31.8 m^2/kg is substituted for DVS< =0.32 (dashed line in Fig. 4.3.1).

Fig. 4.3.2 presents the leaf area index (LAI) for the two plantings in Larissa. The LAI was 3.41 at the end of March, increased to its maximum value of 6.3 just before flowering, and decreased again due to the decreasing SLA and dry leaf mass (leaf senescence), to reach a minimum value at maturation (Fig. 4.3.2). The effect of the soil moisture availability on the LAI is apparent from the same Figure. The lower LAI of the rainfed plants reflects the higher dying rate of their leaves, induced by water stress. In model calibration, no need for different senescence rates than those calculated for the leaves of maize plants became apparent. The accumulated heat requirement for the life span of wheat leaves (TSUMLLS) was thus set to 1300°C-days (threshold temperature, THLLS=0°C), which is of the same order as the values Evans (1983) found for varieties of soft wheat, viz. LLS=77 days at 17.7°C (see also van Heemst, 1988). In the Larissa experiment, this heat requirement was met in the first ten days of May.

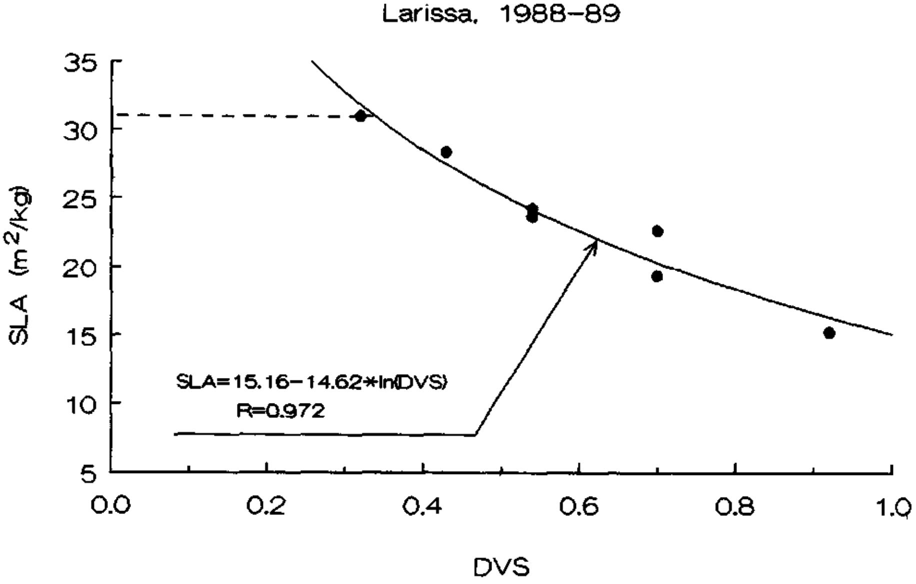


Fig. 4.3.1. Change of the specific leaf area (SLA) of wheat cv. Mexicali with the development stage (DVS).

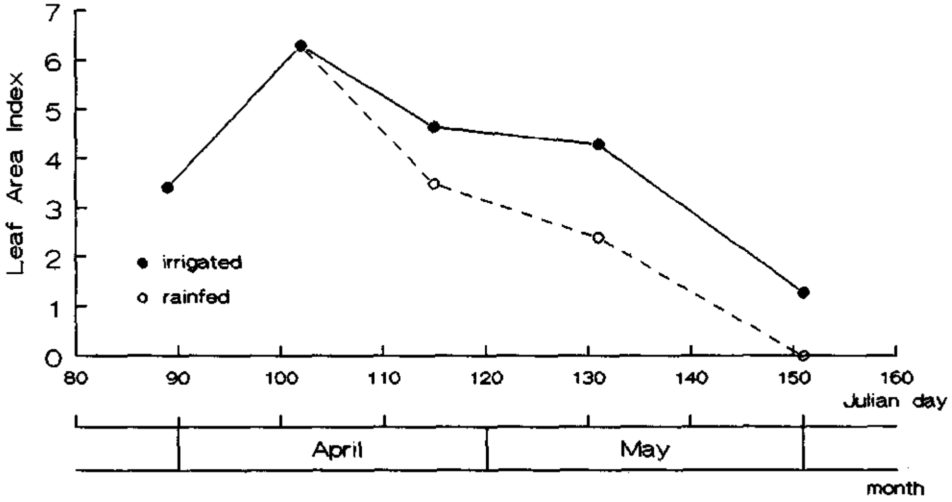


Fig. 4.3.2. Change of the leaf area index of wheat cv. Mexicali for irrigated (•) and rainfed (o) plantings in Larissa, 1988-89.

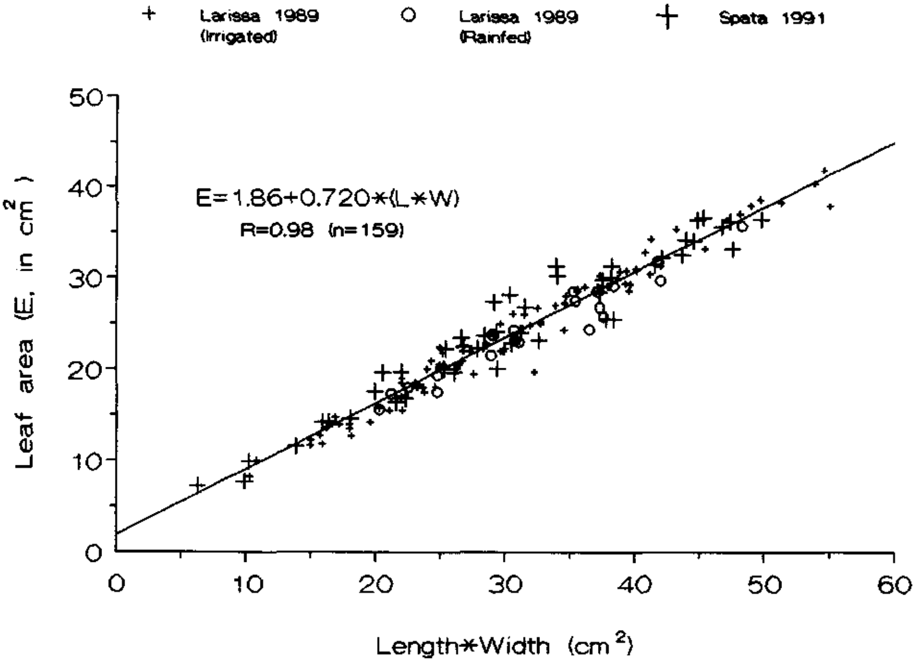


Fig. 4.3.3. Relation between leaf surface and leaf length x width for wheat cv. Mexicali grown in Larissa (1989) and in Spata (1991).

The leaf angle varies with the genotype, especially after the vegetative period. In most cultivars, the leaf lamina, though erect when unfolding at the top of the canopy, soon bend to a more horizontal position (planophylic canopy). The small leaves of some other genotypes resist bending and lead to an erectophilic canopy. The extinction coefficients (KE) for visible light (PAR) reported in literature vary between 0.42 to 0.54 (Thorne *et al.*, 1988). The KE-value was set at 0.5, based on the canopy structure of the studied cultivar.

Measuring the leaf area by planometer is accurate but time consuming. If expensive apparatus for measuring LAI such as electronic LAI-meters, infrared area meters, etc. are not available, much time can be saved by measuring the leaf length and width and correlating these with the leaf area. Fig. 4.3.3 demonstrates that the latter can be estimated with the following empirical linear relation:

$$E = 1.86 + 720 * (L*W) \quad (R=0.98, n=159) \qquad (4.15)$$

where E is the leaf area (cm^2); and L and W are the length and width of the leaf blade (cm).

Assimilate allocation

The results of the growth analysis are summarized for the Larissa and Spata experiments in Tables 4.3.2 and 4.3.3, respectively. The allocation of assimilates is calculated from the total dry matter increase between two successive harvests and expressed as fractions of that total increase. The final result is presented in Fig. 4.3.4a-d. All curves are eye-fitted. Literature data on wheat are scarce (Williams, 1960, 1966; Gregory *et al.*, 1978a&b; summarized in van Heemst, 1988). The adopted FRROOT-DVS relationship (Fig. 4.3.4a) is identical with the one suggested by van Heemst (1988). Similarity exists in the other FR(organ)-DVS relationships too, except for the FRLEAF-DVS and FRSTEM-DVS relations at $DVS<0.1$. Van Heemst (1988) mentions that $FRLEAF=0$ at $DVS=0$, but increases sharply from there to reach 0.59 at $DVS=0.1$, and decreases thereafter. Such low initial FRLEAF values would be acceptable if the initial SLA values were much higher than the ones actually adopted here. The curves of Fig. 4.3.4 are used to feed the crop growth model.

Growth rates

The highest growth rates were obtained on the irrigated (Y), fully fertilized plots in Larissa. They fluctuated around 250 kg/ha per day between the beginning of April and mid-May and reached a maximum of 300 kg/ha per day (Table 4.3.2 and Fig. 4.3.5). In the same period, the canopy was nearly closed ($LAI>4$; Fig. 4.3.2), and the temperature was near optimum, viz. between 14 and 16°C. These growth rates accord with gross canopy assimilation rates of about 700 kg CO_2/ha per day. At an assumed overall relative maintenance requirement of 1.7 percent [$R(organ)=0.017$], the respiration sink of the 8 tons biomass per hectare present at anthesis would be 136 kg CH_2O/ha per day. The resulting (700 * 30/44 - 136) * 0.72 is indeed equal to about 250 kg CH_2O $ha^{-1}d^{-1}$. (30/44 is the ratio of the molar weights of CO_2 over CH_2O, and 0.72 is the approximate conversion efficiency). Calculations for $LAT=40°N$, $DAY=110$, $n/N=0.665$ (see Table 4.3.1) and $LAI=4$ to 5, suggest values of AMAX around 40 kg CO_2/ha per hour. AMAXOPT was set to 40 kg $ha^{-1}h^{-1}$, also suggested in literature for wheat varieties derived from cv. MEXICO (van Heemst, 1988). This is the maximum value of AMAX at optimum temperature. Some literature data AMAX / AMAXOPT vs. temperature are schematically presented in Fig. 4.3.6. The solid line represents the relation adopted here; the effect of day length is accounted for (viz. through the process temperature).

Table 4.3.2. Average dry matter per organ (kg/ha) in successive harvests of durum wheat (cv. Mexicali) grown in Larissa (1988-89) under optimum nutrient supply: rainfed (K), and irrigated (Y).

no. harv.	treatm.	Date(J.day)	Leaf	Stem	S.O. (total)	Seed	Total above	Root
1.	K+Y	30/3/89(89)	1041	1115	0		2156	493
2.	K+Y	12/4/89(102)	2213	3069	0		5282	853
3.	Y	25/4/89(115)	1906	4861	2055		8822	1026
3.	K	do	1471	4107	1849		7427	867
4.	Y	11/5/89(131)	1881	7036	3374		12291	(1026)
4.	K	do	1234	6015	3051		10300	(867)
5.	Y	31/5/89(151)	835	6488	8343	5865	15666	(1026)
5.	K	do	-	4175	6099	4300	10274	(867)
6.	Y	14/6/89(165)	prod. harvest		9554	7338		
6.	K	do	do		5992	4626		

Table 4.3.3. Average dry matter per organ (kg/ha) in successive harvests of durum wheat in Spata (1990-91).

no.	Date(J.day)	Leaf	Stem	S.O. (total)	Seed	Total above	Root
1.	14/3/91(73)	2274	3556	0		5830	566
2.	3/4/91(93)	2046	6516	255		8817	710
3.	16/4/91(106)	2057	6643	1536		10236	(710)
4.	6/5/91(126)	856	8786	3612		13254	(710)
5.	22/5/91(142)	863	7137	6625		14625	(710)
6.	12/6/91(163)	prod. harvest		8484	6745		

An overall conversion efficiency value of 0.72 was mentioned in the above simplified example. The conversion factors (see paragraph 3.1.2) suggested by Penning de Vries & van Laar (1982) and by Penning de Vries *et al.* (1983) are used in the model: ECLEAF=ECROOT=0.72, ECSTEM=0.69, ECSO=0.79 (for ears). The maintenance respiration rates R(organ) adopted after model calibration are: RL=0.0208, RS=0.0145, RR=0.0139 and RSO=0.0165 $kgCH_2O\ kg^{-1}d^{-1}$ for leaves, stems, roots and storage organs, respectively. From these, the RL value is substantially lower than the value calculated by the above authors from biomass composition of leaves (viz. RL=0.03). (The latter value led to considerable underestimation of leaf growth). The reference temperature (Tref) used is 20°C, which is 10°C lower than the value used for the summer crops maize and cotton.

Fig. 4.3.5 (above) presents the growth curves observed for treatment Y and compares them with calculated results obtained with the above crop parameters. Apparently, the measured values and especially the above-ground living dry weight (TLDW) and the final yield production (S.O.) are satisfactorily predicted. In Fig. 4.3.7, the calculated gross canopy assimilation rate (FGC) and the growth rate (NET) are plotted versus time for both plantings in Larissa. Note that FGC and NET were nil throughout the winter due to the prevailing low temperatures (Table 4.3.1). Growth recommenced in the last decade of February, after the temperature rose to 11°C (vs. 4.3°C in the second decade of February). The air temperature (Ta) exceeded 14°C, and accordingly AMAX took its maximum value (AMAXOPT) in the first week of April, when the canopy was almost closed. As a result, both FGC and NET approached their maxima. Leaf senescence resulted in a lower LAI after mid-May (Fig. 4.3.2), and in opening of the canopy and lower FGC rates (Fig. 4.3.7). The temperature fluctuated within the optimum range for assimilation thereafter (Table 4.3.1 and Fig. 4.3.6). The higher temperatures at the end of May resulted in higher respiration losses and accelerated the decrease of NET which finally became nil at maturity (Fig. 4.3.7). Note, however, that grain filling continued at a high rate despite the very low growth rates in late May (Table 4.3.2 and Fig. 4.3.5). This has often been attributed to translocation of stored assimilates to the grains. As in the case of maize, however, it can be explained within the present context without adopting FRSO values in excess of 1. Studies using frequent *in situ* labelling of the whole wheat crop canopy with $^{14}CO_2$ could not confirm translocation of assimilates to the grain (at least not more than about 8%), even under grain filling stress (Stoy, 1979; Bidinger *et al.*, 1977; a.o. mentioned in Fischer, 1988).

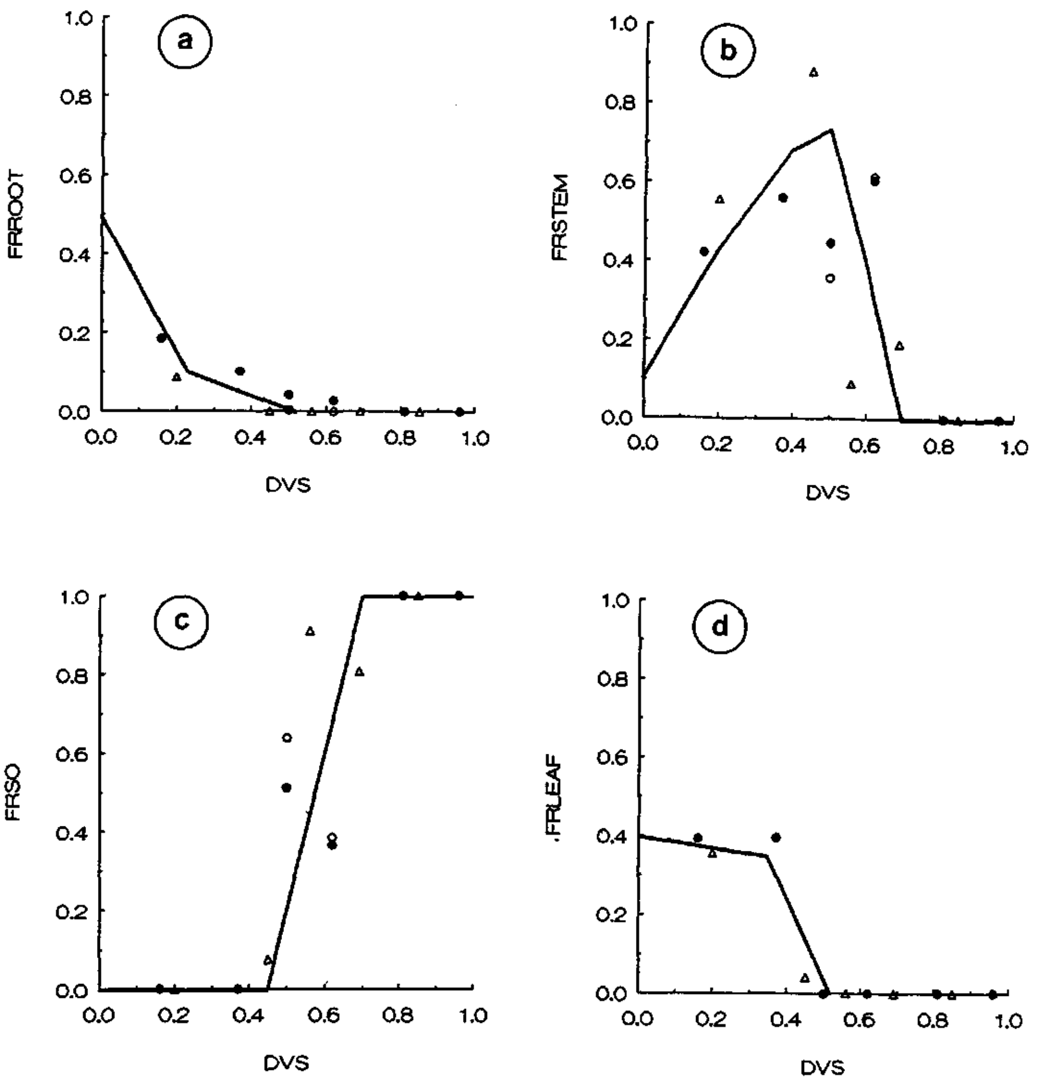


Fig. 4.3.4. Relation between the measured fraction of total dry matter increase invested in the various plant organs, FR(organ), and the development stage (DVS) of wheat grown in Larissa, 1989: (●) irrigated, (o) rainfed; and in Spata, 1991 (Δ).

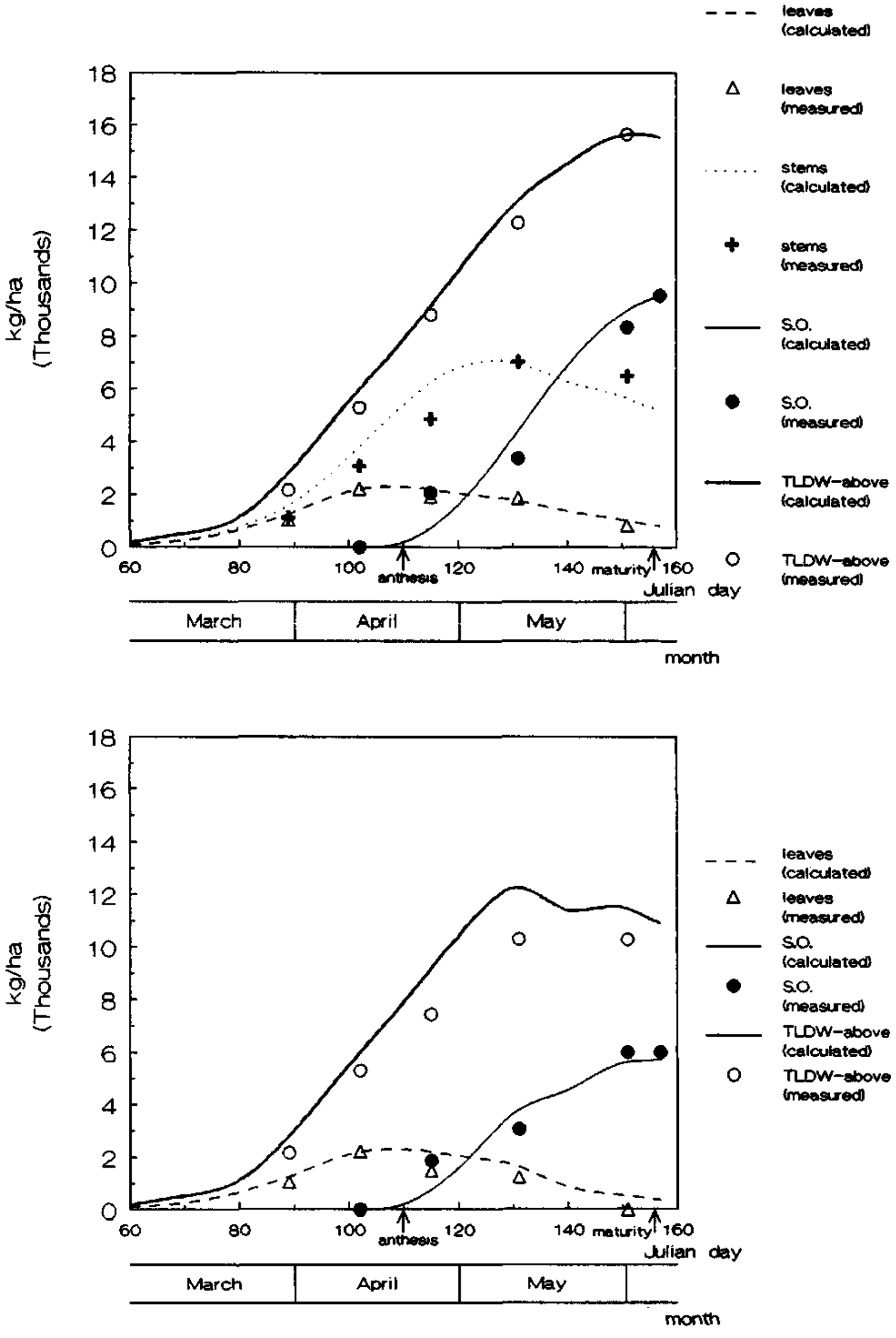


Fig. 4.3.5. Dry matter accumulation in wheat cv. Mexicali grown in Larissa, 1989: irrigated (above) and rainfed (below). (TLDW = above-ground living dry weight; S.O. = storage organ).

Much lower growth rates were observed for the water-stressed plants, especially in late May. Table 4.3.2 and Fig. 4.3.5 (below) suggest an average overall growth rate of about 100 kg/ha per day in the period 10/4-10/5, which dropped to zero thereafter. However, grain filling continued at a rate of approx. 152 kg/ha per day in May, and a reasonably good yield was finally obtained (Table 4.3.2 and Fig. 4.3.5-below). The simulated data of Fig. 4.3.7 indicate a higher drop in FGC of the rainfed vs. irrigated crop in mid-May, which is obviously due to the higher dying rate of senescent leaves induced by drought (see also Fig. 4.3.2). The growth rate declines earlier than that, indicating that water stress occurred at the end of April (Fig. 4.3.7). Low canopy assimilation and considerable drought resulted in a drastic decrease of the net growth rate (NET) of the rainfed crop (K) in May. NET drops to zero or even becomes negative after the 10th of May (Fig. 4.3.7).

Simulated data and field observations deny the occurrence of water stress before the end of April. The potential (Penman) evapotranspiration (based on data of Table 4.3.1) in Larissa was 1.9 mm/day in March and 3.5 mm/day in April 1989. The total consumptive use of 160 mm is about half the precipitation sum (Table 4.3.1). The considerable lower stem weight (about 15% throughout the reproductive growth) and the slightly lower leaf weight than the values calculated at PS2-level are therefore attributed to nutrient stress in the rainfed planting. Recall that planting K missed the top dressing of 210 kg N/ha, which planting Y received in early April. This resulted in the formation or, as explained later, the survival of more shoots at anthesis. As demonstrated in Fig. 4.3.7, however, grain filling and storage organ production were not affected and could be predicted with calculations at PS-2 level (see below).

Yield characteristics, source-sink relations

Crop physiologists maintain that yields can be limited by either the supply of assimilates (source) during grain filling, or by the <u>number</u> and <u>capacity</u> of kernels to be filled (sink), or by source and sink simultaneously. The subject is elaborated by Fischer (1983).

Fig. 4.3.8 shows that the number of kernels per unit area is determined by the number of the individual components of the storage organ of wheat, viz. spikes (storage organs)/surface area x spikelets/spike x florets/spikelet x kernels/floret (the so called "grain set"). The total number of total number of florets initiated per unit area climbs to a much higher value than the final number at anthesis. The actual kernel number at anthesis is by far lower than the potential number because insufficient assimilates are present in the crop to build up all initiated florets to competent ones at anthesis. Fig. 4.3.8 also indicates that the kernel number might decrease further after anthesis but at a rather low rate, and mainly due to tiller mortality. In many studies on the yield components of wheat, their limitation and rise to peak values is reasonably well described, but their survival, which seems highly dependent on the (level of) competition, is poorly understood (Fischer, 1983).

Studies of the kernel weight showed that its final value is less than would be expected on the basis of a linear relation with assimilate supply. At high levels of assimilate supply, the kernel weight approaches asymptotically the potential kernel weight of the genotype (see Fig. 4.3.9). Multiplying both axes of Fig. 4.3.9 by any given kernel number per square meter gives the response of grain yield to total source for that kernel number.

The kernel weight was measured in the last two harvests in Larissa in (small) samples of spikes, randomly collected per replicate and per planting. The mean values are presented in

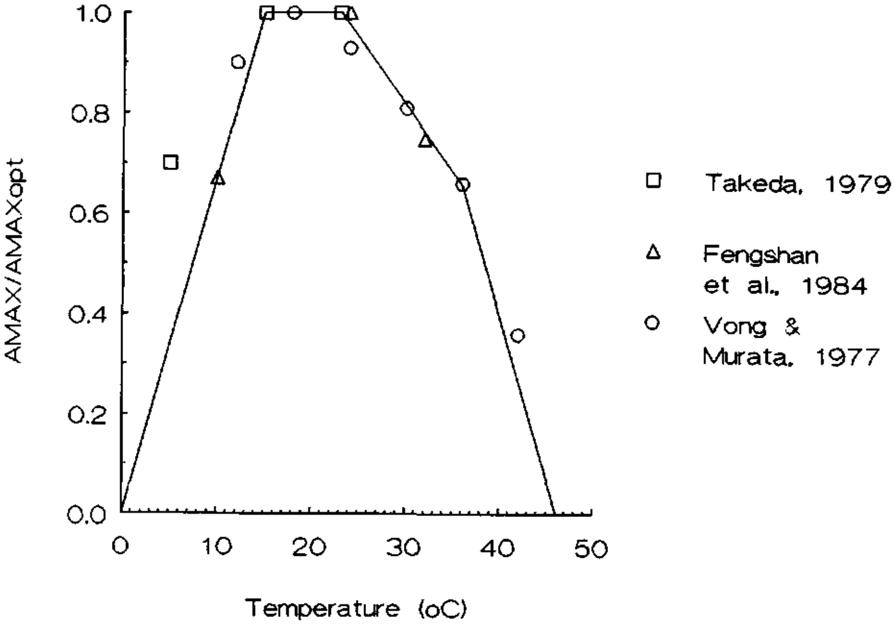


Fig. 4.3.6. Relative leaf assimilation (AMAX/AMAXopt) at various temperatures. Markers denote values suggested in the literature; the solid line represents the relation adopted here.

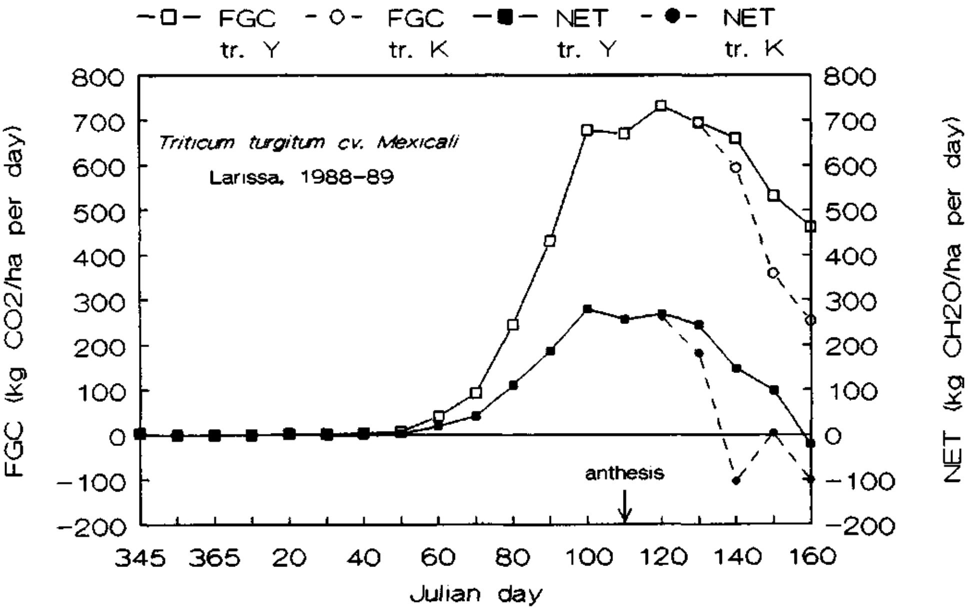


Fig. 4.3.7. Calculated gross canopy assimilation rate (FGC, in kg $CO_2ha^{-1}d^{-1}$; left y-axis) and net growth rate (NET, in kg CH_2O $ha^{-1}d^{-1}$; right y-axis) for rainfed (treatm. K) and irrigated (treatm. Y) wheat cv. Mexicali in Larissa, 1988-89.

Table 4.3.4. Mean of grain yield and straw, and associated traits in durum wheat cv. Mexicali grown in Larissa, 1989.

date	dry	<----------	k e r n e l	---------->		<-- s t r a w -->	
	yield (kg/ha)	/spike ratio	weight (mg)	number /m^2	[N] (percent)	weight (kg/ha)	[N] (percent)
Y-irrigated							
31/5	5,865	0.703	35.5	16,521			
6/6	7,338	0.768	43.6	16,830	2.48	9,539	0.62
Y-control[a]							
6/6	7,153	0.770	49.8	14,361	1.90	8,108[b]	0.37
K-rainfed[a]							
31/5	4,300	0.705	34.1	12,610			
6/6	4,626	0.772	43.3	10,684	2.36	5,541	0.36

[a]Y-control and K without the heavy top-dressing (par. 4.3.1); [b]estimated 85% of treatm. Y.

Table 4.3.4, together with the grain and final biomass attained and the nitrogen concentrations of both plantings in Larissa (1989). It can be seen that the kernel weights in the K and Y plants are similar on 31/5/89, viz. 34.1 (CV=12.5%) and 35.5 mg (CV=6.6%), respectively, and increased at similar rates to their final values at maturity of 43.3 mg (CV=5.6%) and 43.6 mg (10.7%) respectively (Table 4.3.4). These latter values are close to the normal kernel weight reported by the I.C.C.(1985) for the studied cultivar, viz. 44 mg.

Dividing the grain yield over the kernel weight yields an estimate of the kernel number. Table 4.3.4 shows a value of about 16,500 kernels/m^2 for the Y planting. There is no indication of change in the kernel (and tiller) number after anthesis in the irrigated planting (Y), but this seems to be the case in the rainfed crop (K) where the effect of the stressed source (less assimilates due to drought and light efficiency) manifests itself in a decrease of the kernel number rather than in less filling of the existing grains; the weight of the grains continues to increase towards its maximum level. The decrease in the kernel number appears to be caused by tiller mortality (see also Fig. 4.3.8) and (not statistically evident here) by a decreasing number of kernels per spike after anthesis. There is therefore evidence that the crop regulates grain filling to take place under field conditions of source > sink per kernel, even if sink > total source in the post anthesis period. If enough kernels exist at anthesis, the stressed source determines the filling of the grains. This is important for calculations at PS-2 level, because the assimilate production (total source) can be simulated and, if it determines grain filling, the actual storage-organ growth at PS-3 level (nutrient-limited production) can be reasonably predicted.

The final kernel weight in Larissa was near 44 mg for the rainfed planting (see Table 4.3.4), a value which is considered typical for the cv. Mexicali by I.C.C. However, is this the potential weight of the genotype? The answer must be negative. The higher final kernel weight measured in the Y-control planting, viz. 49.8 mg (CV=3.8%) (see Table 4.3.4), is significantly different (at 0.05 and 0.10 levels) from the values which were measured in the K and Y treatments. The Y-control grew under conditions of high source after anthesis. However, the Y-control did not receive a top-dressing of 210 kg N/ha before tillering, as treatment Y, and had a lower sink potential (expressed in kernels per unit area) at anthesis.

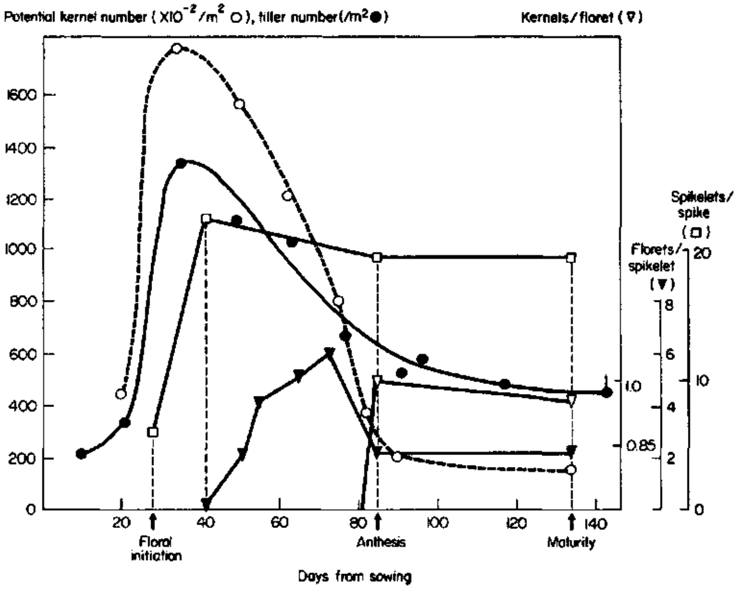


Fig. 4.3.8. Tiller numbers per unit area, spikelets per spike, florets per spikelet, kernels per floret and their product (potential kernel number) for a wheat crop. Potential kernel number refers to tiller number multiplied by either the peak value (at or before its attainment) or the actual value (post-peak) of each of the other components. (Source: Fischer, 1983).

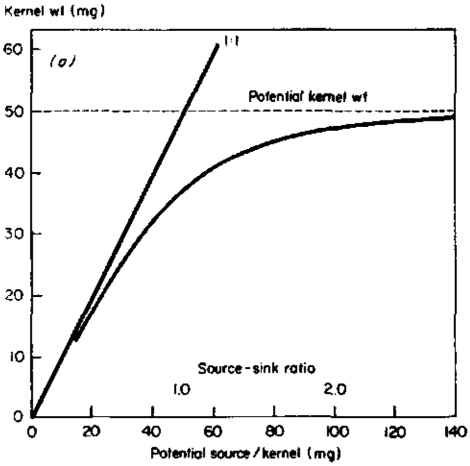


Fig. 4.3.9. Relation between kernel weight and potential source per kernel for a hypothetical cultivar with a potential kernel weight of 50 mg.
(Source: Fischer, 1983).

Assuming that the kernel number remained the same after anthesis (under the prevailing conditions for potential assimilation), the sink potential of Y-control becomes more than 2000 kernels/m^2 less, viz. 14,360 kernels/m^2 vs. 16,520 kernels/m^2 in treatment Y (see Table 4.3.4; lsd(0.05)=2,064). Less tillers survived; kernel numbers per spike were the same for the Y and Y-control plantings, but the data are very variable. The peak yield obtained with treatment Y could also be realized by the control plants (Table 4.3.2) with a kernel weight increased to some 50 mg (Table 4.3.4). This value, therefore, is considered here as the potential kernel weight of the genotype.

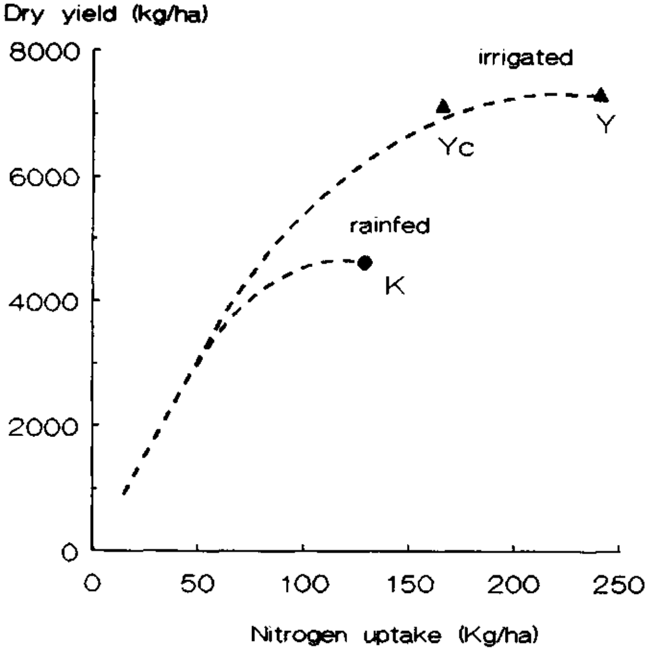


Fig. 4.3.10. The approximate relation between total nitrogen uptake and (dry) grain yield for wheat cv. Mexicali grown in Larissa (1988-89) under rainfed (●) and irrigated (▲) conditions. Markers are based on measured data of Table 4.3.4; the initial slope is set to 60 kg/kg.

Fig. 4.3.10 presents the approximate yield-nitrogen uptake relation for the Larissa plantings. The curves reflect the total nitrogen contained in the final grain- and non-grain biomass produced (see Table 4.3.4). The initial slope of the curve was set to 60 kg/kg. This Figure, though based on minimum information, helps to realize that both irrigated and rainfed plantings reached a plateau level, determined by the total source after anthesis, where the (normal) kernel weight is some 44 mg, and the nitrogen concentration in the grain is relatively high (Table 4.3.4). Towards the initial slope, the minimum possible concentration and the potential kernel weight (50 mg) should be attained. Under conditions of extremely low nutrient levels and accordingly small sink potentials at anthesis, the total source cannot be matched, and kernel growth lags behind the value calculated for the PS-2 level. This happened in Spata (1991), when the storage organ production was by about 1 t/ha lower than predicted. This crop received a basal nitrogen application for average production, whereas the rains during grain filling allowed production at PS-1 level (Table 4.3.1).

When inadequate nutrient supply constrains system performance, the nutrient inputs required to cover the difference can be calculated from the yield-uptake curve and the recovery fraction. This subject will be discussed in the next Chapter. For now, it may be safely assumed that the sink potential of the wheat crop is less than the total source during grain filling.

The high growth rates and the yields obtained (8.5 t/ha at 13-15% moisture), confirm the original hypothesis that the potential production of wheat in Larissa (and more generally in Greece) is considerably higher than formerly assumed. The overall production, and especially the spike growth, of wheat can be satisfactorily predicted at PS-2 level. The dry yield is approximately 77-80% of the calculated final storage organ production (Tables 4.3.2&3).

5 ANALYSIS OF SELECTED LAND USE SYSTEMS

Introduction
Relevant Land Utilization Types
Relevant Land Qualities
Production potentials and reference yield levels
Quantifying the Nutrient Requirement
Land suitability assessment

5.1 Introduction

In recent years, considerable progress has been made in the development of quantified methods for Land Evaluation[1]. Mathematical models (Chapter 1) become increasingly fit to handle Land Use Systems. These are composed of Land Units and Land Utilization Types (see Fig. 5.1) and are by definition dynamic systems (Beek, 1978). Quantified Land Use System analysis requires dynamic simulation of the relevant Land Qualities and of the physical inputs as interrelated variables controlling the fundamental land utilization processes and the resulting outputs (Fig. 5.1). This makes obvious the superiority of deterministic crop-growth models that permit quantitative estimates of the actual and potential yield level.

The actual and potential performance of maize, cotton and wheat was studied in the Larissa plain, the largest lowland formation of Greece together with the Karditsa plain. Rather than attempting to do a land evaluation of the whole area on the basis of the Framework, reference yield levels are calculated and the impact of selected limitations quantified as a basis for Land Suitability Classification. The key attributes of relevant Land Utilization Types are discussed first (Section 5.2). In Section 5.3, the relevant Land Qualities and their arrangement in the simulation model are described, and the Land/Use characteristics considered in the calculations of the production potentials are summarized. The potential production levels are quantified in Section 5.4. These form the basis of Land Suitability Classification in the area (Section 5.6). A methodology for quantifying the "fertilizer-nutrient requirement" (Production Situation 3) is additionally discussed (Section 5.5).

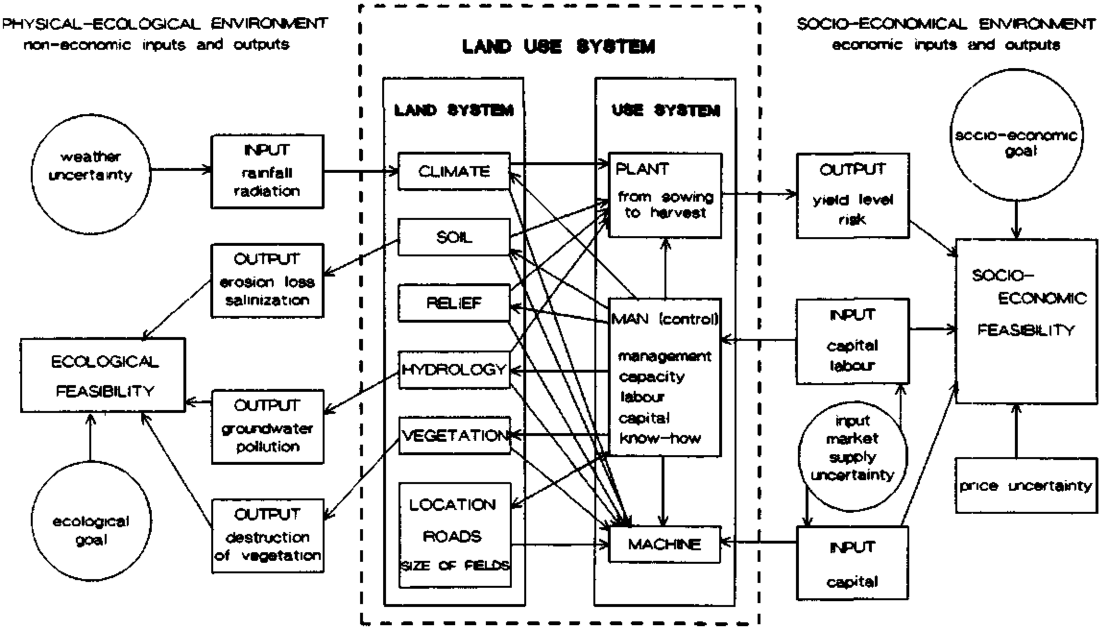


Fig. 5.1. Systems model of Land Evaluation for Agriculture (after Dijkerman, 1983).

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[1] The present text adheres to the concepts and principles outlined in the FAO Framework for Land Evaluation (FAO, 1976); the reader is assumed to be acquainted with the Framework terminology.

5.2 Relevant Land Utilization Types

5.2.1 Major commodities

Maize

Before the late 1950's, maize was grown mainly in the uplands and produced rather low yields. Fig. 1.1 demonstrates that efforts to increase maize production were initially directed at extending the cultivated area. After 1950, the local maize cultivars were replaced by more productive, American hybrids. This, and improved reclamation methods and methods of fertilization and irrigation brought about remarkable yield increases. Fig. 1.1 shows that maize cultivation decreased after 1950. This coincides with a shift of the crop to the more fertile, irrigable lowlands. The parallel introduction of more productive wheat varieties accelerated this shift, as upland maize was replaced by wheat. Mechanization, improved fertilization, pest and diseases control, expansion of the irrigated area and the introduction (1976) of much improved (single) American hybrids resulted in spectacular yield increases in the period 1978-1981 (Fig. 1.1). And so it happened that in 1981, 15 years after rainfed maize growing was pronounced impracticable under the country's climate (Fasoulas & Fotiadis, 1966), Greece ranked first among the maize producing countries, with an average grain yield of about 8.5 t/ha (I.C.C., 1984, based on FAO, 1981).

Maize is among the country's most important crops, with multiple uses in food and other industries and as a vital fodder crop (grain or silage). It is a capital intensive crop, cultivated in areas with existing irrigation structures and comparatively low cost of water, e.g. in the plains of Thessaloniki, Kavala and Agrinio (see Table 5.1). In the Thessaly plain, the water is normally pumped up from deep strata. This water is more expensive.

Table 5.1. Cultivated area, production and grain yield of maize in Greek provinces in 1982.

Province	Cultivated area (ha)	Production (tons)	Average yield (kg/ha)
-East Macedonia & Thrace	70,600	685,450	9,710
-Central and West-Macedonia	27,508	240,929	8,760
-Thessaly	14,641	125,336	8,560
-Peloponnese & Sterea Hellas	30,296	238,543	7,870
-Hepeirus	15,515	120,865	7,790
-Attica & Islands	4,762	37,774	7,930
Total	163,322	1,448,897	8,870

(Source: I.C.C., 1984)

The predominance of the single (American) hybrids since 1980 led to a remarkable yield increase at the cost of some 15 million ECU per annum (prices of 1991). PIONEER 3183 (LORENA) and 3165 (DONA) are among the most popular cultivars. In the mid 1980's, two single hybrids were introduced by the Institute of Cereal Crops to rival the American PIONEER cultivars, viz. ALEXANDROS (1985) with similar specifications as P.3183; and ARIS (1984) with a somewhat shorter growing cycle. Promotion and subsidies furthered acceptance of the Greek hybrids; ARIS covered 10% of the maize-cultivated area in 1985 and (together with cv. ALEXANDROS) about 50% in 1986. Today, maize prices float with the Greek hybrids sold at 3.83 ECU/kg seed vs. 4.26 ECU/kg seed for the American hybrids.

ARIS is a popular cultivar in the Larissa area, together with the cv. P.3183. P.3165-(DONA) is not common in Larissa but is widely used in areas with shallow groundwater, e.g. the plains of Axios-Thessaloniki and Agrinio. P.3183 is also used there, whereas ARIS is less popular.

Cotton

Some 9,050 hectares were planted to cotton in 1911. The crop covered 20,200 ha in 1930, producing an average yield of 530 kg/ha. After 1931, when the Greek Cotton Institute and Organization were founded, the crop received increased attention, especially in the decade 1952-1962 when the irrigated area increased to 55% (Chlichlias *et al.*, 1981). The promotion of *Gossypium hirsutum* L. completely eliminated *Goss. herbaceum* L. and *Goss. arboreum* L., which had been cultivated in Greece for nearly two millennia. The yield was doubled by the late 1950's. The cultivated area reached the record level of 237,000 ha in 1963 (it fluctuated around 160,000 ha thereafter). After the first exports in 1951, emphasis was given to the quality of the yield. In 1983, Greece became 5th among the cotton producing countries with an average yield of approx. 2.5 t/ha and a total of 168,000 ha under cotton.

Due to increasing demands at the local market (lint and seed-oil industries, etc.), it is attempted to extend the (irrigated) cotton cultivation to 200,000 ha. Expansion beyond this target is questionable in the context of the EEC, considering the rapid growth of cotton cultivation in Spain (to more than 200,000 ha). Widening of the EEC to the north and/or east is believed to increase the needs for cotton in the future.

Cotton is particularly important in the Thessaly plain where, according to the latest available figures (Pagonis, 1987), it covers 54% of the total cultivated area (92,880 ha). However, the observed stagnation of the cotton yield in the last decade, the considerable year-to-year yield fluctuations, and the failure of the crop in some areas indicate that Greece lies close to the northern border of the cotton belt. It is therefore useful to investigate whether cotton yields can be further increased using advanced management and up to date production methods such as drip irrigation.

Wheat

Rainfed wheat is by far the widest cultivated crop in Greece. The crop grows on about 1 million hectares (25% of total cultivated land), and produces 3.14 million tons of grain, equivalent to about 640 million ECU (prices of 1991). In the Thessaly plain, wheat grows on 185,000 ha, 48% of all wheat being durum wheat.

The country became self-sufficient in wheat in 1957. Its great adaptability and tolerance to extreme conditions made wheat a popular crop; it was never fully replaced by other winter cereals or fodder crops. In many cases the opposite occurred, i.e. expansion of the wheat area, notably in the uplands, where wheat replaced other crops which were confined to the more fertile and irrigable soils of the lowlands. Per-hectare wheat yields will probably increase in the future as improved cultivars are introduced and (supplemental) irrigation and fertilization become better. This holds especially for durum wheat, which covers only 30% of the cultivated area at national level. The present potential of durum wheat in Greece is estimated at 6 tons grain per hectare (Institute of Cereal Crops, 1985). As apparent from Section 4.3, this probably is an underestimation. It is therefore justified to investigate this potential as well as the inputs required for its realization.

5.2.2 Management attributes and market orientation

Irrigated maize and cotton; farm operations

- *Preparation and sowing*: The cultivation of maize and cotton is fully mechanized in the Larissa area. The fields are normally ploughed in the fall and again at the end of the winter (February-March), and disked and harrowed before sowing. Early sowing is attempted; maize is sown as soon as the temperature stabilizes above 10°C (begin April), and cotton is sown when the temperature reaches 14-15°C in late April. Often, sowing is delayed until mid-May, notably on soils with fine textures and/or shallow groundwater.

Sowing is done with own machinery or with hired means (man-and-machine). About 5,000 sowing machines are registered in Larissa (Min. Env., Plan. and Public Works, 1987), serving an average of 2.1 ha/machine. Maize is sown in rows 70-80 cm apart, with plant distances of 17-22 cm in the row (the depth of sowing is 4-7 cm). Mechanized harvesting of cotton requires a distance between the rows of (typically) 1 meter; 20-30 kg seed is used per hectare (average plant densities 11-14 plants/m^2; emergence >80%).

Weed and insect control usually take place usually before or just after sowing. When the maize plants are 50-60 cm tall, the land is harrowed once more.

- *Fertilization*: A variety of fertilizers is available in Larissa; ammonium phosphate (20-10-0) and ammonium- or calcium ammonium nitrate (35.5-0-0) are the most widely used. These fertilizers are available in bags of 50 kilograms and sold (1991) against 10.2 ECU/bag and 6.38 ECU/bag, respectively.

Normally, a basic dressing of ammonium phosphate is given before sowing. When the maize plants are 40-60 cm tall, or upon formation of the first cotton buds, the soils receive a top-dressing of ammonium nitrate. The average applications are as follows:
Maize: Basal dressing: 500-600 kg (20-10-0)/ha; top-dressing: 400-500 kg (35.5-0-0)/ha. Approximate total cost: 155-188 ECU/ha.
Cotton: Basal dressing: 300-500 kg (20-10-0); top-dressing: 150-300 kg ammonium nitrate per hectare. Approximate total cost: 80-140 ECU/ha.
Potassium fertilizers, though available in Larissa, are normally not used.

- *Irrigation*: Sprinkling irrigation of maize is common in the Thessaly plain and applied in Larissa. In the critical period, evapotranspiration may exceed 7 mm/day, and growth is impossible under rainfed conditions (Section 4.1). However, irrigation is not applied until the plants reach a height of 40 cm, because of the still low atmospheric demand but also to force the plants to grow a deep root system. Shallow rooting might be fatal later in August, when strong north winds occur. From then on, the crop is irrigated every 7-9 days until physiological maturity.

Many farmers seem to underestimate the negative effects of delaying (in some cases without serious reasons) irrigation. Farmers who cultivate small parcels can irrigate more often (viz.

4-6 days), but still follow the general rule and irrigate every 7 to 9 days.

Cotton receives irrigation less frequently than maize, according to the advice of the extension service. Tolerant varieties (ZETA) are widely used in Larissa. Only one irrigation is applied before formation of the first buds, when plant growth ceases under moderate water stress. In total, 3-5 irrigations are applied during vegetative growth (until mid-August). The farmers irrigate when the stem turns reddish 2 cm below the leaf petiole, or when the leaf colour becomes darker. After mid-August, 1-2 irrigations may be applied. The extension services (including both the Cotton Institute and Organization) advice not to apply the last irrigation before the end of August or the beginning of September. The experienced farmer knows, however, that a rainy-cool weather at the end of the summer may cause a substantial yield loss, whereas irrigation throughout a dry September may increase the yield. The time of the last irrigation depends on the farmer's judgement.

Irrigation in the Peneios delta is a particular case; shallow groundwater limits the need for irrigations to 3 to 4.

- *Diseases and their control*: Maize: Reported diseases are due to insect attacks, viz. *Sesamia nonagrioides*, *Aphis maydis*, *Tetranychus urticae*, etc., or fungi, viz. *Ustilago maydis*, *Helminthosporium turcicum*, *Puccinia sorghi*, etc. (I.C.C., 1984). Experience in the area teaches that only *Sesamia* poses a serious problem, particularly in late crops. Yield losses due to *Sesamia* do not exceed 2-5% in most fields. Flooding of the Peneios river may delay sowing, which is associated with yield-losses of more than 20% due to *Sesamia* infestation. Growing maize as a second crop (viz. after wheat, etc.) is thought to be problematic, if not impossible in the Larissa area.

Cotton: Larissa is one of the areas where cotton suffers from *Verticillium dahliae*. The disease could be brought under control by introducing the highly tolerant *Goss. hirsutum* varieties ZETA-2 and ZETA-5, and (two year) rotation with winter cereals and/or maize. These varieties were selected in the Cotton Institute from genetic material from the USA (Greek Cotton Organization, 1985). Two more cotton-diseases are important in Larissa, viz. *Tetranychus* spp. and *Pectinophora gossypiella*; these are especially dangerous in July and August. Chemicals such as Aziphos-ethyl and Carbaryl are available in Larissa.

- *Defoliation* of cotton is normal practice in the study area to facilitate mechanized harvesting. In addition, it accelerates boll maturation, and improves the quality (higher purity, less moisture content). A number of defoliating chemicals, including some recently introduced maturation-accelerating products (Ethrel, etc.), are available on the market and supplied by the Agricultural Bank at low prices. Defoliation is normally induced when 30-40% maturation occurs, but application times and doses depend on the farmer's judgement.

Wheat; farm operations

In Larissa (and more generally in Greece), successful cultivation of rainfed wheat must start early to cope with the increasing temperature and water stress in late spring and early summer. Tillage and sowing take place in the autumn season, when favourable soil conditions prevail after the first rains. In Larissa, this occurs some time between late October to early December, but normally in a dry spell in mid-November, when the temperature is about 10°C. Even though the crop grows in the winter, the Greek varieties belong to the spring wheat types. They are (moderately) sensitive to low temperatures if compared to the highly tolerant winter types, but the latter are too late and therefore unsuitable for rainfed cultivation in Greece.

The crop receives some 100-150 kg N and 30-40 kg P per hectare, in one or two applications, normally as ammonium phosphate and ammonium nitrate (estimated cost=76-102 ECU/ha). The crop is rainfed with the possible exception of a few fields neighbouring irrigation channels. These may receive one or two supplemental irrigations. The irrigated crops yield considerably higher, viz. 4-6 t/ha, but still not as much as could be with better fertilization. There is the impression that farmers are unaware that heavy fertilization, harmful under rainfed conditions, may triple their yields if applied correctly under irrigated conditions. Yields of 8 t/ha are claimed by some farmers on very fertile soils, e.g. Farsala Mollisols.

The crop flowers normally between 10 and 30 April and is harvested between 15 June and 15 July. Harvesting is fully mechanized (hired man-and-machine). In the province of Thessaly, 1,500 combine harvesters serve 150 ha each (Pagonis, 1987); 8% of the harvested product covers the average harvest cost.

Methods and cost of irrigation

General

The Larissa plain is plagued by a general lack of water. In 1987, 79,000 ha were irrigated; this area constitutes only 39% of the total arable land of the Larissa prefecture (National Service of Statistics). Irrigation water is normally drawn from the groundwater. Further exploitation of the aquifers is questionable (Pagonis, 1987); the lack of water is expected to aggravate in the future, at least until the Aheloos-River-Works irrigation project is completed.

Due to the water shortage, overhead (sprinkling) irrigation is normal practice in Larissa, and more generally in the Thessaly plain. The water is pumped either from private wells using deep-water pumps installed on-farm, or it is delivered to the farms from a closed conveyance system with a communal central pumping station. Only along the Peneios river, surface methods are occasionally applied. These involve small basins for orchards or gardening, or wild flooding in some wheat fields adjacent to irrigation/drainage channels. During the last decade, drip irrigation is used in orchards and vineyards, particularly on the slowly infiltrating Alfisols of the Pleistocene terrace.

Sprinkling irrigation makes use of "traditional" periodic hand-moving lateral systems with small sprinklers, and systems involving large sprinklers. The latter can be further divided into stationary large sprinklers and automatic travelling guns. Travelling guns have recently gained in popularity and tend to replace all other irrigation systems in spite of the high initial cost.

The most commonly used sprinkling irrigation systems and their advantages and disadvantages are briefly discussed in the following paragraphs with emphasis on cotton and maize cultivation. Drip irrigation is also discussed because of its potential for the immediate future.

Lateral moving systems

Irrigation with these systems has a tradition in Thessaly. Hand-moved, light aluminum laterals are available on the local market in lengths of 6 meters. The rotating sprinklers are single or double-nozzled and discharge 1-4 m^3/hour; the most popular (or available?) sprinklers in Larissa discharge 1.5 or 2.5 m^3/hour. Operating pressures range from 2 to 4 atm.

The set-up of an irrigation system is normally worked out by staff of the Institute of Soils or the Land Reclamation Service. Note that the following three conditions should be met:

- the distance between the sprinklers on the laterals (Ss) should be equal to or less than half the wetted diameter of the sprinkler;
- the distance between the laterals (Sl) should be equal to or less than 65% of the wetted diameter for low wind speed (0-2.2 m/s), or 50% for high wind speeds; and
- the distance between two diagonal sprinklers (on adjacent laterals) should be less than or equal to 75% of the wetted diameter.

Theoretically, it is always possible to irrigate with rates similar to the infiltration capacity of the soil. The maximum application rate is given by the formula:

$$Vo = 1{,}000 * q / (Ss * Sl) \quad \text{(mm/hour)} \tag{5.1}$$

where q is the discharge per sprinkler (m^3/hour), and Ss and Sl are expressed in meters.

Assume for example that a soil is to be irrigated, having an infiltration capacity as low as 6 mm/hour (viz. Platanoulia Alfisols, etc.). A combination of discharge and wetted radius is chosen from the manufacturer's table for a given pressure. Assume that q=1.5 m^3/hour and radius=14.5 m. The distances Ss and Sl, should be divided by the length of the aluminum laterals available on the market, i.e. 6 meters. Taking into account the above 3 conditions, one may choose: Ss=12 m, Sl=18 m, and SsxSl=216 m^2. This set-up provides a Vo=1,500/216=6.9 mm/hour, which is in the range of the infiltration capacity of the soil. The number of sprinklers can be simply calculated by dividing the total discharge of the pump by the discharge of the sprinkler, q. For q=1.5 m^3/hour and a pumped discharge of 30-32 m^3/hour, 20 sprinklers suffice, e.g. 2 laterals with 10 nozzles per lateral.

This method takes advantage of the low discharge rates of private pumps (low water availability). The system is ideal for the sloping areas of the Middle Thessalic Threshold and the undulating to rolling piedmonds and foot slopes surrounding the Larissa area. The already high labour cost for moving the laterals (normally after 3-6 hours), inspecting the proper operation of the system, and travelling to/from the field are multiplied if the area irrigated consists of several parcels situated at some distance from each other. The high pumping costs and the sensitivity to strong winds are additional disadvantages, but these are much less disturbing than in the case of travelling guns.

Large sprinklers and travelling guns

Many farmers in the area use large (gun) rotating sprinklers to avoid the high labour requirements for moving the installations. The large sprinklers have diameters of 18-26 mm, and serve to a radius of 40 m. However, the high pressures involved increase the pumping costs considerably.

The travelling gun sprinkling system consists of a gun sprinkler mounted on a chassis to which a flexible 400 m hose is connected. The traveller unit -a metal structure with 2 or 3 wheels- is pulled along fixed travel lanes by a cable reel. The speed of the reel can be regulated.

The rainfall intensity (Vo, in mm/hour) is constant and determined by the discharge (Q, in m^3/hour) and the width of the irrigated strip (E, in m). The sprinkling radius is determined by the nozzle diameter (nd, in mm) and ultimately by the Q and the operating pressure (H, in m). The system used during the field experiments of 1987 operated with a discharge of 50 m^3/hour (H=55 m, nd=24 mm, and E=70 m) and a rainfall intensity of 20 mm/hour. The large discharges and pressures required for the operation of travelling guns, result in rainfall intensities between 15 and 22 mm/hour in the study area. At an average discharge of 30 m^3/hour and an irrigation width E=60 m, the application rate would amount to 17 mm/hour. Such high intensities result in incipient ponding on many of the studied soils. The farmers take advantage of the initially high infiltration rate because of the high sorptivity component, especially after a long irrigation interval to realize a sizeable irrigation depth (Section 3.3). It is remarkable that many cotton and maize producers, though skilled with regard to other cultural practices, make incorrect use of the travelling guns on their land. Many of them believe that ponding or run-off indicate that the soil received sufficient water to meet the crop requirement over a "normal" irrigation interval. Some farmers know that only the uppermost soil layer is wet when ponding starts, but still use this "system" that saves them time and efforts. The farmers are experienced enough to regulate the travelling speed so that run-off is largely or totally avoided.

Travelling guns involve minimum effort. The farmer moves the rotating reel to the next strip, unreels the cable with his tractor, regulates the travelling speed and turns the motor on. The overall operation should not take more than 30 minutes. After one strip is irrigated, the system turns off automatically. In spite of their high price, travelling guns tend to replace the traditional sprinkling irrigation systems in Larissa, even in areas with low conductivity rates. In 1991, the price of the complete system ranged between 10,640 and 14,900 ECU, depending on the reel diameter. An additional disadvantage is the rather irregular distribution with strong winds. This is particularly disturbing if irrigation takes place when the strong "livas" blows. Irregular distribution due to strong winds might have caused a difference of 2 t/ha in maize grain-yield on two neighbouring fields in the Nikea area in autumn 1987.

Drip irrigation

Drip irrigation is common in orchards (pears, apples) and vineyards on the Pleistocene terrace, which produce excellent yields. In 1988, only a few progressive cotton farmers applied drip irrigation in the study area. Exact figures do not yet exist, but is believed that the irrigated area in the greater Thessaly plain may exceed 1,000 ha today.

Operation pressures and pumping costs are rather modest. The high degree of automation minimizes labour costs and maximizes the operating hours. The installation and removal of the laterals is simple and not time consuming, and the laterals do hardly hinder cultivation practices. The obvious disadvantage of micro-irrigation is the high investment required. In 1988, drip irrigation was applied to maize and cotton in TEI-Larissa, with laterals placed every second row and emitters at every meter. The price of the laterals ran as high as 1,390 ECU/ha (price and exchange rate of 1988). In the case of sandy soils, the price might be even higher. Manufacturers guarantee the laterals for many years. It is believed that with a proper storage, 5 years of use may be safely assumed.

Market orientation

Maize: No restrictions exist as in sugar beet and tobacco cultivation. There is a steady market; the State (via KYDEP) is the major buyer. Prices are announced every year and are irrespective of the cultivar and the quality of the product (viz. N-concentration, etc.). In 1991 the price was fixed at 167 ECU/ton grain with a moisture content 13-15%. For every percentage unit above 15%, the farmer was charged 5.35 ECU/ton (drying cost). This rarely affects farmers in Larissa, where the commonly used maize hybrids mature well before the onset of the autumn rains. The harvest is mechanized (hired man-machine). The price is close to 8% of the value of the harvested product.

Cotton is a basic commodity with a secured bottom price. In 1991, the average price was 1,063.8 ECU/ton seed-cotton. The actual price depends on the quality of the product, notably on the micronaire index, the moisture content, and the purity and weight (percentage) of the lint. In 1988, cotton of reasonably good quality was sold at 14% less than a product of the highest quality (viz. 3.5/29/8/0/36) (Souflias, pers. commun.). In 1991, the farmer bought the seed for 1.30 ECU/kg; this brings the average seed cost to 36-39 ECU/ha. Picking is mechanized in most of the Larissa plain (except for some fields in the Peneios delta area); 815 cotton collectors were registered in the Thessaly plain corresponding to about 115 ha/collector (Pagonis, 1987).

Wheat: As for maize and cotton, the market of wheat is secure. The price is determined each year. In 1991, the price was 191.5 ECU/ton for soft wheat and 234 ECU/ton for durum wheat. In the same year, the farmer bought the seed for 0.68 ECU/kg; this brings the average seed cost to about 17 ECU/ha.

5.3 Relevant Land Qualities

5.3.1 Comparative importance of major Land Qualities

Following the "Wageningen approach" (see Chapters 1&3), the algorithm consists of a hierarchical arrangement of Land Quality analyses. At the highest level, the availability of light is evaluated (Production Situation 1 or PS-1; Table 5.2). As temperature and light regimes cannot be manipulated, these factors determine, within the physiological capacity of the crop/cultivar, the "biophysical production potential". The PS-1 potential serves as a reference for production calculations at lower hierarchical levels.

The lower the hierarchical level at which a Land Use System is analyzed, the more Land Qualities and Land Use Requirements are considered, and the closer the resemblance between the simulated Production Situation and the situation in which Greek farmers operate. The influence of moisture availability on crop production is additionally taken into account in analyses at the second hierarchical level situation (PS-2). In other words, system performance in PS-2 is determined by intercepted irradiance, temperature and availability of water.

At the third hierarchical level (PS-3), the availability of nutrients is additionally taken into account. And so forth.

Although more land quality/requirement analyses can be added at still lower hierarchical levels (Table 5.2), data needs and analytical complexity might increase to a point where meaningful analysis is no longer possible.

Table 5.2. Analysis of Production Potentials

	LAND USE SYSTEM	
	LAND UNIT	LAND UTILIZATION TYPE
PRODUCTION SITUATION	LAND QUALITY	ASSOCIATED REQUIREMENT
PS-1 (level 1)	Availability of solar irradiance	Photosynthetic energy requirement at prevailing temperature
PS-2 (level 2)	Availability of water for uptake	Maximum water requirement (transpiration rate)
PS-3 (level 3)	Availability of nutrient(s) for uptake	Nutrient(s) requirement
PS-4 (level 4)	"Another land quality"	"Corresponding crop requirement"
PS-5 (level 5)	etc.	etc.
etc.		

Table 5.3. Basic data required for the simulation of the biophysical production potential (Production Situation 1).

Symbol	Description	Source/availability
Location		
LAT	Latitude (^{0}N)	** Topographic maps
Weather data		
AVRAD	Measured total radiation (J m^{-2} d^{-1}), or	* Meteorol. Service
SD	Measured sunshine duration ratio	** Meteorol. Service
TMAX	Measured maximum air temperature (^{0}C)	** Meteorol. Service
TMIN	Measured minimum air temperature (^{0}C)	** Meteorol. Service
Crop/cultivar data		
KE	Extinction coefficient for visible light	** WL
SLA	Specific leaf area (m^2 kg^{-1})	** This text
AMAXOPT	Max. rate of gross CO_2 assimilation of a single leaf (kg CO_2 ha^{-1}h^{-1})	** WL, adapted here
FR(organ)	Assimilates partitioning fractions	** This text
EC(organ)	Conversion efficiency [kg (dry matter) kg^{-1}(CH_2O)]	** WL, adapted here
R(organ)	Relative maintenance respiration rate [kg (CH_2O) kg^{-1} (dry matter) d^{-1}]	** WL, adapted here
TSUM(1)	Temperature sum before anthesis (^{0}C-days)	** This text
TSUM(2)	Temperature sum after anthesis (^{0}C-days)	** This text
TSUMLLS	Temperature sum for leaf life span (oC-days)	** This text
TH	Threshold temperature(s) (^{0}C)	** This text
THLLS	Threshold temp. for leaf life span (^{0}C)	** This text
SINI(organ)	Total dry weight at beginning of the first interval (kg ha^{-1})	** Values suggested in this text

WL: values from (Wageningen) literature can be used.
Data availability in Greece: ** available; * available for some areas.

For the first 2 Production Situations, dynamic simulation of Land Use Systems behaviour uses the "state variable approach": dependent variable values are assumed invariant for the duration of short intervals in the growth cycle and reflect the state of the system during these intervals. All values are adjusted after completion of the calculations of an interval. The major advantage of this technique is that interactions between quality-requirement combinations, positioned at different hierarchical levels, are accounted for automatically (Driessen & van Diepen, 1986). The outcome of the calculations are production/yield figures. From PS-3 on, production and yield can be introduced as target values; PS-3 calculations estimate the inputs that must be made to realize them.

5.3.2 Data needs

The data required can be divided into 4 types:

- Constants do not change in the course of a crop cycle as they are invariant characteristics of a certain location or land use. Examples are the pore space, the standard sorptivity, the saturation conductivity of the soil, and the threshold temperature, the accumulated heat units for anthesis, the saturated photosynthesis of single leaf, etc.

- Forcing variables vary with time, but in an exogenous way, independent of the crop production process. They do influence system behaviour, e.g. weather data- temperature, precipitation, wind velocity, etc.

- State variables vary also with time, but in an endogenous way as a result of calculations. Their values have to be set at the onset of the simulation. The rate of change during a certain interval times the interval length is used to adjust each state variable value at the end of an interval. The resulting value is used in the calculations of the next interval; and so on. Examples of state variables are the initial soil moisture content, dry weight, and the equivalent rooting depth.

- Rate variables quantify the rates of change of the state variables. Their values are determined by the state variables and the forcing variables according to rules formulated from knowledge of the underlying physiological and physical processes, viz. SLA, FR(organ). The functional relations of the rate variables are input in the model.

The data required for Production Situations 1 and 2 are summarized in Tables 5.3 and 5.4. Some data values are generally valid while others are system-specific so that measured values are imperative. In the above Tables, a distinction is made between system-specific data and data, which can safely be taken from literature. In addition, the availability of the data in Greece is indicated.

The weather data TMAX, TMIN and SD (Table 5.3) are forcing variables; TSUM(1), TSUM(2), TSUMLLS, TH and THLLS are crop/variety/cultivar-specific constants, and -as a rule- measured values should be used. The value of SINI (Table 5.3) depends on local cultivation practices, notably on the plant density of the crop. SLA and FR(organ) (Table 5.3) are rate variables calculated as functions of the development stage of the crop (input of functional relations is imperative). EC(organ) and R(organ) (Table 5.3) are crop constants that depend largely on plant composition, and -as discussed in Section 3.1- values are available in the literature, and used here with or without adaptation (Chapter 4). The same applies to the crop constants AMAXOPT and KE (Table 5.3).

Much of the soil physical information required for simulating the crop's production environment is related to the geometry of the soil matrix and correlated with the matrix potential. In the pilot areas, quantitative correlations have been established for representative soils with similar mineral composition and other conditions, viz. cultivation, compaction and degree of development, with respect to soil physical constants like SMO, SO, A, KTR, GAMA and KO, (Table 5.4). For GRAVEL (Table 5.4), measured values are used, whereas for the texture specific constants AK, ALF and PSIMAX (Table 5.4), default values are to be used. If measured PSINI-values are not available, they can be estimated considering the type of cultivation. The same holds for TOTDEP (Table 5.4), the value of which may be inferred from the (Greek) soil-map-unit symbol (Fig. 2.12) with regard to the beginning of the growing season. RDM and RDINI are crop/cultivar constants and their values are given in the agronomic literature. However, the value of RDM might be diminished with respect to soil conditions, viz. pans or shallow ground water (Table 5.4). DEPLF is crop-weather-dependent rate variable, and the required functional relation is given in Tables (FAO Drainage & Irrigation Papers 24 and 33). As the rest weather data, PREC, WIND and RH (Table 5.4) are forcing variables.

Table 5.4. Additional basic data required for the simulation of the water-limited production potential (Production Situation 2).

Symbol	Description	Source/availability
Location		
ALT	Altitude (m)	** Topographic maps
Weather data		
PREC	Gauged rainfall rate (cm d^{-1})	** Meteorol. Service
RH	Mean daily relative humidity (%)	** Meteorol. Service
WIND	Mean daily wind velocity (m s^{-1})	** Meteorol. Service
Plant data		
DEPLF	Soil water depletion factor	** FAO(Dr.& Ir. Paper 24,33)
RDINI	Rooting depth at the beginning of first time interval (cm)	** Agronomic literature
RDM	Maximum rooting depth (cm)	** Agronomic literature
Soil/land data		
RDM	same as above; the minimum value counts	** Soil reports
TOTDEP	Ground-water at the beginning of first time interval (cm)	** Soil maps/measurements
SMO	Total pore space (cm^3 cm^{-3})	** Soil reports
GRAVEL	Gravel content (volume percentage)	** Soil reports
GAMA	Texture-specific geometry factor (cm^{-2})	* Studied soils only
SO	Standard sorptivity (cm $d^{-1/2}$)	* Studied soils only
KTR(A)	Transmission zone permeability (cm d^{-1})	* Studied soils
KO	Saturated hydraulic conductivity (cm d^{-1})	* This text and soil reports
AK	Texture specific constant ($cm^{2.4}$ d^{-1})	- WL, default values
ALF	Texture specific constant (cm^{-1})	- WL, default values
PSIMAX	Texture specific suction limit (cm)	- WL, default values
PSINI	Matrix suction at beginning of first time interval	** Field observations and experience
Management data		
SSMAX	Maximum surface storage capacity of the soil surface (cm), calculated from slope angle, surface roughness and clod/furrow angle	** Soil maps/field observations
INPIRR	Rate of water release in the field (cm d-1)	** User defined
VO	Irrigation intensity (cm h^{-1})	** User defined

WL: values from (Wageningen) literature. Data availability in Greece: ** available; * available for some soils/needs further research; - not available

5.4 Production potentials and reference yield levels

5.4.1 The SO.CR.AT.E.S. program

The program written for this thesis is the SOil-CRop-ATmosphere Evaluation System, Vs.1. SO.CR.AT.E.S. consists of a number of discrete modules which were gradually developed and tested for accuracy and plausibility of the results. Readers acquainted with the "Wageningen modelling approach" might recognise some of the names.

Name	Description
SUCROS1	SubMain module, named after the SUmmary CROp Simulation model by CABO, and consisting of:
ASTRO	Computes the day-length and declination of the sun from latitude and day number.
TOTRAD	Computes the solar constant, daily extra-terrestrial radiation and average global radiation. Diffuse light is computed from the atmospheric transmission as function of the sunshine duration ratio.
RADIAT	Computes the amounts of diffuse and direct photosynthetically active radiation (PAR).
ASSIM	Performs Gaussian integration over the depth of the canopy by selecting three different LAI levels and computing assimilation at these levels based on PAR, extinction coefficients for direct and diffuse light, and light-saturated photosynthesis of single leaves.
TOTASS	Computes the gross canopy assimilation rate by performing a Gaussian integration over time. At three different times of the day, radiation is computed and used to determine assimilation whereafter integration takes place.
GROWTH	SubMain module, computes assimilate allocation to the various plant organs, respiration and conversion losses and growth (dry matter per plant part).
WATERBAL	SubMain module, computes the ratio of actual over maximum transpiration as a function of the soil moisture content in the root zone of a layered soil. It consists of:
PENMAN	Computes the daily potential evaporation (EO) and evapotranspiration (ETO) rates according to Penman, from TMAX, TMIN, SD, WIND, RH, LAI.
DEPLE	Computes the depletion fraction for critical soil moisture content from maximum daily transpiration.
CRISE	Computes the rate of capillary rise from the moisture content of the deepest soil compartment and the depth-to-groundwater, using the Rijtema (1969) tables.
MODIS	Analyzes daily fluxes in the upper and lower soil boundaries by considering intervals of less than 1 day (normally DELTAT=15 min). Simulates water fluxes within the rooted part of the layered soil. A version of this module

simulates moisture redistribution in a multi-layered soil using very small time intervals (viz. 1 sec). It particularly assisted in the infiltration study (Section 3.3) and is referred to as "the detailed model" (Sections 3.2 & 3.3).

OTHONI Module permitting graphical representation of soil moisture distribution, weather data, etc. on the screen.

In the remainder of this Chapter, the program[2] will be used to calculate the production potentials of selected Land Use Systems in the Larissa area.

5.4.2 Land Use Systems with maize

General

Table 5.5 summarizes the yield-potentials calculated for systems with various maize cultivars and germination dates in different years. Note that the highest values are obtained with early plantings of cvs. PIONEER (20 t/ha). Note further that the year-to-year fluctuation of this potential may reach 5.5 t/ha (viz. late planting of cv. ARIS in Larissa, 1988; Table 5.5), or more. The large fluctuation in maize-yield potential (even for the same cultivar; Fig. 5.2) should be a consideration in any land evaluation exercise.

Table 5.5. Potential yield (kg/ha) of 3 maize cultivars calculated for 3 different germination dates, viz. 10/4, 30/4 and 20/5, using data from Larissa (1987, 1988 and average year) and Aliartos (1988).

Place/	cultivar	<---------	germination date	---------->
year		10 April	30 April	20 May
Larissa	cv.ARIS	16,106	15,380	14,545
1988	cv.P.3183	17,205	17,074	16,692
	cv.P.3165	17,154	17,423	16,795
Larissa	cv.ARIS	16,806	16,304	15,914
1987	cv.P.3183	17,874	17,724	17,268
	cv.P.3165	17,961	17,826	17,523
Larissa	cv. ARIS	17,860	17,300	16,440
av.year	cv.P.3183	19,698	19,446	18,750
	cv.P.3165	19,764	19,504	18,889
Aliartos	cv.ARIS	18,228	17,828	16,197
1988	cv.P.3183	19,725	19,443	18,491

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[2] SO.CR.AT.E.S. executable files are available for authorized use after personal contact with the author.

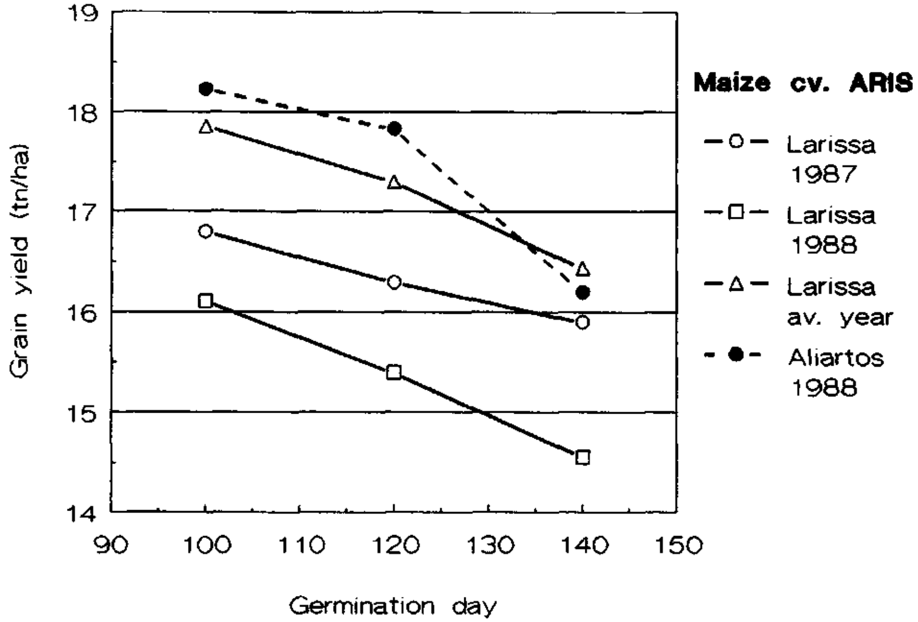

Fig. 5.2. The potential grain yield of maize cv. ARIS calculated for different germination dates in Larissa (1987, 1988 and an average year) and in Aliartos (1988).

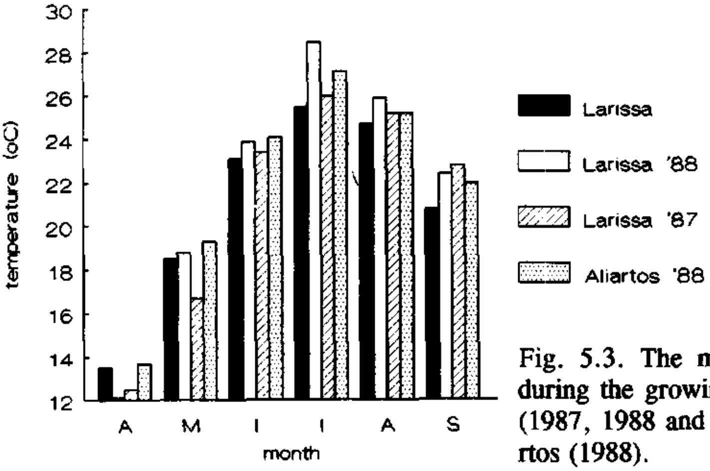

Fig. 5.3. The mean monthly air temperature during the growing period of maize in Larissa (1987, 1988 and an average year) and in Aliartos (1988).

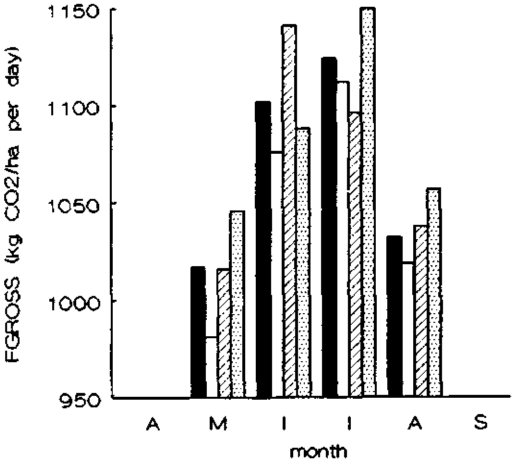

Fig. 5.4. The potential gross assimilation rate of maize calculated for Larissa (1987, 1988 and an average year) and for Aliartos (1988). (A leaf area index-value of 5 is assumed; for legend see Fig. 5.3).

Year-to-year fluctuations

The effect of the radiation income on the yield potential of maize is straightforward. The temperature is optimal for most the growing period in Larissa (Fig. 5.3). However, the higher its value (within the optimum range), the shorter the growing period and the higher the respiration losses. Fig. 5.2 summarizes the values calculated for cv. ARIS and confirms the observed year-to-year fluctuation of the maize yield potential. The potentials calculated for 1988 in Larissa when temperatures were high and radiation relatively low, represent the lower end of the range. The highest potentials calculated for Aliartos (1988) are thought to represent the upper limit.

The higher than average temperatures in 1988 (Fig. 5.3) accelerated the development of maize in Larissa. Germination on 30/4 was followed by flowering on 30/6, i.e. 2 days earlier than in an average year. The much higher temperatures of July 1988 (Fig. 5.3) accelerated grain filling even more; it occurred 8 days earlier than in an average year (maturity on 19/8 vs. 29/8). Radiation in Larissa was less in 1988 than average (Fig. 5.4). Low temperatures in May 1987 (Fig. 5.3) delayed flowering to mid-July. The higher than average temperatures that followed (see Fig. 4.1.1) accelerated grain filling, which, for germination on 30/4, required 5 days less than in an average year. The lower radiation in July (Fig. 5.4) and the higher temperature explain why the potential was about 1 t/ha less in 1987 than in an average year.

The influence of the germination date

Later emergence is associated with less yield potential (Table 5.5 and Fig. 5.2). This is demonstrated by Fig. 5.5, which shows data from two plantings of cv. ARIS in Larissa in an average year. It can be seen that postponing germination by 40 days, viz. from 20/4 to 30/5, delays grain filling by 20 days, viz. to the first half of September, when the gross photosynthetic production (FGROSS; Fig. 5.3) is considerably less than maximum. In this example, the yield potential of the late crop decreases by 1.75 t/ha (16,020 vs. 17,780 kg/ha at 15% moisture), despite the slight elongation of the post-anthesis period, induced by the lower temperatures in early fall. This difference might be roughly represented by the difference of the areas included within the vertical lines at F1-F2 and M1-M2.

In an average year, the canopy closes even in late plantings (Fig. 5.5). In warm years, however, late germination may be accompanied by accelerated development, and the crop may enter the reproduction stage with a still open canopy. Fig. 5.6 demonstrates that in the exceptionally hot year 1988, late plantings of cv. ARIS had a canopy correction factor, CFL, of less than 1.0 throughout the growing season, and a rather thin canopy during the grain filling period. The difference in the gross canopy assimilation rate (FGC) is shown by Fig. 5.6 (thick dashed lines). The long-cycle cultivar P.3165 is superior under these conditions because it closes its canopy even in late plantings, realizing more effective light interception at advanced development stages. Note that the combined effects of temperature and germination date on the growth of the two cultivars is demonstrated in the above example by introducing a sub-optimal moisture supply. The irrigation scenario of the cv. ARIS experiment in 1988 was assumed for this purpose (K-treatment). The calculated yields of cv. ARIS are 12,127 kg/ha (early planting) and 9,346 kg/ha (late plantings). The yields of cv. P.3165 are 13,641 kg/ha (early planting) and 11,700 kg/ha (late planting).

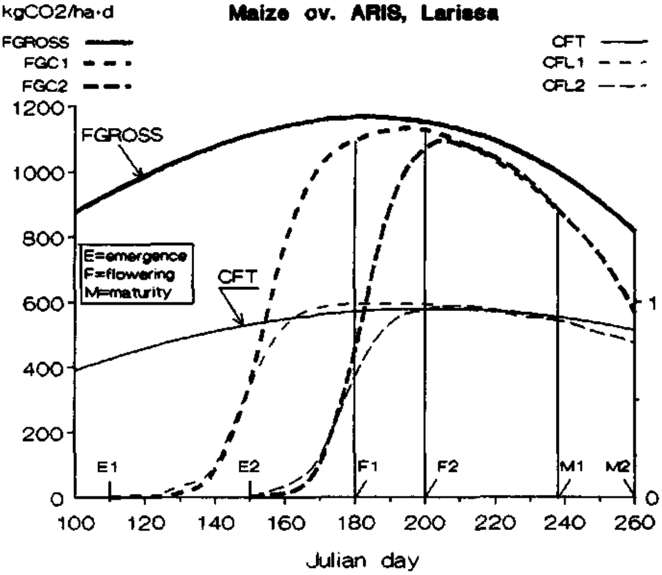

Fig. 5.5. The potential gross assimilation rate (FGROSS; at LAI=7); the temperature correction factor (CFT); the ratio of light intercepted by the canopy ($CFL=1-e^{0.6*LAI}$); and the gross canopy assimilation rate (FGC), calculated for two plantings of maize cv. ARIS under optimum conditions in Larissa. Emergence dates: (1) 20 April, (2) 30 May.

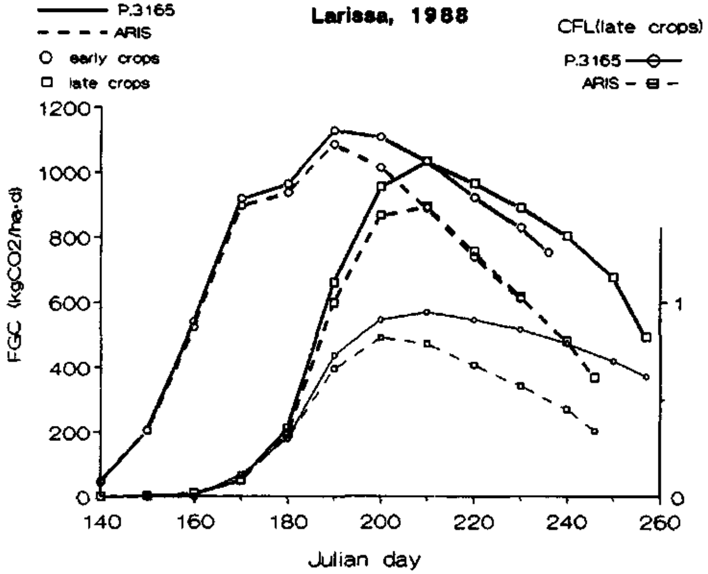

Fig. 5.6. The calculated gross canopy assimilation rate (FGC) of 2 maize cultivars (viz. cv. ARIS and P.3165-DONA) germinating on 20 April and 30 May 1988 in Larissa (left y-axis), and the ratio of light intercepted by the canopy (CFL) of the late plantings of both cultivars (right axis).

The effect of the plant density

The impact of the germination date and light interception on the yield potential is influenced by the plant density. This is shown in Fig. 5.7, for two plant densities of cv. ARIS grown under optimum conditions in Larissa, in 1987 and 1988. It can be observed, that increasing the plant density increases also the yield potential of early plantings, especially in 1988, because of the more effective light interception. If germination takes place after 20 May, the yield potential drops sharply; increasing the plant density (more foliage) could partly undo this drop in the hot year 1988.

The risk of very low yields from late crops is well-known in the study area. Late sowing is also risky because it implies unfavourable conditions for germination, high risk of insect attack (*Sesamia*; see parag. 5.2.2) and maturation late in September with adverse conditions for drying of the grain. Germination after 20/5 is no option in the study area.

The high(er) yield potential associated with high plant densities of early crops has little practical significance. Fig. 5.7 demonstrates that the difference is less than 500 kg/ha. Considering that an additional input of 20 kg seed material is required per hectare, and that the price ratio per kilogram of seed material over harvested grain is 1000 drs/40 drs (prices of 1992), it can be concluded that increasing the plant density beyond the normal range (5 to 6 pl/m) is not economical.

The growth potential per cultivar

Table 5.5 shows that the yield potential of cv. PIONEER is generally higher than that of ARIS; the difference ranges from 1 t/ha, in the early plantings, to 2 t/ha or more, in the late plantings, especially in warm years. Since the heat requirements from flowering to maturity are the same for all cultivars (Section 4.1), and early plantings of cv. ARIS in Larissa (in an average year) realize optimum light interception (see Fig. 5.5), the better performance of the American cultivars must be attributed to earlier assimilate allocation to the grain (Section 4.1). If early sown, especially in warm years and/or under sub-optimal moisture conditions, PIONEER plants form a richer foliage than plants of ARIS because of the longer period from germination to flowering. Although they mature some days later than cv. ARIS, they generally have a higher yield potential. This is illustrated in Fig. 5.8, which shows all studied maize cultivars in Larissa (average year) under sub-optimal soil moisture conditions (irrigation scenario of planting K in 1988; Section 4.1). All cultivars germinate on May 10th. It can be seen that the greater light interception (due to richer foliage) of P.3183 plants results in higher FGC rates than realized by ARIS plants, even though the flowering-maturation period of the former starts 4 days later. The gross difference in production may be very roughly represented by the difference of the areas included within the vertical lines F1-F2 and M1-M2. The calculated final yields in the above example are 15,143 kg/ha for cv. ARIS and 16,229 kg/ha for cv. P.3183; under optimal conditions, these figures would have been 16,870 kg/ha and 19,098 kg/ha for ARIS and P.3183 respectively.

Fig. 5.8 shows that cv. P.3165 matures on 15/9, viz. 10 days later than cv. ARIS and 1 week later than cv. P.3183, in an average year in Larissa (emergence on 10/5). The dry, warm weather in September of years 1987 and 1988 would allow drying of the grain to the required moisture level. The small difference in yield potential between this cultivar and cv. P.3183 (Table 5.5), does not justify the use of P.3165 in Larissa, especially since too late maturation can be a serious problem. Recall that the farmer is charged about 4.3 ECU/ton grain for every percent moisture beyond the limit of 15%.

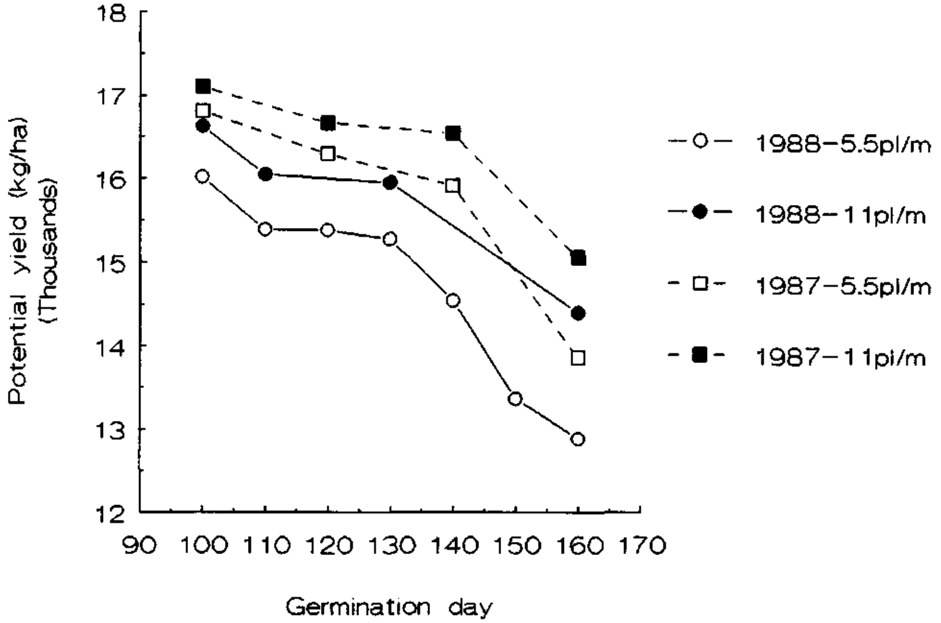

Fig. 5.7. The potential grain yield of maize cv. ARIS in Larissa (1987 and 1988) as a function of the germination date and the plant density (5.5 pl/m correspond to approx. 70,000 pl/ha and 20 kg seed/ha; a moisture content of 15% is assumed).

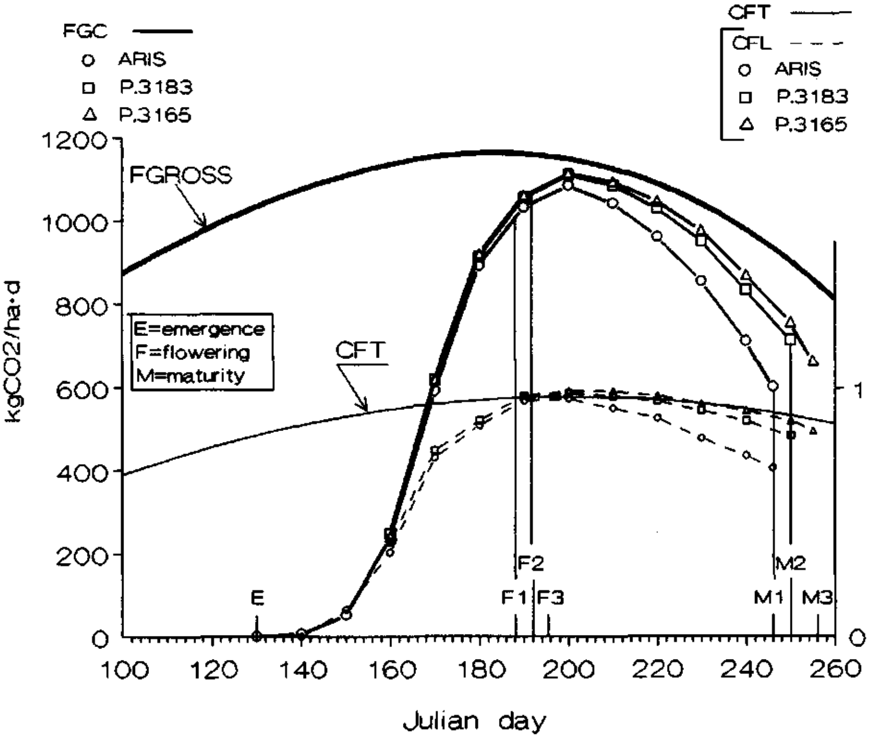

Fig. 5.8. The calculated potential gross assimilation rates (FGROSS), temperature correction factors (CFT), light interception fractions (CFL), and gross canopy assimilation rates (FGC) of 3 maize cultivars in Larissa in an average year. Emergence occurs on May 10th.

From the potential to the actual yield

All data of Table 5.5 were calculated for scenarios with a shallow ground-water table. It is a practical impossibility to realize potential production of maize in the study area without a shallow ground-water table. Recall, for example, that the yield of cv. ARIS in the experiment in Larissa was 4.5 t/ha less than its potential (viz. about 16 t/ha with germination on 20/5; Table 5.5 and Figs. 5.2 & 5.7) in 1987. With frequent and heavy (drip) irrigation in 1988, the yield obtained was still 1.8 t/ha less than the calculated potential (viz. 15.5 t/ha for germination on 10/5; Fig. 5.7). With a shallow ground-water table, frequent irrigation with surface methods bears the risk of excessive soil moisture and is normally avoided. This was the case in the experiment in Thessaloniki, were the high yield obtained in 1987 (viz. 17 t/ha, 20% moisture) was still less than the potential. The potential yield was almost reached in Aliartos (1988; see Fig. 5.2) where 17.3 t/ha (15% moisture) were obtained from cv. ARIS grown on a fertile alluvial soil with ground-water table permanently at 80-100 cm depth, and irrigated with sprinklers (unpublished data of Nitrogen-STEP, EEC Project, AUA, Kosmas *et al.*, in prep.).

5.4.3 Land Use Systems with wheat

General

The low threshold temperature of wheat (viz. TH=0°C; Section 4.3) theoretically enables the crop to grow throughout the year. However, the great variation in the yield potential at different sowing/germination dates limits the possibilities. Fig. 5.9 demonstrates that a maximum grain-yield potential of about 9.5 t/ha (13% moisture) is associated with germination in late autumn. The lowest potential is 4 t/ha or less with germination in the summer. The value of the maximum yield potential is slightly less than in earlier runs with data from the literature, but still impressive and about 50% higher than the presently assumed maximum yield (6 t/ha).

The effect of germination date

Fig. 5.10 shows how the yield potential changes with germination dates between late October and middle December, both in an average year and in the less favourable year 1988-89. In both cases, the yield potential is maximum for germinations after 20/11 and less for earlier crops. Radiation and temperature are responsible for this. Fig. 5.11 presents the gross CO_2 production rate (FGROSS; dashed line) for a closed canopy (LAI=7) and the average monthly radiation in Larissa. The effect of temperature on assimilation is reflected by the CFT (dotted line in Fig. 5.11), and results in a lower gross (closed) canopy assimilation rate (FGC=FGROSS*CFT; thick line in Fig. 5.11). FGC(LAI=7) is plotted again in Fig. 5.12 (thick line), together with the fraction of light intercepted by the canopies (CFL) of 3 crops with emergence dates on 27/10, 16/10 and 19/6. Considering for the moment the first two plantings, it is obvious that the grain filling period of the second crop, though of shorter duration, takes place in a period of higher assimilation, which explains the higher yield potential (see also Fig. 5.10). With germination later than mid-December, grain filling might be shifted to an even more favourable period (Fig. 5.12), but rapid shortening of this period

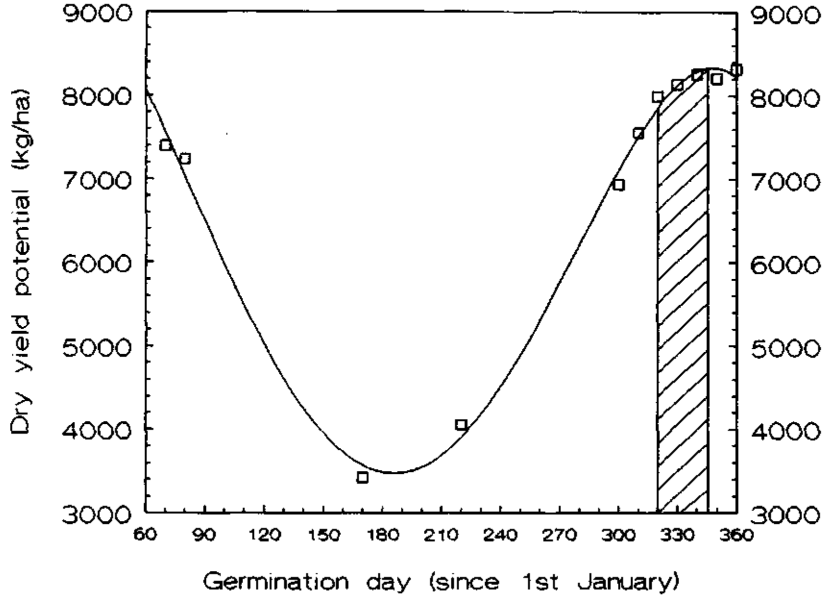

Fig. 5.9. The calculated (dry) grain-yields of wheat cv. Mexicali in Larissa. Scenarios with different germination dates in an average year. An initial dry weight of 10 kg/ha is assumed, except for the 2 summer-plantings, viz. 30 kg/ha. The shaded area represents the normal range in germination).

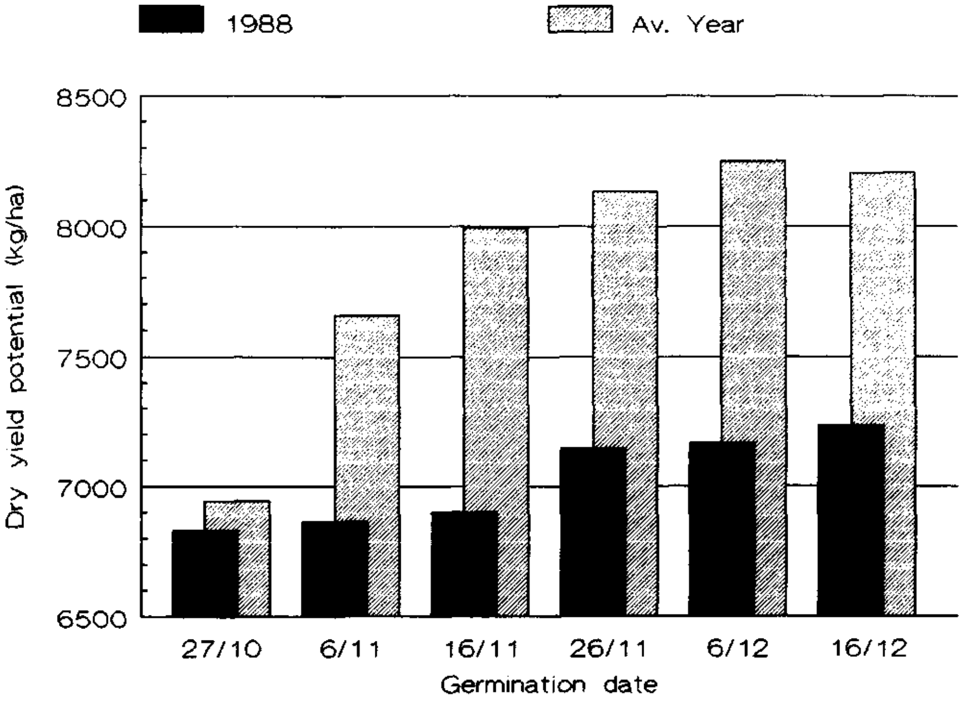

Fig. 5.10. The yield potential of durum wheat cv. Mexicali grown in Larissa in 1988-89 and in an average year. Values calculated for scenarios with different germination dates.

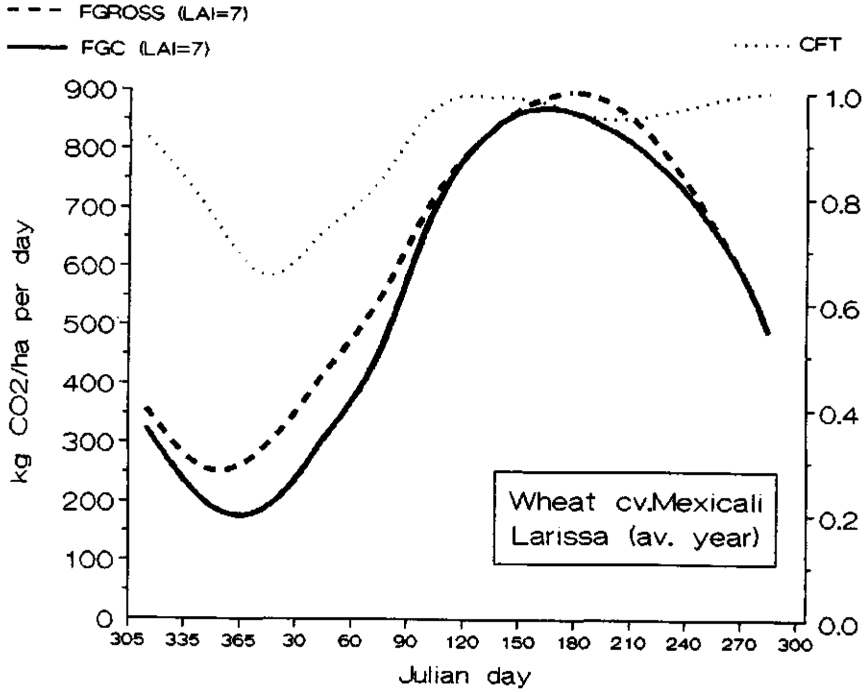

Fig. 5.11. The gross assimilation rate (FGROSS), temperature correction factor (CFT) and corrected gross assimilation rate (FGC; at LAI=7) of a closed canopy of durum wheat cv. Mexicali grown in Larissa in an average year. (Note that FGC(LAI=7)=FGROSS*CFT, where CFT = f (AMAX/ AMAXOPT) and not the rate itself. Note also that CFT < 1 in the summer due to higher than optimum temperatures).

and higher respiration losses (induced by the high summer temperatures) cause the potential to drop. Further delay in germination accelerates this drop due to further shortening of the emergence-flowering period, and the crop might enter its reproduction stage with a still open canopy. This clearly happens in the case of the third planting in Fig. 5.12. The calculated dry-yield potential is only 2.1 t/ha; the value plotted in Fig. 5.9 is based on a three-fold initial dry weight to mitigate the adverse effect of the short emergence-anthesis period. The adverse effect of the rather high summer temperatures on tiller formation is, however, unknown (lack of experimental data), and the values presented for the summer crops in Fig. 5.9 should be interpreted with caution.

Year-to-year fluctuation

Fig. 5.10 gives an impression of the year-to-year fluctuation of the "maximum" potential level of wheat. Judging from the data available, and considering the exceptionally cold winter of 1988 (Table 4.3.1), this fluctuation might not be much greater than 1.2 tons per hectare. The lower potential of the plantings in the late autumn of 1988 is attributed to both delay and shortening of the flower-maturity period and to the lower than average radiation in May 1989. A yield potential in excess of 9.5 t/ha might occur in a year with lower-than-average temperatures in May (less respiration losses and longer grain-filling period). The positive effect of lower temperatures, however, might well be outweighed by the negative effect of the associated lower than average radiation. The limited climatological data available suggest that a yield potential (of the studied cultivar) of more than 10 t/ha is rather exceptional in Larissa area.

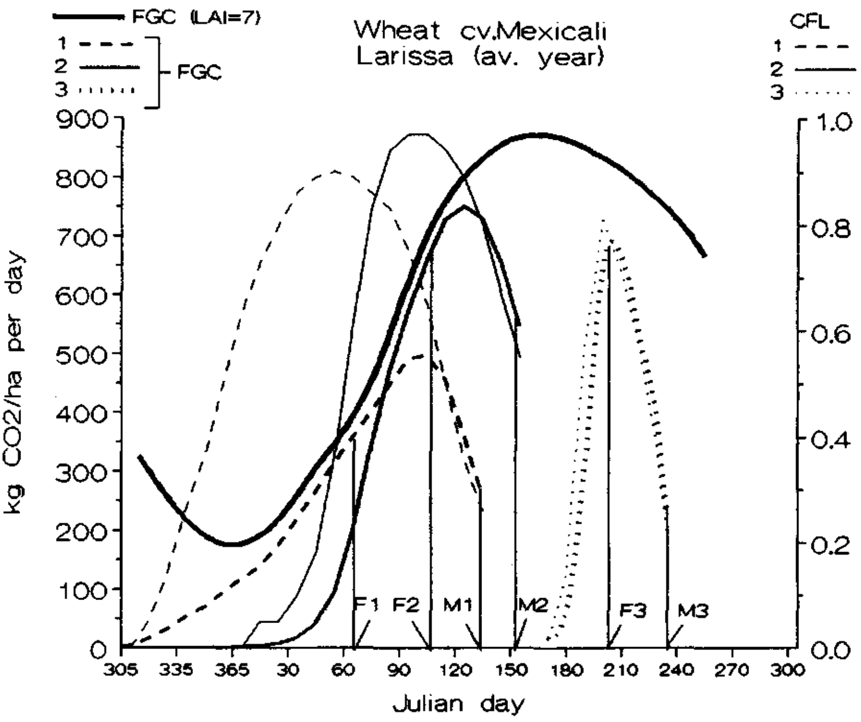

Fig. 5.12. The gross assimilation rate of a closed canopy (FGC; LAI=7), canopy interception factor (CFL=1-$e^{0.5*LAI}$), and the gross canopy assimilation rates [FGC=FGC(LAI=7)*CFL], calculated for 3 plantings of durum wheat cv. Mexicali in Larissa in an average year. [E=Emergence, F=Flowering, M=Maturity; J.days at E/F/M: (1) 300/65/132, (2) 350/107/153, (3) 170/203/236). The gross assimilate production during the grain filling period is (roughly) represented by the surface areas included between the vertical lines Fn-Mn, n=1,2,3. The calculated dry grain-yields are: (1) 6.9 t/ha, (2) 8.2 t/ha, and (3) 3.4 t/ha (triple initial weight)].

5.4.4 Land Use Systems with cotton

Fig. 5.13 shows the dry-yield potentials of cotton in the study area, calculated for different years and 2 germination dates, viz. April 20th(110) and May 10th(130). A rather large year-to-year fluctuation is apparent. In the examples examined, it may exceed 60%. In an average year, the dry-yield potential may fluctuate around 2 t/ha, and this value is close to the average yield obtained in practice. In a warm year such as 1987 (1°C higher than average temperature in the period June-September), maximum yields of 3-4 t/ha may be obtained, whereas in a cool year (1°C lower than average temperature) the yield potential might not exceed 1.5 t/ha. These results are confirmed in practice, by the high yields that are occasionally obtained. In exceptionally cold years, very low yields to even crop failure may occur in places.

The year 1988 was warmer than 1987, mainly because temperatures were higher in July (Fig. 5.3). Simulated results suggest that summer temperatures higher than a certain level do not increase the production potential any more (Fig. 5.13). The potential may further increase if higher than average temperatures occur near the margins of the growing period. This

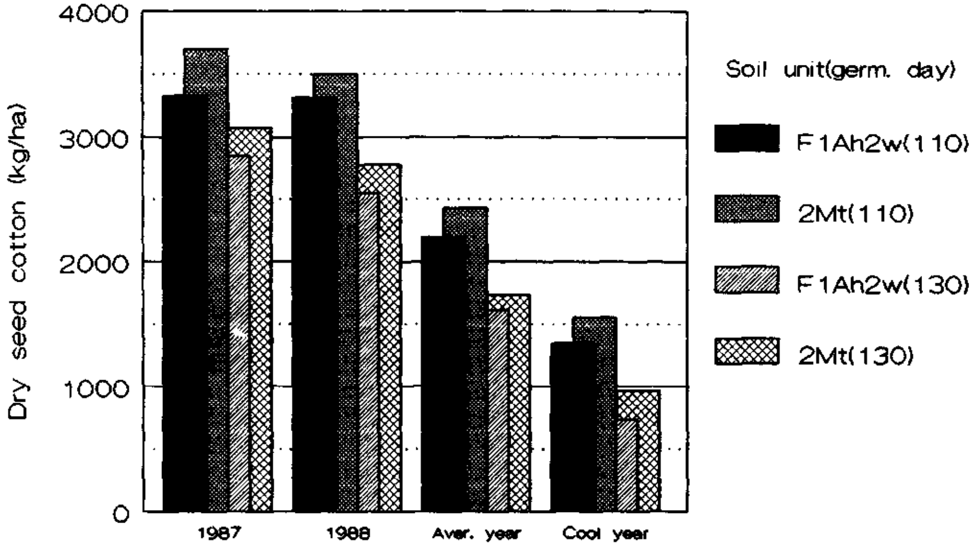

Fig. 5.13. The (dry) yield potential of cotton cv. Zeta-2, calculated for 2 soils and 2 germination dates in Larissa (1987, 1988, an average and a cool year). F1Ah2w: Calcic Haploxeralf of the Pleistocene terrace; 2Mt: Typic Calcixeroll of the Tertiary tracts. (Note that the period June-September 1987 is 1°C warmer than in an average year and 2°C warmer than in a cool year).

suggests that the length of the growing period is the most limiting factor in Larissa, and more generally in Greece. With an average temperature lower than 22°C in the 6 warmest months, the country lies close to the northern margin of the cotton belt.

It is common knowledge in the study area that early sowing might largely compensate the negative effects of low temperatures in unfavourable years. Fig. 5.13 demonstrates that 20 days earlier germination, viz. 20/4 vs. 10/5, increases the yield potential by 500-1000 kg/ha. This increase is more important in cool years.

Figs. 5.14a&b demonstrate that for the same soil, year and germination date, an optimum (total net) water input permits to reach the yield-potential. This optimum is associated with moderate water stress (even in the warmest year 1988), and a certain range of LAI-values at flowering. Higher water input (especially before flowering) results in too luxuriant vegetative growth, lower canopy temperatures, delay of the reproductive growth and boll ripening, and a lower yield potential. Fig. 5.14 shows that the decrease in yield is sharp in an average year and/or in the case of late plantings.

Unlike in maize and wheat, the reference yield-level of cotton is determined by light, temperature and the availability of water. The yield-potentials presented in Fig. 5.13 refer to two soil-examples, viz. F1Ah2w and 2Mt (see Section 5.6). They refer to the highest values found after testing a large number of irrigation scenarios for the studied years and germination dates. In all cases, 7 irrigations were assumed viz. 2 applications until flowering (J.days 170 and 190) and 5 applications every 10 days until the end of August (J.day=240). Fig. 5.14b shows that the maximum yield is obtained with early planting (germination before 10 May) and a total input of 210 mm water (70 mm more are required in 1988). For another soil, such as 2Mt, the yield potentials presented in Fig. 5.13, were calculated for a total input of 350 mm water. Thorough quantification of the cotton-yield potentials for all soils of the study area is a time consuming exercise. Fig. 5.13 confirms that the year-to-year variation in cotton-yield potential is much higher in time than in space.

Confusion exists with respect to over-irrigation of cotton. The writer is aware of some reports in which yield-decreases of over-irrigated cotton in Thessaly are (unfortunately) misinterpreted. The field experiments (Section 4.2) but also Fig. 5.14 demonstrate that considerable yield reductions may be incurred as a consequence of severe water stress.

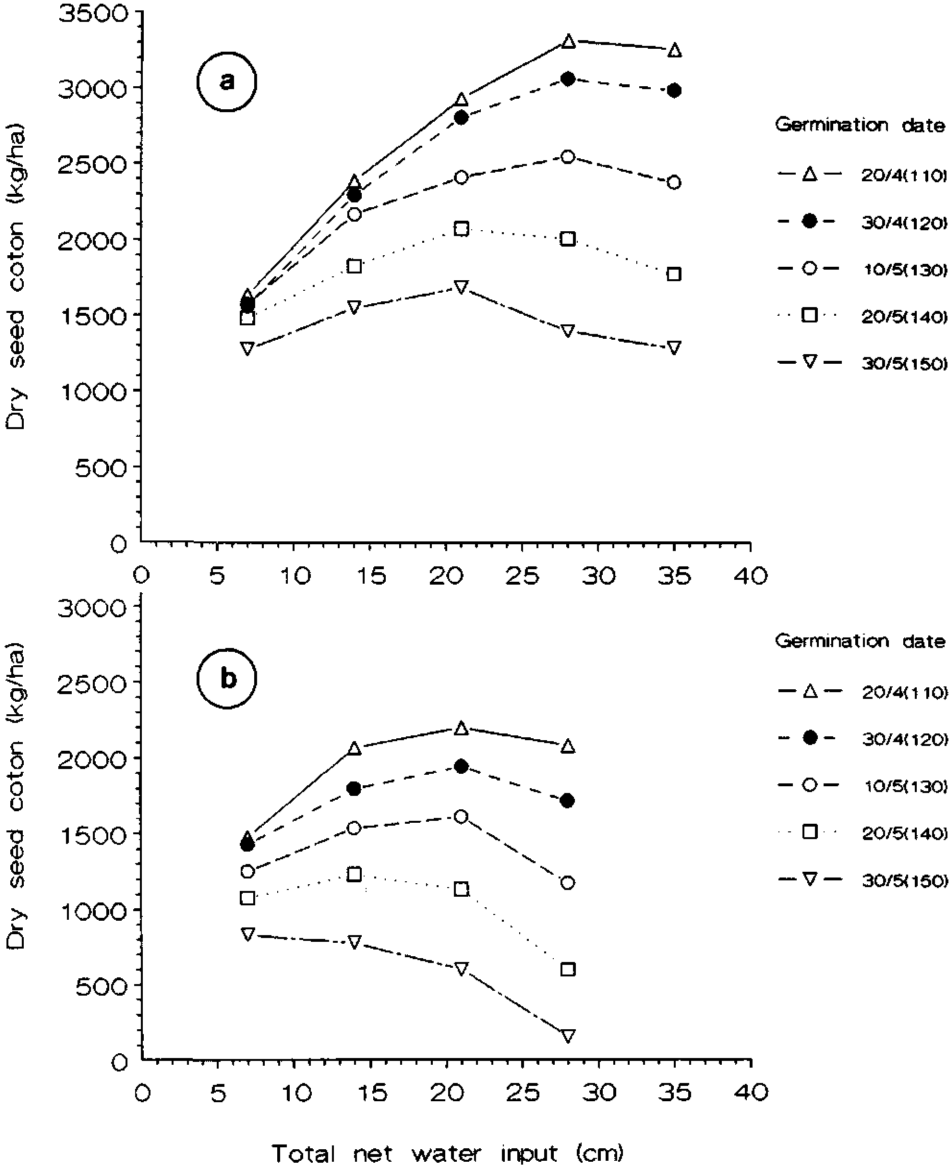

Fig. 5.14. The (dry) yield potential of cotton cv. Zeta-2 calculated for different emergence dates and total irrigation applications in 1988 (a) and in an average year (b). Soil unit: F1Ah2w (Calcic Haploxeralfs on the Pleistocene Terrace). A total of 7 applications are assumed with equal net water inputs per application (appl. dates: 170, 190, 200, 210, 220, 230 and 240; initial soil-suction PSI = 1000 cm).

5.5 Quantifying the Nutrient Requirement
(Production Situation 3).

In Production Situation 3, plant nutrients, notably nitrogen and phosphorus, are additionally considered as possible constraints to crop growth. The increasing complexity of the production environment makes it impossible to reliably quantify PS-3 yield and production as dependent variables. Consequently, dynamic simulation is not applied in PS-3 analyses as in the first two Production Situations. The "Wageningen approach" calculates the "fertilizer-nutrient requirement" instead, i.e. the quantity of fertilizer nutrient, needed to realize the yield target.

The nutrient element is assumed to be the only active element of the fertilizer applied (van Keulen, 1982). To approximate the fertilizer requirement, the following characteristics must be known:

- How much of the nutrient is furnished by the soil itself under unfertilized conditions. This is the "base uptake" of the nutrient.
- Which fraction of applied fertilizer nutrient is actually taken up by the crop. This is the "recovery fraction" of the fertilizer-element.

The nutrient input requirement is approximated by subtracting the base uptake from the calculated total uptake requirement, and dividing the result by the recovery fraction.

The minimum set of land/use characteristics needed is listed in Table 5.6. It can be seen that the determination of the total nutrient requirement in PS-3 requires knowledge of the minimum element concentrations of the harvested product and the crop refuse -N_Y and $N_{(P-Y)}$ (Table 5.6)-. Such data can be determined in pot experiments, as they seem independent of the growing conditions. The actual concentration N_A (Table 5.6) can be determined by a tissue analysis, or it can be inferred from physiological symptoms or the pursued quality of the product.

The following sample calculation approximates the nitrogen requirement, based on the data of Table 5.7. Assume for the moment that the [N]-values in the control plot are the minimum ones, viz. $N_Y=0.0111$ and $N_{(P-Y)}=0.0034$. Note that: $Y_c=6{,}549$; $Y_{AN}=11{,}258$; $A_N=445$ kg N/ha and $N_A=0.014$ (Tables 5.6 and 5.7). The base uptake (Uo) and the uptake from the fertilized plot can now be calculated with:

$$Uo = (0.0111*6{,}549) + (0.0034*5{,}500) = 91.4 \text{ kg ha}^{-1}\text{, and} \qquad (5.2)$$
$$Uf = (0.019*11{,}258) + (0.0083*7{,}963) = 280 \text{ kg ha}^{-1}. \qquad (5.3)$$

The recovery fraction is then:

$$R_N = (Uf-Uo)/A_N = 0.424 \text{ kg kg}^{-1}. \qquad (5.4)$$

Fig. 5.15 schematically presents the relations between grain yield and nitrogen uptake and between nitrogen application and uptake, in this example. The plateau level is that of Production Situation 2.

Assume that the pursued (dry) yield target is Y = 12,500 kg/ha with a harvest index of 0.60. The total quantity of the element to be taken up in this case is $Um=(Y/0.60)*N_A=292$ kg N/ha. The nitrogen requirement (D_N) amounts to:

$$D_N = (Um-Uo)/R_N = (292-91.4)/0.424 = 473 \text{ kg N ha}^{-1}. \qquad (5.5)$$

Table 5.6. Minimum set of basic data needed to estimate the nutrient requirement (PS-3).

Symbol	Description	Source/ availability
Plant data		
N_Y	Minimum element concentration in marketable product (kg kg^{-1})	* Agronomic literature/ WL
$N_{(P-Y)}$	Minimum element concentration in crop residue (kg kg^{-1})	* Agronomic literature/ WL
N_A	Actual element concentration in plant tissue (kg kg^{-1})	** Chemical analysis
Management data		
Y	Target yield level (kg/ha)	** User defined, usually the output of PS-2 calculations
Yc	Control yield of fertilizer experiment (kg ha^{-1})	* Agronomic literature
Y_{AX}	Yield obtained on experimental plot fertilized with A kg ha^{-1} of nutrient x	* Agronomic literature
A_X	Application of nutrient x in fertilizer (kg ha^{-1})	** Agronomic literature

WL: values from (Wageningen) literature can be used.
Data availability in Greece:** available; * needs further research.

Table 5.7. Nitrogen concentration (%) in the grain and straw of maize (cv. ARIS) at maturity (Larissa, 1988).

Treatment	Grain		Straw		N-supply
	N	kg/ha	N	kg/ha	(kg/ha)
Y (wet)	1.90	11,258	0.83	7,963	445
Y-control	1.11	6,549	0.34	(5,500)	0

(the value in brackets is approximated).

The phosphorus requirement can be approximated in the same way.

Further information on the recognition of nutrient limitations, the nutrient demand and the fertilizer requirements, and a review of the advantages and weak points of the methodology are given by van Keulen (1986) and Driessen (1986).

The water-limited production potential is within the reach of the farmers of the study area. The good availability and relatively low prices of fertilizers in Greece are conducive to lavish applications, and nutrient-limited production is not common in the study area. Assume that ammonium nitrate (33.5-0-0) is to be used for realization of the yield-target in the above example. This implies that 1,330 kg of fertilizer must be applied per hectare. The total cost would be 176 ECU/ha versus a gross return of about 2,460 ECU/ha.

Over-fertilization is common in the study area. A four-year intensive programme on fertilization has recently been worked out under the aegis of the Ministry of Agriculture; the low response to applications of the main nutrients found in this project (unpublished data of

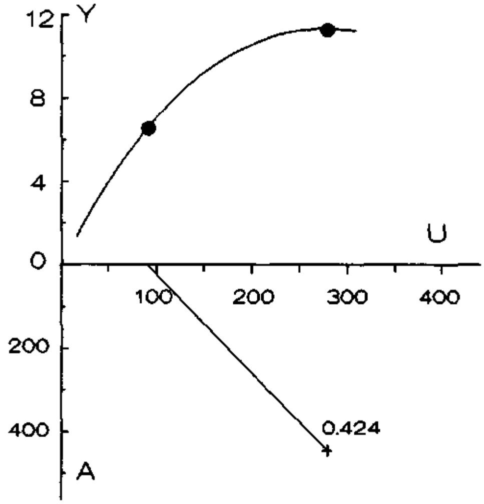

Fig. 5.15. Approximate relation between the total nitrogen uptake (U, in kg ha^{-1}) and the dry-grain yield (Y, in t/ha); and the relation between nitrogen application (A, in kg ha^{-1}) and nitrogen uptake by maize (cv. ARIS). (Larissa, 1988; treatment Y).

ISMC, Larissa) are attributed to the high residual levels of these nutrients in the control plots. This also hindered experimentation in the first year of the present study (1987). The data summarized below refer to the maize (cv. ARIS) experiments in 1987 and illustrate this point.

Larissa, 1987	dry grain yield (kg/ha)		[N] in grain (%)	
	fertilized	control	fertilized	control
Treatment A	9,922	9,058	1.71	1.39
Treatment B	8,390	7,912	1.65	1.61

In the second year (1988), the same control plots were chosen. The results (Table 5.7) indicate that the control yield is limited by nitrogen shortage, and actually lies on the linear yield-uptake curve (Fig. 5.7). Then, the nitrogen concentration of the tissue of the control plants reached minimum levels (1% N in the grain and 0.2-0.4% in the straw).

A complete set of N, P and K-concentrations in the marketable product and the crop residues was collected in the experiments; the results differ with the soil, weather conditions and management. It is hoped that more data required for PS-3 analyses, including "base uptake" and recovery fraction" data, can be correlated with chemical soil properties in future studies.

Irrigated wheat (and probably other winter cereals) deserve special attention in this context. As apparent from the next Section, introduction of drip irrigation may be worthwhile, especially in rotations of cotton and wheat. The nutrient requirement for maximum grain yields would then become much higher than at present (on average 120 kg/ha). Assuming a target yield (dry grain) of 6,500 kg/ha and an initial slope of the yield-uptake relation of 55 kg/kg, a base uptake of 50 kg N/ha and a recovery fraction of 0.35, the nutrient requirement is about 195 kg N/ha. Nitrogen deficiency might have been the main cause of the less than potential yields obtained in wet years or on the (few) fields adjacent to irrigation/drainage channels and irrigated with surface methods. The yields of 8 t/ha, claimed in some years especially on Farsala Mollisols, may be explained by the high base uptake (and perhaps recovery fraction) from these soils.

5.6 Land suitability assessment

5.6.1 The physical suitability of land for selected uses

General

The water-limited production potential in the Larissa plain is within the reach of the farmers, and production means -other than water- are available as needed. Running alternative scenarios under Production Situation 2 permits to compare alternative management strategies, especially doses, intervals and methods of irrigation, for various crop or cultivar selections, planting and seeding dates, etc.

The land characteristics required for analysis at the PS-2 level are listed in Tables 5.3 and 5.4; The crop/cultivar data are summarized in Table 5.8. Daily weather data for the years 1987 through 1990 are presented in the appendices (App. B), just as soil physical (land) characteristics of 50 mapping units (3 layers per soil profile, in line with the Greek soil mapping unit code; see App. D).

As said, a complete land evaluation of the area on the basis of the FAO Framework, is not attempted. Such an exercise would be extremely time consuming. Assume, for example, that 5 crops/cultivars on 50 soil (mapping) units are to be examined, with 3 germination dates, 3 planting densities and 3 irrigation methods. Such an analysis would involve 5 x 50 x 3 x 3 x 3 = 6,700 combinations. Year-to-year fluctuations, important to evaluate possibly involved risks, and different initial soil moisture conditions (depending on the climate, crop and management in the previous growing season) have not even been considered.

Soil units

In this exercise, two sample soil (mapping) units will be examined as examples. The first unit, F1Ah2w, represents the Calcic Haploxeralfs (Peneios Series) on the Pleistocene terrace (Platanoulia area). The second unit, 2Mt, represents the Typic Calcixerolls of the foot-slopes of the Tertiary tracts (Nikea area). Detailed descriptions of these soils are included in Sections 2.2 and 2.3.

Soil F1Ah2w remained after much or all of the upper soil layer(s) of the original Typic Palexeralfs (FAO: Planosols) had eroded away. Palexeralfs have an extremely low permeability. The surface soil of their eroded counterparts (F1Ah2w) is mixed with the argillic Bt-horizon, and has a higher infiltration capacity, but still not enough to be very productive under sprinkling-irrigated maize. Soil F1Ah2w is cultivated with rainfed wheat, irrigated cotton (travelling guns or moving laterals) or with drip-irrigated orchards (mainly pears and apples).

Where irrigation water is available, soil 2Mt is planted to a number of crops, e.g. maize, cotton, potatoes, and sugar beets. In the absence of irrigation water, wheat is normally grown in rotation with peas. Soil 2Mt was selected as an example for two reasons: it has a considerably higher infiltration capacity than soil F1Ah2w and is distinctly different in its productivity under different water managements; and it illustrates the need for proper soil (taxonomic) classification to enable the establishment of correlations. It is believed that many dark soils with well structured topsoils are too easily classified as Inceptisols in soil-genetic

Table 5.8. Summary of land and land use data needed to quantify the water-limited production potential of the selected Land Use Systems.

Location: Larissa; LAT=39.6; ALT=77

Weather: Larissa (1987, 1988, 1989, average year)
mean daily values of TMAX, TMIN, SD, PREC, WIND, RH during the growing period of the studied crops are summarized in Appendix B.

Crop/cultivar:	Maize			Cotton	Wheat
	cvs: ARIS	P.3183	P.3165	ZETA-2	Mexicali
AMAXOPT	85.00	85.00	85.00	50.00	40.00
KE	0.60	0.60	0.60	0.60	0.50
ECLEAF	0.72	0.72	0.72	0.72	0.72
ECSTEM	0.69	0.69	0.69	0.69	0.69
ECSO	0.72	0.72	0.72	0.61	0.79
ECROOT	0.72	0.72	0.72	0.72	0.72
RL (x10^{-3})	20.83	20.83	20.83	13.89	20.83
RS (x10^{-3})	11.59	11.59	11.59	11.59	14.49
RSO (x10^{-3})	20.83	20.83	20.83	16.39	16.45
RR (x10^{-3})	13.89	13.89	13.89	13.89	13.89
TSUM(1)	660.00	730.00	780.00	840.00	920.00
TSUM(2)	843.00	843.00	843.00	600.00	860.00
TSUMLLS	1000.00	1000.00	1000.00	n.r.	1300.00
TH(1)	10.50	10.50	10.50	15.00	0.00
TH(2)	10.50	10.50	10.50	15/10	0.00
THLLS	10.50	10.50	10.50	15.00	0.00
SINI(normal)	10.00	10.00	10.00	10.00	10.00
RDINI	10.00	10.00	10.00	10.00	10.00
RDM	90.00	90.00	90.00	90.00	90.00
DEPLF(group)	4	4	4	4	3

SLA, FR(organ); see functional relations in Chapter 4 and App. C.1.

Soil:

Soil Unit	RD cm	SO cm/√min	KTR cm/min	KO cm/min	SMO cm^3/cm^3	GRV %	GAMA cm^{-2}	PSIm cm	AK $cm^{2.4}/d$	ALF cm^{-1}
				Section: 0 - 20 cm						
FlAh2w	70	0.50	0.0010	0.0016	0.361	3	0.01215	300	55.6	0.0174
2Mt	75	1.43	0.0300	0.0475	0.490	7	0.00966	300	55.6	0.0174
				Section: 20 - 80 cm						
FlAh2w				0.0028	0.548	4	0.00725	300	55.6	0.0174
2Mt				0.0475	0.493	7	0.00929	300	55.6	0.0174
				Section: 80 -140 cm						
FlAh2w				0.0028	0.455	7	0.00945	300	55.6	0.0174
2Mt				0.0475	0.500	7	0.00854	300	55.6	0.0174

studies (e.g. to stress the occurrence of a cambic horizon in the subsoil), even though the difference in infiltration characteristics between Mollisols and Inceptisols may affect land-use-system performance more profoundly.

The characteristics of the 2 sample-soil units are summarized in Table 5.8.

Land Utilization Types

Major crops: The land uses examined include:
- *Zea mays* cv. ARIS,
- *Zea mays* cv. Pioneer 3183,
- *Goss. hirsutum* cv. ZETA-2, and
- *Triticum turgitum durum* cv. Mexicali 81.

Relevant crop/cultivar characteristics are summarized in Table 5.8.
April 30 is the considered germination date of both maize and cotton; two germination dates are considered in scenarios with wheat, viz. 26/11 and 16/12.

Irrigation methods: Maize and cotton are irrigated with moving laterals or large sprinklers (irrigated maize is absent from soil unit F1Ah2w). System productivity with these methods will be calculated and compared to that of systems with drip irrigation. Wheat is normally grown rainfed. The productivity of irrigated wheat will be investigated as well. However, only drip irrigation is relevant.

Irrigation management: Table 5.4 indicates the **water supply in the field** (INPIRR, cm per application day), the **application intensity** (VO, cm/hour) and the **maximum surface storage capacity** (SSMAX, cm).

- The water supply (INPIRR) is conditioned by the actual water discharge rate, the parcel size and the irrigation interval.

A parcel size of 10 ha is the size of an average holding in the Nikea area (where irrigation water is scarce).

Application intervals used in sprinkling irrigation are 7 days for maize and 10 days for cotton. The (Julian) days of irrigation are:
Maize: 146,156,164,170,177,184,192,198,205,212,220,227,234 and 241.
Cotton: 170,190,200,210,220,230,and 240.

In the Platanoulia-Agia Sophia-Dendra area, 42 public pumping stations discharge an average of 8,820 m^3/hour to serve 1,664 ha (Section 2.3). On the Tertiary tracts, only 10% of the cultivated area is irrigated (valley bottoms and footslopes). Water is lifted by private pumps with a capacity of 30-40 m^3/hour. In the Nikea area, 235 pumps irrigate 600 ha (2.5 hectares per pump). This is only a fraction of the average holding (11 ha; see Section 2.2), which is due to the fact that holdings in the undulating/rolling tracts normally include "poorer" soils of the higher slopes and tops, and "richer" soils on the footslopes and valley bottoms. This configuration leads to tillage operations perpendicular to the contours (SSMAX=0) and limits the efficiency of irrigation. In the present calculations, an average discharge rate of 35 m^3/hour per pump is assumed.

The water supply is estimated from the rotation days (7 days for maize and 10 days for cotton), and the operating hours (13 for move-laterals and 18 for large sprinklers and drip irrigation), according to the following formula:

$$Q = (100 * A * INPIRR) / (t * h), \tag{5.6}$$

where Q is the discharge (m^3/hour), A is the irrigated area (ha), t is the number of days required for a complete irrigation, h is the number of operating hours per day, and INPIRR is the water supply (cm per application).

Example: irrigation of maize grown on 2Mt soil (Nikea area) and using large sprinklers: $Q=35$ m^3/hour, $A=10$ ha, $t=7$, $h=18$ (efficiency=100%). Equation (5.6) reads:

INPIRR = (35 m^3/hour x 18 hours x 7 days) / (10 ha x 100) = 4.4 cm,

The possible combinations are summarized in Table 5.9, assuming an overall efficiency of 75% in the distribution of irrigation water in the Platanoulia area.

Table 5.9. Calculated maximum water availability (INPIRR, cm) at field level in the selected land use systems.

L.U.S.	Land Utilization Type			
Soil Unit	MAIZE		COTTON	
	I + II	III	I + II	III
F1Ah2w	5.0	3.6	7.0	5.0
2Mt	4.4	3.2	6.0	4.5

where I=drip irrigation, II=travelling guns, III=moving laterals.

The analyses of the potential production of irrigated cotton on the two soil types (see Section 5.4), suggest an optimum INPIRR-value for each reference-yield level. If this value is less than the INPIRR-value cited in Table 5.9), the lower value is used in the calculations, assuming a medium to high know-how level. This does not apply in the case of maize and wheat where the effects of water supply are more straightforward.

- The irrigation application rate, VO:

The discharge rates of travelling guns are between 1.7 and 2.0 cm/hour. Both these VO-values are used in the calculations.

Moving laterals with sprinklers discharging 2.5 m^3/hour each and irrigating an area of $12x18=216m^2$ are thought to be representative. The resulting VO is 1.2 cm/hour.

For drip irrigation, VO is set to 0.4 cm/hour. Such a low value precludes ponding and runoff in all scenarios studied.

- The maximum surface storage capacity, SSMAX, is nil in the Nikea area and on soil F1Ah2w due to surface crusting. In the latter case, however, an additional scenario with SSMAX=0.5 cm is considered to represent improvement of the surface structure (by calcium compounds, organic manure, etc.).

The examined combinations are summarized below:

Irrigation method	A		B	
	VO	SSMAX	VO	SSMAX
I. Drip irrigation	0.4	0.0	n.r.	n.r.
II. Travelling guns	1.7	0.5	2.0	0.0
III. Small sprinklers	1.2	0.5	1.2	0.0

Results and discussion

Land use systems with maize

Tables 5.10 and 5.11 demonstrate the great impact of the level of technical skill on maize production on the studied soils. Very high yields can be obtained with drip irrigation on F1Ah2w soil. The production potential can be realized except for the year 1988, when water stress depresses yields by 1-1.5 t/ha. The permeability of this soil is so low, that the use of large sprinklers or travelling guns leads to waterlogging and very low yields. The yields vary greatly with the applied management (viz. more than 4 t/ha; Table 5.10), and the risk of "crop failure" is great in unfavourable years (yields of 2.9-3.5 t/ha in 1988; Table 5.10). The simulated results show that premature wilting of the crop takes place under management II.B. Using moving laterals on the same soil gives appreciably higher yields, viz. 12-13.5 t/ha depending on cultivar and management, without the risk of a sharp decrease in yield in unfavourable years (yields of 8-10 t/ha in 1988; Table 5.10).

The simulation is different on soil unit 2Mt. There, low water availability (Table 5.9) precludes potential production even if drip irrigation is used (Table 5.11). The high infiltration capacity of this soil makes ponding and runoff unlikely under the highest application rates (VO=2 cm/hour), and the same production is calculated for different levels of technical know-how. Since drip irrigation and travelling gun systems operate for 18 hours/day, both systems attain the same productivity (100% efficiency of the travelling gun). Table 5.11 shows that yields of 13.5 t/ha for cv. ARIS and 15.4 t/ha for cv. P.3183 are obtainable, but they may be reduced by 4 t/ha in a warm year like 1988. The response of this soil to warmer and drier conditions is more pronounced than the Platanoulia Alfisol. Rather low yield-potentials were found for systems with moving laterals, especially in 1988 (Table 5.11). Although move-laterals seem superior to travelling guns on F1Ah2w soils, high production on the Nikea soil requires the use of travelling guns. Note that it is assumed that use is made of the available water (discharge). Lower yields obtained in practice when large sprinklers are used are due to the irregular water distribution under strong winds. Fig. 5.16 shows that 90% efficiency of application (viz. 54 vs. 60 cm of net water input) explains a 2 t/ha yield reduction (viz. 12 vs. 14 t/ha) on soil 2Mt. The same was observed in the Nikea area in 1987 (on soil unit 3Vt).

The difference in production observed between maize cv. ARIS and cv. PIONEER (under optimum conditions) is of the order of 1 to 2 t/ha, depending on germination date and the year (Section 5.4). Tables 5.10 and 5.11 show that this difference in productivity remains visible under conditions of moderate water stress, albeit that the gap narrows beyond a certain level when the water-stress increases and the yield decreases. This is shown in Fig. 5.17,

Table 5.10. The potential grain yield (kg/ha) of maize cultivars on Pleistocene Calcic Haploxeralfs (unit F1Ah2w), in 1987, 1988 and an average year, calculated at PS-2 level for 3 irrigation methods and 2 know-how levels.

Year	1988		1987		Av. Year	
Cultivar	<------------- I. Drip irrigation				---------------->	
	I.A	Potential	I.A	Potential	I.A	Potential
cv.ARIS	14,250	15,380	16,340	16,304	17,062	17,300
cv.P.3183	15,618	17,074	17,640	17,724	19,446	19,454
	<------------ II. Travelling guns				---------------->	
	II.B	II.A	II.B	II.A	II.B	II.A
cv.ARIS	2,976	6,320	4,519	8,230	4,079	8,446
cv.P.3183	3,470	6,711	4,828	9,602	4,598	9,135
	<----------- III. Moving laterals				---------------->	
	III.B	III.A	III.B	III.A	III.B	III.A
cv.ARIS	8,235	9,742	10,651	12,017	10,927	11,804
cv.P.3183	8,972	10,670	12,139	13,644	12,637	13,642

Table 5.11. The potential grain yield (kg/ha) of maize on Typic Calcixeroll (soil unit 2Mt), in 1987, 1988 and in an average year, calculated at PS-2 level for 3 irrigation methods.

Year	1988	1987	Av. Year
Cultivar	Drip irrigation (I) and travelling guns (III)		
cv. ARIS	9,839	13,844	13,645
cv.P.3183	11,125	15,391	15,390
		II. Moving laterals	
cv. ARIS	4,792	8,041	7,346
cv. P.3183	5,425	9,308	8,465

which is based on data from Tables 5.10 and 5.11 (marked). The triangles in Fig. 5.17 indicate the potential yield-values (no water-stress; see Table 5.5). If the cost of the seed(ling) material and procurement price of the (grain) product are known (Section 5.2), tentative cost/benefit analyses can be made, both at farm- and national level (see also Table 5.19).

The difference in productivity between the 2 American hybrids is not significant in the studied systems. Simulations suggest that the grain yields of cv. P.3165-DONA are 300 to 500 kg/ha higher than cv. P.3183. This difference is too small to compensate for the occasionally too late maturation of the long-cycle hybrid.

Land use systems with cotton

An entirely different situation exists in systems with cotton. Table 5.12 shows that a pronounced year-to-year yield fluctuation (about 1.3 t/ha) obscures any spatial variations, including differences induced by different soils and/or irrigation methods and management. If germination takes place on April 30th, soil unit 2Mt is slightly more productive than soil unit F1Ah2w (about 200-300 kg/ha).

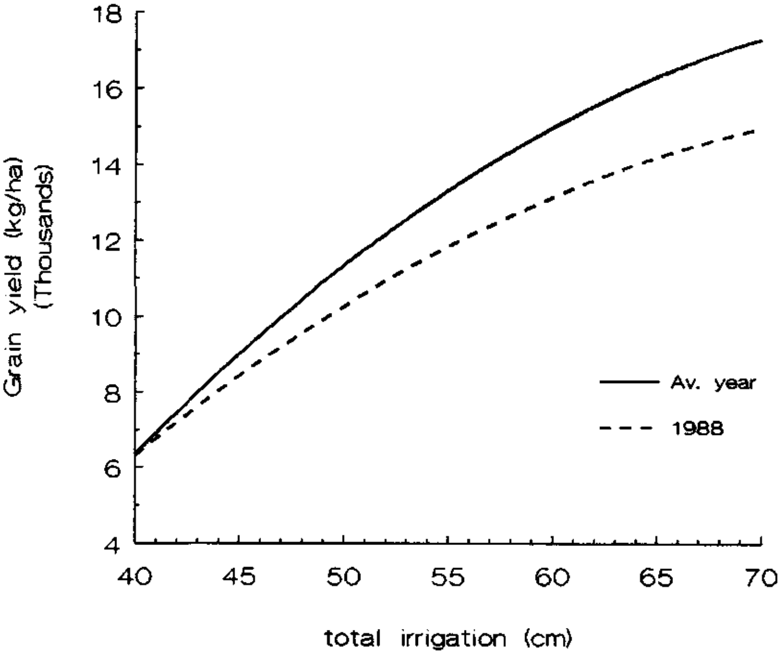

Fig. 5.16. Calculated yield of maize (cv. ARIS) on 2Mt soil (Nikea area) as a function of the total (net) water input in 1988 and in an average year. (Emergence occurs on 30/4. Irrigation rotation 7 days; equal water inputs per application).

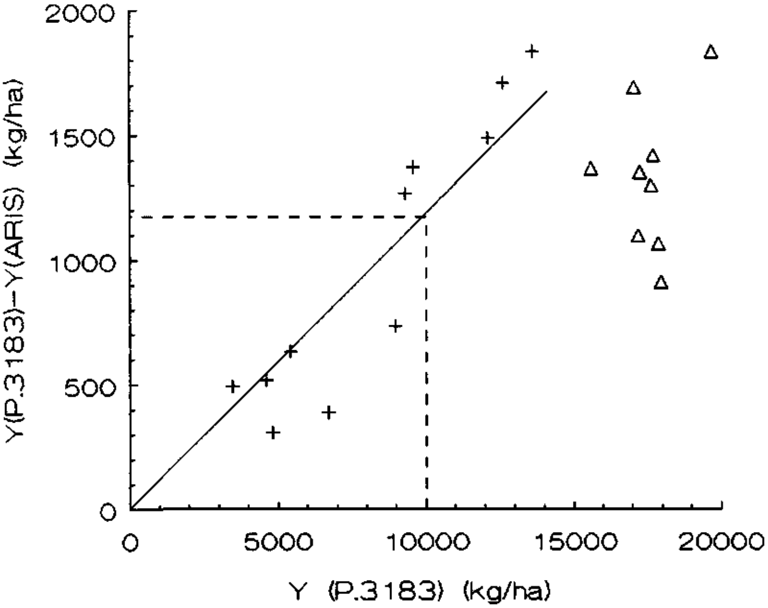

Fig. 5.17. The difference in the production potentials (Y, in kg/ha) of maize cv. P.3183 and cv. ARIS versus the yield potential of cv. P.3183, calculated for scenarios with water stress (+) and constraint-free conditions (Δ).

Table 5.12. Potential yield (kg/ha) of cotton cv. Zeta-2 calculated at PS-2 level for soil units F1Ah2w and 2Mt in 1988 and an average year; 3 irrigation methods and 2 technical levels are assumed (10% moisture content).

Year	1988		Av. Year	
Soil unit	<---------- I. Drip irrigation ------->			
	I.A	Potential	I.A	Potential
F1Ah2w	3,430	3,430	2,104	2,195
2Mt	3,554	3,593	2,380	2,380
	<--------- II. Travelling guns ------->			
	II.B	II.A	II.B	II.A
F1Ah2w	2,844	3,364	2,104	2,195
2Mt	3,554	3,554	2,380	2,380
	<-------- III. Moving laterals ------->			
	III.B	III.A	III.B	III.A
F1Ah2w	3,430	3,369	2,104	1,973
2Mt	3,593	3,593	2,282	2,282

Table 5.12 suggests that the use of moving laterals may improve cotton yields on Platanoulia soil by 600 kg/ha (management II.B vs. III.B in Table 5.12), but only in a warm year such as 1988. Simulation results indicate an average sorptivity of about 0.35 cm $\text{min}^{-1/2}$ (standard sorptivity, SO=0.5 cm $\text{min}^{-1/2}$; see Table 5.8) for soil F1Ah2w. Under these conditions, percolation of more than 2-2.3 cm water per application appears to be impossible under management II.B (see also Fig. 3.29). The 600 kg/ha yield reduction is also apparent in Fig. 5.14a, for germination on 30/4(J.day #120) and a total net water input of 2.3*7=16 cm (for 7 irrigations; see earlier). Using the sorptivity values for Alfisols on the Pleistocene terrace (Tables 3.6 and 3.7) permits to compute the production potential(s) of these soils under a defined management. It appears that Palexeralfs (F1Ap; FAO: Planosols) and Xerochrepts (F1Ic; severely eroded Palexeralfs) produce only low yields if irrigated with travelling guns, especially in warm years.

Note that Palexeralfs are traditionally seen as poor soils (low pH, base saturation in the topsoil, etc.). Since drip irrigation is applied in orchards on the Pleistocene surface, these soils rank among the most productive ones for orchards. For maize and also for cotton, these soils are still considered to be poor. However, the author noted that cotton on a "poor" (calcic horizon exposed at the surface) but highly permeable soil, performed better than cotton on the Pleistocene surface (field estimate: 3 tons vs. 1.8-2.2 tons seed cotton per hectare). Cotton grown on an Alfisol of Amygdalea performed equally well as cotton on Nikea Vertisols and Mollisols (3 t/ha seed cotton). The farmer applied water for a second time (by travelling gun) after the main irrigation application, knowing that the crop needed more water than applied when ponding started.

In the beginning of this paragraph it was shown that year-to-year fluctuations in cotton yield may obscure spatial soil variation. This, however, cannot be generalized, as spatial soil variation and differences in management may appreciably affect the cotton productivity values in other than the examined systems. Those soil properties which directly affect the time of sowing/germination, such as the texture of the topsoil, gravel content and drainage, may cause yield variations of 1 ton/ha or more. Classical is the example of clay soils with shallow ground-water in the Peneios delta area, where cotton fails altogether.

Land use systems with wheat

Grain yields of rainfed and irrigated wheat on the 2 sample soils in 1988-89 and in an average year are presented in Table 5.13 for two germination dates. Only drip irrigation of wheat is relevant. The Larissa experiment in 1988-89 suggests that potential production can be realized with drip irrigation; the reference yields calculated in Section 5.4 are included in Table 5.13, for the irrigated crop.

The better water-holding capacity of soil F1Ah2w explains why wheat grain production on this soil is 1-1.5 t/ha higher than on the Nikea Mollisol. The reference-yield level is stable if germination is the period from 26/11 to 16/12 (Table 5.13). However, the yield of the late rainfed crops (same germination period) is 1-1.2 t/ha less, because of water stress in late May. Earlier germination than 26/11 results in slightly lower yield potentials (Section 5.4) and should be avoided in irrigated crops.

Table 5.13. Grain yield (kg/ha) of rainfed and irrigated wheat cv. Mexicali on 2Mt and F1Ah2w soils for 2 germination dates (in brackets) in 1988-89 and in an average year (13% moisture in grain).

Year	1988-89		Av. Year	
Soil unit	Drip irrigation			
	(26/11)	(16/12)	(16/11)	(16/12)
F1Ah2w	8,215	8,318	9,350	9,432
2Mt	do	do	do	do
	Rainfed			
	(26/11)	(16/12)	(16/11)	(16/12)
F1Ah2w	5,186	4,032		
2Mt	3,865	2,661	4,340	3,484

Physical land suitability

The land suitability class is an expression of the fitness of a given land unit for a defined use. The calculated yield figures reflect the overall Land Use System-performance and are used to group land into suitability classes. The physical suitability classification precedes any socio-economic evaluation.

The relative yield, i.e. the yield per hectare, relative to that of the best land (FAO, 1985), is the most widely used indicator of physical land suitability. The first step is to establish the reference yield levels; the following values are in line with the results of Section 5.4.

Crop	Ref. yield (kg/ha)
Maize	20,000
Cotton	4,000
Wheat	10,000

The preliminary suitability class is established using the approach described in the FAO Framework (FAO, 1976, 1983). See Table 5.14. The S1/S2 boundary marks the lower limit of "highly suitable" conditions. The S2/S3 boundary marks the point where conditions are becoming marginal, and productivity is considerably reduced (=<40% of the reference yield). The S/N boundary marks the limit beyond which land use is impracticable. A yield of 20% or less than its reference value has been taken to represent this point.

Current land suitability may differ from the suitability after major land improvements have been made. Table 5.10 illustrates the importance of proper management: with management II.B, the suitability for land utilization types with maize cv. ARIS is N (yield about 4 t/ha), whereas with management III.A it becomes S2 (yield 11.8 t/ha), and with management I.A even S1 (17.3 t/ha).

Table 5.14. Structure of the suitability classification (FAO, 1983).

Order	Class	Description	Relative Yield
S Suitable	S1	Highly Suitable	100-80%
	S2	Moderately Suitable	80-40%
	S3	Marginally Suitable	40-20%
N Not Suitable		Not Suitable	<20%

The S3 class is comparatively narrow (40-20% of the reference yield); the S2 class is much wider. Table 5.14 shows that this class would include yields of 8,000-16,000 kg/ha of maize and 1,600-3,200 kg/ha of cotton. Such a wide range implies considerable loss of information. Therefore, a number of subclasses are distinguished within class S2, viz. S21, S22, etc. The subclasses are chosen narrow enough to support meaningful economic evaluation in a later stage. In the case of maize, for example, differences in yield of 2 t/ha correspond with differences in capital returns of not less than 3,400 ECU (holding of 10 ha). Where moving laterals were used to irrigate maize cv. P.3183 on soil F1Ah2w, the yields fluctuated by 1 t/ha in response to only slight differences in technical skill and know-how (12,637 kg/ha in III.B vs. 13,642 kg/ha in III.A; Table 5.10). Introducing somewhat different initial conditions in the calculations, did the final grain yield fluctuate by 1 t/ha or more. It seems reasonable to introduce subclasses for every 10% decrease of the relative yield within class S2.

The final suitability classes are summarized in Table 5.15. These descriptions are irrelevant for rainfed wheat (a yield of 4-5 t/ha is "good" rather than "marginally good"). The subclass code and relative yield levels may be maintained, but an additional S4 subclass, coded "Low Suitability" is more appropriate than the class N "Not Suitable".

The data of Tables 5.10 through 5.13 can be arranged in suitability classes. Table 5.16 shows classes based on the relative yield in an average year, averaged for the two levels of technical skill and know-how (A and B). Other than average conditions (e.g. warm years, etc.) may cause deviations by one (sub)class. If deviations are greater than one subclass (in exceptional years), this signals possible risks to the farmer, or the promise of an exceptionally good yield (e.g. cotton in hot years). If a risk of total failure exists, this should always be indicated, e.g. S3/N.

Table 5.15. Criteria for classifying the physical land suitability for irrigated crops in the Larissa region.

Suitability Subclass	Description	Relative Yield	<---- Yield (t/ha) -----> Maize	Cotton	Wheat
S1	Excellent	100-80%	20-16	>4.0-3.2	10-8
S21	Very Good	80-70%	16-14	3.2-2.8	8-7
S22	Good	70-60%	14-12	2.8-2.4	7-6
S23	Fairly Good	60-50%	12-10	2.4-2.0	6-5
S24	Marginally Good	50-40%	10- 8	2.0-1.6	5-4
S3	Marginal	40-20%	8- 4	1.6-0.8	4-2
N	Not Suitable	<20%	<4	<0.8	<2

Table 5.16. The physical land suitability for selected LUTs with a medium to high level of management skill.

L.U.S.	Land Utilization Type										
Soil Unit	Corn (ARIS)			Corn P.3183			Cotton			Wheat	
	I	II	III	I	II	III	I	II	III	I	R
F1Ah2w	S1	S3 --- N	S23	S1	S3 --- N	S22 --- S24	S23 --- S1	**S23** --- **S21**	S23 --- S1	S1	**S23**
2Mt	S22 --- S24	**S22** --- **S24**	S3 --- N	S21 --- S23	**S21** --- **S23**	S24	S23 --- S1	**S23** --- **S1**	S23 --- S1	S1	**S24**

(Note: I drip irrigation; II travelling guns; III move-laterals; R rainfed).

5.6.2 Some socio-economic implications

The bold figures in Table 5.16 represent the present land use and management in the selected LUSs. The most promising of the studied land use systems are those already practiced (except for drip irrigation). Note for example that sprinkling-irrigated maize is absent from soil unit F1Ah2w because of the high risk of crop failure in unfavourable years. The soil is irrigated with travelling guns, and nonetheless more productive under cotton (Table 5.16). Note, however, that sound conclusions on merits of present and future land use and management (e.g. introduction of drip irrigation, etc.) cannot be drawn if based on physical ratings only.

In the following, the physical land (sub)classes are combined with farm budget studies for "typical" farms (FAO, 1985; 1986). Subtracting all variable and fixed costs from the gross value of production on a given land unit yields the approximate net income.

Table 5.17. Cost and returns to irrigated maize (cv. ARIS) per hectare. Irrigation method: II. Travelling gun (high level of technical skill).

Soil mapping unit 2Mt, Nikea area	
Item	Amount (ECU)
Receipts: 13.64 tons at 170.2 ECU/ton	2,321.7
Expenses:	
Materials	
Fertilizers	170.0
Seed	85.0
Pesticides	13.0
Operation:	
Fertilization	8.0
Sowing	28.0
Ploughing (x2), disking, harrowing	123.0
Pest control	8.0
Harvest (8% of receipts)	185.7
Pumping cost (irrigation)	42.0
Miscellaneous (incl. maint. of buildings)	8.0
Subtotal	670.7
Interest on recurrent costs (at 0.075)	50.3
Annual pay-off of buildings and constructions	77.0
Annual pay-off of travelling gun	205.0
Labour (-irrigation)	60.0
Labour for irrigation	25.0
Taxes	20.0
Total expenses	1,108.0
Net income	1,213.7

(Based on land utilization studies in the Larissa region by Min. Env., Land Use Plan. & Public Works, 1987; see also Appendix E).

Table 5.18. Class boundaries for economic suitability classification.

Suitability Subclass	Description	Net Income in ECU
S1	Excellent	>2,400-2,100
S2	Very good-excellent	2,100-1,800
S3	Very Good	1,800-1,500
S4	Good	1,500-1,200
S5	Fairly Good	1,200- 900
S6	Marginally Good	900- 600
Sc	Condit. Suitable	600- 300
N	Not Suitable	<300

An example of such a farm budget is presented in Table 5.17. This budget concerns a situation with maize (cv. ARIS) on 2Mt soil (Nikea area) and irrigated with travelling guns at a high level of know-how (efficiency of irrigation 100%), and is expressed per hectare. The method is based on the farm utilization studies in the Larissa region conducted by the Min. of Environment, Land Use Planning & Public Works in 1987, and is fully explained in Appendix E. The operation costs are discussed first (App. E.1), with emphasis given to the costs of irrigation (labour, pumping and capital investment). The results are summarized in Appendix E.2. The cost of the materials needed (see Section 5.2) and the operational costs per LUT are listed in Appendix E.3 for each of the 3 studied crops. Similar budgets were worked out for all land use systems included in Table 5.16.

Table 5.18 presents suggested suitability criteria based on net income. Class S1 ("Excellent") enjoys the highest income (based on a calculated reference yield of 4 tons cotton per hectare). The structure of the suitability classification is simple (increments for every 300 ECU/ha) with the possible exception of the class Sc "Conditionally Suitable". This class may accommodate farmers whose net income is less than 300 ECU/ha under the condition that this limit is reached if adjustments are made for the (family) labour cost.

The final result of the economic suitability exercise is summarized in Table 5.19. A number of conclusions can be drawn, strictly for the studied LUSs:

The results confirm the economic viability of the present land use and management (see also Table 5.16). They also confirm that cultivation of maize is impossible on Platanoulia Alfisols if travelling guns are used, and marginally good if small sprinklers are used. Traditional rainfed wheat production gives the same economic return (S6).

Introduction of drip irrigation is not always justified. Drip irrigation seems highly recommendable for systems with maize on F1Ah2w soil (Table 5.19), though properly used travelling guns are a better choice for irrigating the 2Mt soil. The simulation results indicate that large sprinklers are economic even at application efficiencies of less than 100% (strong winds, etc.). Drip irrigation is also not economic if cotton is grown on F1Ah2w soil, except in warm years (viz. S5/S3 (II) vs. S6/S2 (I); Table 5.19). Analysis of more years is needed. Note that the infiltration capacity of the F1Ah2w soil is marginal if travelling guns are used to irrigate cotton on the Pleistocene terrace. Drip irrigation is more economic in areas with Palexeralfs (FAO: Planosols) and their (severely) eroded counterparts (Calcixerollic Xerochrepts).

Table 5.19. Economic suitability of the selected LUTs; medium to high management level.

L.U.S.	Land Utilization Type										
Soil Unit	Corn (ARIS)			Corn P.3183			Cotton			Wheat	
	I	II	III	I	II	III	I	II	III	I	R.
F1Ah2w	S3 --- S5	N	S6	S2 --- S4	Sc --- N	S6	S6 --- S2	S5 --- S3	Sc --- S3	S5	S6
2Mt	S5 --- Sc	S4 --- S6	Sc --- N	S4 --- Sc	S3 --- S6	Sc --- N	S6 --- S2	S5 --- S1	S6 --- S2	S5	Sc

(Note: I drip irrigation; II travelling guns; III move-laterals; R rainfed).

If water is available, drip irrigation may double the income of wheat producers on Nikea soil (viz. S5 vs. Sc in Table 5.19), and raise it by 30% in the Platanoulia area (viz. S6 vs. S5). In both cases, cotton and maize are the more attractive commodities (Table 5.19). These results have practical significance for compound and multiple land use systems (e.g. the suggested cotton-cotton-wheat rotation), and for land scheduling for irrigation.

Options involving high capital investment, e.g. drip irrigation vs. travelling guns, are often relatively more straightforward because of the minimal labour requirements. Comparing Tables 5.19 and 5.16 shows that, for the same physical suitability classes, farmers' preference for travelling guns over small sprinklers is founded on economic considerations (compare for example these Tables for the case of cotton on 2Mt soil). Moreover, the (labour) cost of operating small sprinklers (Appendix E) outweighs the other costs of irrigation to such extent that travelling guns are economically more attractive despite lower yields. Sample calculations involving maize on 2Mt soil suggest a yield reduction of some 1.2 t/ha. However, even greater yield reductions are tolerated in the study area. Apparently, other financing implications and social factors are additionally involved (subsidies, off-farm employment opportunities, education of the children, and so forth).

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APPENDICES

Soil profile descriptions and analytical data
Climatological data files
Listing of selected program modules
Summary of soil physical data
Costs of operations
Soil maps (loose)

A. SOIL PROFILE DESCRIPTIONS AND ANALYTICAL DATA

A.1. Nikea pilot area

Pedon P1

Classification: USDA (1975): Vertic Calcixeroll; FAO (1988): Haplic Calcisol

435
Pedon code: B-----Mxcv   Mapping unit: 3Mv
A13

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. The profile is situated 4.5 km SW from the village of Nikea, 800 m from where the canal crosses the main field road, 150 m from this road (northern side). Coordinates: 39°31'54.8 N-22°25'08.0 E.
Phys. position: Level valley bottom of the undulating Tertiary surface, 115 m elevation.
Topography: Nearly level, slope less than 2 percent.
Drainage: Well to moderately well drained, very slow permeability when wet, high when dry.
Cultivation: Irrigated cotton, maize, sugar beets, potatoes etc.
Parent material: Very calcareous alluvium and colluvium.
Sampled by: N.G.Danalatos, V. Samaras and I. Varvaroussis, April 27, 1988.
Remarks: soil moisture content near field capacity (normal for the end of spring); later, the dry surface cracks (1 cm or more wide) down to a depth of 50 cm.

Ap 0-18 cm. Dark brown (10YR 3/3) clay; moderate to strong medium subangular blocky and fine granular structure; hard (dry), friable (moist), sticky (wet); common very fine and few fine tubular pores; few very fine and fine roots; strong effervescence; clear wavy boundary; pH=8.3 (Sample No. 10065).

Bk1 18-33 cm. Brown to dark brown (7.5YR 4/4) clay; moderate to strong medium subangular blocky and fine granular structure; hard (dry), friable to firm (moist), sticky (wet); common very fine and fine interstitial pores, few fine tubular pores; few very fine and fine roots; very few small nodules of calcium carbonate; strong to very strong effervescence; gradual irregular boundary; pH=8.5 (Sample No. 10066).

Bk2 33-52 cm. Strong brown (7.5YR 4/6) clay; moderate to strong medium subangular blocky breaking down to fine granular structure; hard (dry), friable to firm (moist), sticky (wet); many very fine and common fine interstitial pores, few fine tubular pores; few very fine roots; common fine tubular pores; few large (>1 cm in diameter) nodules of calcium carbonate; violent effervescence; gradual irregular boundary; pH=8.6 (Sample No. 10067).

BC 52-84 cm. Reddish yellow (7.5YR 6/6) clayloam; strong coarse prismatic structure; hard (dry), friable to firm (moist), sticky (wet); common very fine and fine interstitial pores; common large nodules of calcium carbonate; violent effervescence; gradual irregular boundary; pH=8.5 (Sample No. 10068).

Ck 84-125 cm. Reddish yellow (7.5YR 6/6) sandy clay; weak to moderate medium prismatic breaking down to medium subangular blocky structure; friable to firm (moist), slightly sticky (wet); common very fine and fine interstitial pores; extremely calcareous with common carbonatic nodules; pH=8.7 (Sample No. 10069).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH
10065	P1	0- 18	Ap	29	19	52	C	2.10	10.50	8.3
10066		18- 33	Bk1	29	19	52	C	1.34	26.46	8.5
10067		33- 52	Bk2	29	20	51	C	0.84	49.56	8.6
10068		52- 84	BC	43	19	38	CL	0.43	65.52	8.5
10069		84-125	Ck	47	17	35	SC	0.33	78.12	8.5

Pedon P2

Classification: USDA (1975): Typic Chromoxerert
FAO (1988): Calcic Vertisol
435
Pedon code: B-----Vxct Mapping unit: 3Vt
A03

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. The profile is situated about 3.5 km SW of the village of Nikea, 300 m eastern of the point where field road crosses canal (east). Coordinates: 39°32'18.3 N, 22°25'43.8 E.
Examinated by: N.G.Danalatos and V. Samaras, April 28, 1988.
Phys. position: On level valley bottom of the undulating Tertiary surface, 112 m elevation.
Topography: Flat
Drainage: Well drained, very slow permeability when wet, high when dry.
Cultivation: Spring wheat (4-5 t/ha), irrigated cotton, maize, potatoes, sugarbeets etc.
Parent material: Accumulated calcareous alluvium+colluvium.
Sampled by: N.G. Danalatos, V. Samaras and I. Varvaroussis, April 28, 1988.
Remarks: Soil at about field capacity, normal for the end of spring. In the summer, the dry soil surface cracks (1 cm or more wide down to a depth of 50 cm.

Ap 0-20 cm. Dark brown (10YR 3/3) clay; moderate medium angular blocky structure; very hard (dry), firm (moist), sticky to very sticky (wet); few very fine pores; many very fine and fine roots; very calcareous; gradual wavy boundary; pH=8.2 (Sample No. 10070).

Ah1 20-34 cm. Dark brown (10YR 3/3) clay; moderate medium angular blocky structure; hard (dry), firm (moist), sticky (wet); abundant very fine and fine roots; few very fine and fine interstitial pores; strong effervescence; gradual wavy boundary; pH=8.2 (Sample No. 10071).

Ah2 34-56 cm. Dark yellowish brown (10YR 3.5/4) clay; moderate medium subangular blocky structure; very firm (moist), sticky to very sticky (wet); few very fine and very few fine roots; common very fine interstitial pores; very few slickensides; strongly calcareous; gradual wavy boundary; pH= 8.3 (Sample No. 10072).

Ah3 56-96 cm. Dark yellowish brown (10YR 3.5/4) clay; strong coarse subangular blocky structure; firm (moist), sticky to very sticky (wet); many very fine and common fine interstitial pores; very few very fine roots; strongly calcareous; common slickensides; gradual wavy boundary; pH=8.3 (Sample No. 10073).

Ah4 96-140 cm. Dark yellowish brown (10YR 3.5/4) clay; moderate medium subangular blocky structure; firm to very firm (moist), sticky to very sticky (wet); many very fine pores; few very fine roots; violent effervescence; very few small (<1 cm diameter) nodules of calcium carbonate; pH=8.3 (Sample No. 10074).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	CaCO$_3$ tot.(%)	pH
10070	P2	0- 20	Ap	27	23	50	C	3.33	12.80	8.2
10071		20- 34	Ah1	27	23	50	C	2.71	8.40	8.2
10072		34- 56	Ah2	25	21	54	C	1.87	10.08	8.1
10073		56- 96	Ah3	28	20	52	C	1.62	13.02	8.3
10074		96-140	Ah4	25	21	54	C	1.25	17.22	8.3

Pedon P3 (Plate 3E)

Classification: USDA (1975): Typic Chromoxerert
FAO (1988): Calcic Vertisol
435
Pedon code: B-----Vxct Mapping unit: 3Vt
A03

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. 2.6 km SW of the village of Nikea, 50 m from canal. Coordinates: 39°32'45.6 N,22°26'09.4 E
Phys. Position: Edge of valley bottom, lowest part of a convex slope (200 m) of the undulating Tertiary surface, 106 m elevation.
Topography: Flat
Drainage: Well drained, slow permeability when wet, basic intake 2.4 cm/h.
Cultivation: Well performing winter wheat; water being available, cotton, potatoes, maize etc. give high production.
Parent Material: Accumulated calcareous sediment from higher elevations (eroded A-horizons).
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, June 6, 1988.
Remarks: Dry upper part, somewhat moist below. The gravelly surface has large cracks which (especially later in the season) are 3 cm or more wide; cracks of 1 cm extend down to 50 cm.

Ap 0-24 cm. Very dark greyish brown (10YR 3/2) clay, brown (10YR 5/3) when dry; weak to moderate medium subangular blocky structure; hard to very hard (dry), firm (moist), sticky (wet); common very fine and few fine pores; abundant very fine and fine, and few medium roots; about 5 percent gravel by volume; calcareous; clear smooth boundary; pH=7.9 (Sample No. 11936).

Ah1 24-53 cm. Very dark greyish brown (10YR 3/2) clay, brown (10YR 5/3) when dry; moderate medium subangular blocky breaking to moderate fine to very fine subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); many very fine pores; many very fine and fine roots; very few fine rounded limestone gravel; effervescence; gradual smooth boundary; pH=8.1 (Sample No. 11937).

Ah2 53-74 cm. Dark brown to very dark brown (10YR 2.5/3) clay; strong medium prismatic structure; very firm (moist), sticky to very sticky (wet); common very fine and fine interstitial pores; gravel as above; common very fine roots; calcareous; gradual smooth boundary; pH=8.1 (Sample No. 11938).

AC 74-135 cm. Dark yellowish brown (10YR 3.5/5) clay; moderate medium to coarse angular blocky structure; very firm (moist), sticky (wet); visible slickensides deeper than 80 cm increasing with depth; common very fine and few fine interstitial pores; gravel as above; few very fine roots to a depth of 100 cm; strongly calcareous with few carbonate nodules up to 2 cm in diameter; pseudomycelia of calcium carbonate and white pockets increasing with depth; pH=8.4 (Sample No. 11939).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	CaCO$_3$ tot.(%)	pH
11936	P3	0- 24	Ap	28	26	46	C		13.44	7.9
11937		24- 53	Ah1	26	22	52	C		13.02	8.1
11938		53- 74	Ah2	26	20	54	C		11.97	8.1
11939		74-135	AC	26	20	54	C		15.54	8.4

Pedon P4 (Plate 3B)

Classification: USDA (1975): Calcixerollic Xerochrept
FAO (1988): Haplic Calcisol
435
Pedon code: B-----Ioxc Mapping unit: 2Id4
B13

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. 2.6 km SSW of the village of Nikea, Coordinates: 39°32'37.2 N, 22°26'17.4 E.
Phys. Position: Middle of convex slope (400 m) of the undulating Tertiary surface, 110 m elevation.
Topography: 5% west-facing slope .
Drainage: Well drained, basic intake 0.9 cm/h
Cultivation: Spring wheat and fodder crops in rotation. Yields of wheat 3-4 t/ha. If water is available cotton performs well (3-4 t/ha). Maize yields maximally 12-13 t/ha. Neighbouring parcels planted to potatoes.
Parent Material: Old, gravelly alluvium+colluvium, very calcareous.
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, June 30, 1988.
Remarks: Dry upper part, somewhat moist below. Fairly gravelly surface.

Ap 0-21 cm. Dark brown to dark yellowish brown (10YR 3.5/3.5) clay, yellowish brown (10YR 5/4) when dry; moderate medium subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); abundant very fine and fine roots; common very fine and fine interstitial pores; very few small rounded limestone gravels (2-4% by volume); strong effervescence; clear smooth boundary; pH=8.2 (Sample No. 11940).

Ah 21-46 cm. Dark brown to dark yellowish brown (10YR 3.5/4) clay; few fine faint strong brown mottles (7.5YR 5/6); weak medium subangular blocky structure; slightly hard to hard (dry), friable (moist), sticky (wet); abundant very fine and fine roots; common very fine and few fine interstitial pores; gravel as above; strong effervescence; gradual wavy boundary; pH= 8.3 (Sample No. 11941).

Bw 46-69 cm. Yellowish brown to dark yellowish brown (10YR 4.5/4) clay; few fine distinct reddish yellow mottles (7.5YR 7/4); moderate medium to coarse subangular blocky structure; slightly hard to hard (dry), friable (moist), sticky (wet); few very fine roots; many very fine and common fine interstitial pores; gravel as above; strongly calcareous with soft powdery filaments of calcium carbonate on structural faces commonly branching, soft coatings in pores and few small white pockets, estimated less than 5%; very strong effervescence; irregular wavy boundary; pH=8.3 (Sample No. 11942).

Bk 69-110 cm. Light yellowish brown to brownish yellow (10YR 6/5) clay; moderate medium to coarse subangular blocky structure; slightly hard to hard (dry), friable (moist), sticky (wet); pores and gravel as in Bw; violent effervescence; secondary carbonate in soft powdery forms and nodules up to 2 cm in diameter; clear smooth boundary; pH=8.4 (Sample No. 11943).

2Ck 110+cm. Very gravelly, white, silty clayloam; structureless; extremely calcareous with continuous thick coatings on pebbles; 70 percent gravel (5-7 cm in diameter) and 5 percent cobbles by volume (Sample No. 11944).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	CaCO$_3$ tot.(%)	pH
11940	P4	0- 21	Ap	32	22	46	C		23.94	8.2
11941		21- 46	Ah	28	20	52	C		26.88	8.3
11942		46- 69	Bw	20	24	56	C		39.48	8.3
11943		69-110	Bk	16	30	54	C		46.20	8.4
11944		110+	2Ck	14	54	32	SiCL		97.44	8.5

Pedon P5 (Plate 3C)

Classification: USDA (1975): Typic Calcixeroll
FAO (1988): Haplic Calcisol
4 3 5
Pedon code: B ------- Mxct Mapping unit: 2Mt
C 1/2 3

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. About 2.5 km SSE from the village. Coordinates: 39°32'33.0 N, 22°26'25.4 E.
Phys. Position: Middle of straight slope of the undulating Tertiary surface, 124 m elevation.
Topography: 8% west-facing slope.
Drainage: Well drained, basic intake 3 cm/h.
Cultivation: Spring wheat and fodder crops in rotation.
Par. Material: Gravelly, very calcareous alluvium+colluvium.
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, July 5, 1988.
Remarks: Dry upper part, somewhat moist deeper down; gravelly surface with cobbles up to 7 cm in diameter.

Ap 0-18 cm. Very dark brown to greyish brown (10YR 3/2.5) slightly gravelly light clay to clayloam (40% clay); moderate medium subangular blocky structure; hard (dry), firm (moist), sticky (wet); many very fine and fine roots; common very fine and fine interstitial pores; about 5-7% by volume gravel and few stones up to 10 cm in diameter; strong effervescence; clear smooth boundary; pH=8.1 (Sample No. 11945).

Ah 18-28 cm. Dark yellowish brown (10YR 3/4) slightly gravelly clayloam; moderate medium subangular blocky structure; hard (dry), firm (moist), sticky (wet); abundant very fine and fine roots; common very fine and few fine interstitial pores; few rounded and angular limestone and serpentine fragments usually up to 3 cm in diameter, about 5-8% by volume; strong effervescence; clear wavy boundary; pH=8.3 (Sample No. 11946).

Bw 28-60 cm. Brown to dark brown (7.5YR 4/4) slightly gravelly clay; moderate medium subangular blocky structure; hard (dry), firm (moist), sticky (wet); few very fine long roots; many very fine and common fine interstitial pores; very calcareous with carbonate mycelia in the walls of some pores and ped faces; gradual wavy boundary; pH=8.4 (Sample No. 11947).

Bk 60-93 cm. Brown to dark brown (7.5YR 4.5/4) clay; moderate fine to medium subangular blocky and fine angular blocky structure; hard (dry), friable (moist), sticky (wet); common very fine and few fine interstitial pores; gravel as above; extremely calcareous with common nodules of calcium carbonate up to 2 cm in diameter; gradual smooth boundary; pH=8.5 (Sample No. 11948).

Ck 93-125+ cm. Olive grey (5YR 4/2) calcareous gravelly clay; massive; slightly hard (dry), friable (moist), sticky (wet); extremely calcareous with very frequent nodules of calcium carbonate; pH=8.5 (Sample No. 11949).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH
11945	P5	0- 18	Ap	39	21	40	C/CL		23.52	8.1
11946		18- 28	Ah	34	20	46	C		29.82	8.3
11947		28- 60	Bw	30	22	48	C		35.28	8.4
11948		60- 93	Bk	20	26	54	C		51.24	8.5
11949		93-125	Ck	22	28	50	C		40.32	8.5

Pedon P6 (Plate 3A)

Classification: USDA (1975): Calcixerollic Xerochrept
FAO (1988): Haplic Calcisol
334
Pedon code: B-----Ioxc Mapping unit: 1Ic3
B13
Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. 2,450 m SSW of the village. Coordinates: 39°32'33.0 N, 22°26'28.6 E.
Phys. Position: Top of Tertiary hill, 132 m elevation. Surrounding slopes are 8%.
Topography: Nearly level for about 15 meters at either side of the profile in NE-SW direction and 150 m in NW-SE direction with micro-undulations.
Drainage: Well to somewhat excessively drained, basic intake 3 cm/h.
Cultivation: Spring wheat and fodder crops in rotation. Yields of durum wheat < 2.5 t/ha.
Par. Material: Gravelly, very calcareous old alluvium and colluvium.
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, July 4, 1988.
Remarks: Dry upper part, somewhat moist below; gravelly and stony surface.

Apk 0-20 cm. Dark brown to dark yellowish brown (10YR 3.5/3) gravelly sandy clayloam, light brownish grey to greyish brown (10YR 5.5/2) dry; moderate fine subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky (wet); many very fine and fine pores; common very fine roots; 30% gravel and stones up to 20 cm in diameter rounded and not; the gravels are limestone, sandstone, serpentine, quartz or cemented $CaCO_3$, increasing with depth; very strong effervescence; clear smooth boundary; pH=8.1 (Sample No. 11950).

ACk 20-44 cm. Light yellowish brown to yellowish brown (10YR 5.5/4), gravelly sandy clayloam; weak fine subangular blocky structure; soft (dry), friable (moist), non sticky (wet); many very fine and fine pores; common very fine and few fine roots; gravelly as above; very strong effervescence; calcium carbonate concretions and pendants below cobbles; clear irregular boundary; pH=8.4 (Sample No. 11951).

Ck1 44-63 cm. Light yellowish brown (10YR 6/4) gravelly sandy loam; weak fine subangular blocky structure; soft (dry), friable (moist), non sticky (wet); many very fine and fine interstitial pores and few tubular pores; common very fine and few fine roots; gravel 50% by volume; violent effervescence; calcium carbonate in powdery forms but also many nodules and pendants below pebbles; diffuse wavy boundary; pH=8.4 (Sample No. 11952).

Ck2 63-105 cm. Light yellowish brown (10YR 6/4) very gravelly sandy clayloam, white (10YR 8/2) dry; massive; extremely calcareous; pH=8.3 (Sample No. 11953).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH
11950	P6	0- 20	Apk	52	24	24	SCL		34.86	8.1
11951		20- 44	ACk	56	24	20	SCL		37.38	8.4
11952		44- 63	Ck1	54	28	18	SL		39.96	8.4
11953		63-105+	Ck2	51	25	24	SCL		56.70	8.3

Pedon P7

Classification: USDA (1975): Vertic Calcixeroll
FAO (1988): Calcic Chernozem
435
Pedon code: B-----Mxcv Mapping unit: 3Mv
A13

Location: Map Sheet 4392/5, Nikea (Larissa), Thessaly, Greece. 2.3 km south-south-west of the village. Coordinates: 39°32'35.1 N, 22°26'35.8 E.
Phys. Position: Bottom of secondary valley in undulating Tertiary surface, running in SSE-NNW direction, 116 m elevation.
Topography: Almost flat, slope less than 2 percent.
Drainage: Well drained, slow permeability when wet, high when dry.
Cultivation: Spring wheat and fodder crops in rotation.
Par. Material: Accumulated calcareous materials from surrounding slopes.
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, July 5, 1988.
Remarks: The surface is cracked into large polyhedrons. Some cracks are 4 cm wide. Vertical cracks 1 cm wide detected down to 84 cm. Fairly gravelly surface, with cobbles up to 6 cm in diameter.

Ap 0-23 cm. Very dark brown (10 YR 2/2) heavy clay, dark greyish brown (10YR 4.2) when dry; moderate medium and weak fine subangular blocky structure; hard (dry), very firm (moist), very sticky (wet); common very fine and fine pores; gravel 1% by volume; abundant very fine and fine and few medium roots; very calcareous with some pseudomycelia and small nodules of calcium carbonate; clear wavy boundary; pH=8.2 (Sample No. 12100).

A12 23-41 cm. Black (10YR 2/1) clay; moderate medium and weak fine subangular blocky structure; hard (dry), very firm (moist), very sticky (wet); many very fine and few fine pores; gravel as in Ap; abundant very fine and fine and few medium roots; strong effervescence with carbonate features as in Ap; gradual smooth boundary; pH=8.3 (Sample No. 12101).

A13 41-71 cm. Black (10YR 2/1) clay; strong medium prismatic and coarse angular blocky structure; very firm (moist), very sticky (wet); many very fine and few fine interstitial pores; gravel 1-2% by volume; many very fine and few fine roots; strong effervescence; calcium carbonate as above; clear smooth boundary; pH=8.3 (Sample No. 12102).

A14 71-108 cm. Black (10YR 2/1) clay; strong medium prismatic and coarse angular blocky structure; very firm (moist), very sticky (wet); many very fine and common fine interstitial pores; gravel as above; strong effervescence with few coatings and threads of calcium carbonate; gradual smooth boundary; pH=8.4 (Sample No. 12103).

ACk 108-140+ cm. Very dark greyish brown (10YR 3/2) clay; few medium distinct reddish mottles and fine black mottles; weak to moderate medium prismatic structure; very firm (moist), very sticky (wet); many very fine pores; no roots; gravel 2-3% by volume; powdery carbonate coatings in pores, and few irregular carbonate nodules; violent effervescence; pH=8.6 (Sample No. 12104).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	CaCO$_3$ tot.(%)	pH
12100	P7	0- 23	Ap	14	21	65	C		23.10	8.2
12101		23- 41	Ah1	34	21	45	C		16.80	8.3
12102		41- 71	Ah2	32	20	48	C		15.33	8.3
12103		71-108	Ah3	34	17	49	C		16.38	8.4
12104		108+	ACk	28	21	51	C		23.52	8.4

Pedon P8

Classification: USDA (1975): Typic Calcixeroll
FAO (1988): Calcic Kastanozem
334
Pedon code: B-----Mxct Mapping unit: 2Id3.
A23

Location: Map Sheet 5392/5, Nikea (Larissa), Thessaly, Greece. 2.1 km south of the village, 1.8 km west of the main road to Farsala, 200 m from the field road (eastern side). Coordinates: 39°32'41.4 N, 22°26'54.2 E.
Phys. Position: Lower convex slope of undulating to rolling tertiary surface, 134 m elevation.
Topography: 9% east-facing slope.
Drainage: Well drained, moderate permeability, basic intake 1.2 cm/h
Cultivation: Spring wheat in rotation with fodder crops.
Parent Material: Calcareous slightly gravelly alluvium+colluvium
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, July 6, 1988.
Remarks: Dry in the upper part, somewhat moist below; fairly gravelly surface with occasional cobbles 10 cm in diameter (class 1).

Ap	0-16 cm. Very dark greyish brown (10 YR 3/2) slightly gravelly clayloam, dark greyish brown to greyish brown (10YR 4.5/2) when dry; gravelly and 3% stones; moderate to strong medium subangular blocky structure; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores, and few fine tubular pores; rounded limestone as well as serpentine and quarz fragments up to 3 cm in diameter occupy 3% by volume, and few stones 10 cm in diameter; common very fine and few fine roots; strong effervescence; clear smooth boundary; pH=8.1 (Sample No. 12105).
Ah1	16-26 cm. Dark brown to brown (10YR 3.5/3) slightly gravelly clayloam; moderate fine to medium subangular blocky structure; slightly hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores and few fine tubular pores; gravel as in Ap; common very fine and few fine roots; strong effervescence; clear smooth boundary; pH=8.2 (Sample No. 12106).
Ah2	26-39 cm. Very dark brown (10YR 2/3) slightly gravelly clayloam; moderate medium and fine subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); many very fine and common fine interstitial pores; gravel as in the upper horizons; common very fine roots; very calcareous with pseudomycelia of calcium carbonate; clear smooth boundary; pH=8.2 (Sample No. 12107).
Bw	39-62 cm. Dark yellowish brown (10YR 3.5/4) slightly gravelly clayloam; strong coarse prismatic and moderate medium subangular blocky breaking down to fine subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky (wet); many very fine and common fine interstitial pores; gravel as above and few small shells; very few very fine roots; very calcareous with a moderate amount of secondary lime occurring as threads and coatings; gradual wavy boundary; pH=8.2 (Sample No. 12108).
BC	62-89 cm. Dark yellowish brown (10YR 3/4) slightly gravelly clay; moderate to strong medium to fine prismatic breaking down to moderate fine angular blocky structure; slightly hard (dry), friable (moist), sticky (wet); many very fine and few fine pores; gravel as above; very strong effervescence; secondary carbonates occur in soft powdery forms (coatings in pores and on structural faces) as well as discontinuous carbonate coatings on pebbles; gradual wavy boundary; pH=8.3 (Sample No. 12109).
Ck	89-130 cm. Yellowish brown (10YR 5/6) slightly gravelly clayloam to clay, very pale brown (10YR 7/3) when dry, white mottles (30%); weak to moderate fine to medium angular blocky structure; slightly hard (dry), friable (moist), slightly sticky (wet); many thick carbonate films and coatings in pores and on pebbles, and frequent small carbonatic nodules; very strong effervescence; pH=8.5 (Sample No. 12110).

Pedon P9

Classification: USDA (1975): Calcixerollic Xerochrept
FAO (1988): Haplic Calcisol

434
Pedon code: B-----Ioxc   Mapping unit: 2Id4
B13

Location: Map sheet 4392/5 Nikea (Larissa), Thessaly, Greece. About 2.0 km south of the village, 50 m. from the main road to Farsala (western side). Coordinates: 39°32'40.4 N, 22°28'00.6 E.
Phys. Position: Lower concave slope, of undulating to rolling (8% slope) Tertiary surface, 128 m elevation.
Topography: 4% east-facing slope
Drainage: Well drained, basic intake 3 cm/h.
Cultivation: Well performing rainfed wheat and fodder crops.
Parent material: Calcareous gravelly alluvium+colluvium.
Sampled by: N.G.Danalatos, V. Samaras and V. Diamandas, July 7, 1988.
Remarks: Dry in the upper part, somewhat moist below, fairly gravelly surface, cobbles up to 6 cm in diameter.

Ap	0-18 cm. Dark yellowish brown (10 YR 3/4) clayloam, yellowish brown (10YR 5/4) when dry; weak to moderate medium subangular blocky structure with some vertical cracks up to 2 cm wide; hard (dry), firm (moist), sticky (wet); few very fine pores; few rounded semi-weathered limestone and serpentine gravel rarely up to 6 cm in diameter (<5% by volume); many very fine and few fine roots; strong effervescence; gradual smooth boundary; pH=8.1 (Sample No. 12111).
Ah	18-37 cm. Dark brown (10YR 3/3) clay; moderate fine to medium subangular blocky structure with cracks up to 2 cm wide which disappear deeper than 25 cm; slightly hard (dry), friable (moist), sticky (wet); many very fine and common fine interstitial pores and few medium tubular pores; gravel as above; many very fine roots; strong effervescence; gradual smooth boundary; pH=8.3 (Sample No. 12112).
Bw1	37-65 cm. Dark brown to strong brown (7.5YR 4/5) clay; moderate medium to coarse prisms breaking down to moderate medium subangular blocks; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores; many very fine and some fine roots; gravel as above; very calcareous with pseudomycelia of calcium carbonate as filaments on some structural faces; diffuse boundary; pH=8.4 (Sample No. 12113).
Bw2	65-93 cm. Strong brown (7.5YR 4/6) clay; moderate medium to coarse prisms breaking down to moderate medium subangular blocks; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores; common very fine and some fine roots; very calcareous with calcium carbonate as soft powdery filaments on structural faces, soft powdery coatings and white pockets of about 1 cm, >5% by volume; diffuse boundary; pH=8.3 (Sample No. 12114).
BC	93-118 cm. Strong brown (7.5YR 4/6) clay; moderate medium subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); many very fine and few fine pores; few very fine roots; very strong effervescence; increased gravel content to about 8% by volume; secondary lime in the above forms and additionally some small (less than 1cm in diameter) nodules of calcium carbonate; clear smooth wavy boundary; pH=8.3 (Sample No. 12115).
Ck	118-140 cm. Strong brown (7.5YR 4/6) gravelly clay with white mottles (40%); massive; slightly hard (dry), friable (moist), sticky (wet); many very fine and few fine pores; many limestone and serpentine gravels up to 6 cm in diameter; common small and large modules of calcium carbonate; violent effervescence; pH=8.5 (Sample No. 12116).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH
12105	P8	0- 16	Ap	42	26	32	CL		17.10	8.1
12106		16- 26	Ah1	44	20	36	CL		19.32	8.2
12107		26- 39	Ah2	44	19	37	CL		18.22	8.2
12108		39- 62	Bw	40	21	39	CL		23.31	8.2
12109		62- 89	BC	40	19	41	CL/C		29.78	8.3
12110		89-130	Ck	40	20	40	CL		16.8	8.4
12111	P9	0- 18	Ap	38	24	38	CL		16.17	8.1
12112		18- 37	Ah	34	21	45	C		13.65	8.3
12113		37- 65	Bw1	34	22	44	C		18.90	8.4
12114		65- 93	Bw2	32	24	44	C		27.30	8.3
12115		93-118	BC	32	23	45	C		28.56	8.3
12116		118-140	Ck	37	25	43	C		31.92	8.5

A.2 Platanoulia pilot area

Pedon P1 (Plates 4C and 4D)

Classification: USDA (1975): Typic Haploxeralf
FAO (1988): Haplic Luvisol
4 3 3
Pedon code: B------ Axht   Mapping unit: HAh
A 0 0

Location: Map Sheet 4380/4, Larissa, Thessaly, Greece. 2.2 km southwest of the village of Platanoulia, 700 m. north of Peneios, 6 m. from the field road (eastern side). Coordinates: 39°39'37''N., 22°17'03''E.
Physiographic position: Holocene terrace, 78.5 m. elevation.
Topography: Nearly level (slope 1%).
Drainage: Well drained; moderately slow permeability.
Cultivation: Pears grown in "palmetes", i.e. in parallel lanes. Drip irrigation is applied. Neighbouring parcel was under maize (cv. De Kalb) and produced 7.8 tons grain per hectare (15% moisture).
Parent material: Holocene, non-calcareous colluvium.
Examined by: N.G. Danalatos and J. Sgouras, September 1, 1987.

Ap 0 - 25 cm. Yellowish brown (10 YR 5/4) sandy clayloam; weak coarse subangular blocky structure; soft (dry), friable (moist), slightly sticky and non plastic (wet); common very fine and few fine interstitial pores; common fine roots; clear smooth boundary. pH=7.5 (Sample No. 7577).

B/A 25-37 cm. Dark yellowish brown to yellowish brown (10 YR 4.5/5) sandy clayloam; moderate coarse angular blocky structure; slightly hard (dry), firm (moist), sticky and slightly plastic (wet); broken moderately thick clay skins on ped surfaces; many very fine and few fine interstitial pores; common fine roots; gradual wavy boundary. pH=7.5 (Sample No. 7578).

Bt1 37-81 cm. Dark brown (7.5 YR 3.5/3) sandy clayloam; strong coarse angular blocky structure; hard (dry), firm (moist), sticky and plastic (wet); continuous thick clay skins; many very fine and few fine interstitial pores; common fine roots; clear wavy boundary. pH=7.8 (Sample No. 7579).

Bt2 81-120 cm. Dark brown (7.5 YR 3.5/3) sandy clayloam; strong coarse angular blocky structure; very hard (dry), very firm (moist), sticky and plastic (wet); continuous thick clay skins; common very fine and few fine interstitial pores; few fine roots; gradual irregular boundary. pH=7.9 (Sample No. 7580).

B/C 120+ cm. Dark yellowish brown (10 YR 4/5) sandy clayloam; weak coarse angular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); patchy thin clay cutans. pH=7.9 (Sample No. 7581).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
7577	P1	0- 25	Ap	54	16	30	SCL	2.94	tr.	7.5	14.0	32	17.33	0.10
7578		25- 37	B/A	52	16	32	SCL	0.72	-	7.5	6.5	8	17.88	0.10
7579		37- 81	Bt1	50	16	34	SCL	0.44	-	7.8	5.0	4	19.80	0.13
7580		81-120	Bt2	54	16	30	SCL	0.36	-	7.9	5.0	4	19.80	0.13
7581		120+	B/C	55	18	27	SCL	0.22	-	8.1	5.0	2	17.88	0.13

Pedon P2

Classification: USDA (1975): Palexerollic Chromoxerert
FAO (1988): Calcic Vertisol
434
Pedon code: C------ Vxcp   Mapping unit: F1Vpw
A01
Location: Map Sheet 4380/4, Larissa, Thessaly, Greece. 1.7 km southwest of the village of Platanoulia, 1 km north of Peneios. Coordinates: 39°39' 47.5''N., 22°17'20''E.
Physiographic position: Pleistocene terrace (higher level), 83 m. elevation.
Topography: Nearly flat (slope 1%).
Drainage: Moderately well drained.
Cultivation: The parcel was in fallow; the neighboring field was under irrigated maize.
Parent material: Pleistocene, calcareous, fine textured alluvium.
Examined by: N.G. Danalatos, September 2, 1987.
Remarks: The dry surface has large cracks (> = 1 cm wide) extending down to 50 cm.

Ap 0-28 cm. Dark yellowish brown (10YR 4/4) clayloam; weak medium to coarse subangular blocky structure; very hard (dry), friable (moist), slightly sticky (wet); very few small 0.1 cm spherical Mn concretions; common very fine and few fine interstitial pores; abundant very fine and many fine roots; irregular smooth boundary. pH=7.3 (Sample No. 8072).

Bt1 28-73 cm. Dark brown to brown (10YR 4/3) clay; moderate coarse angular blocky structure; very hard (dry), friable (moist), sticky and plastic (wet); broken thin clay skins; very few spherical Mn concretions; common very fine and few fine interstitial pores; many very fine and common fine roots; clear smooth boundary. pH=7.5 (Sample No. 8073).

Bt2 73-108 cm. Dark brown to brown (10 YR 4/3) clay; moderate coarse angular blocky structure; common slickensides; hard (dry), friable to firm (moist), sticky to very sticky and plastic (wet); broken thin clay skins; very few small spherical Mn concretions; common very fine and few fine interstitial pores; few roots; clear smooth boundary. pH=7.5 (Sample No. 8074).

Ck 108-140 cm. Yellowish brown (10 YR 5/6) moist and light yellowish brown (10 YR 6/4) dry, clay; weak medium to coarse subangular blocky structure; soft to slightly hard (dry), very friable (moist), slightly sticky (wet); very calcareous with secondary lime as nodules. pH=8.3 (Sample No. 8075).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
8072	P2	0- 28	Ap	34	30	36	CL	0.93	-	7.3	5.5		14.85	0.15
8073		28- 73	Bt1	27	27	46	C	0.82	-	7.5	3.0		20.90	0.23
8074		73-108	Bt2	26	21	53	C	0.62	-	7.5	3.0		27.50	0.30
8075		108-140	Ck	30	20	41	C	0.18	25.6	8.2	8.0		25.50	0.20

Pedon P3 (Plate 5B)

Classification: USDA (1975): Calcic Haploxeralf
FAO (1988): Calcic Luvisol.
4 3 3
Pedon code: B------ Axhc Mapping unit: F1Ah2m
A 0 1

Location: Map Sheet 4380/4, Larissa, Thessaly, Greece. 750 m. west of the village of Platanoulia, 325 m. west of the crossing point of the main field road to Platanoulia and the peripheral road of the village. Coordinates: 39°40'25''N., 22°17'37''E.
Physiographic position: Pleistocene terrace (higher level), 89 m. elevation. Topography: Nearly level (slope <2%).
Drainage: Well drained; moderately slow permeability.
Cultivation: Irrigated cotton; average to low yields.
Parent material: Pleistocene, calcareous alluvium of Peneios river.
Examined by: N.G. Danalatos and J. Sgouras, September 3, 1987

Ap	0-10 cm. Yellowish brown (10 YR 5/4) dry, loam; weak medium to coarse granular structure; hard (dry), friable (moist), sticky (wet); common very fine and few fine interstitial pores; common very fine and many fine roots; clear wavy boundary. pH=7.6 (Sample No. 7582).
B/A	10-20 cm. Dark brown (7.5 YR 3.5/4) clayloam; strong medium to coarse subangular blocky structure; hard to very hard (dry), friable to firm (moist), very sticky (wet); patchy thin clay cutans; common very fine interstitial pores; common very fine and many fine roots; clear wavy boundary. pH=7.3 (Sample No. 7582A).
Bt	20-72 cm. Dark brown (7.5 YR 3.5/4) clay; strong coarse angular blocky and strong coarse prismatic structure; very hard (dry), firm (moist), very sticky (wet); continuous clay skins on ped surfaces; common very fine interstitial and few medium horizontal pores; common very fine roots; clear wavy boundary. pH=7.3 (Sample No. 7583).
B/C	72-80 cm. Dark brown (7.5 YR 3.5/4) clay; strong coarse angular blocky structure; very hard (dry), very firm (moist), very sticky (wet); common very fine interstitial pores; calcareous with broken thick calcium carbonate concretions 1 cm in diameter or larger; clear smooth boundary. pH=7.8 (Sample No. 7584).
Ck	80-120 cm. Orange coloured sandy clayloam; weak coarse subangular blocky breaking down to medium angular blocky structure; very hard (dry), firm to very firm (moist), slightly sticky (wet); very calcareous with many calcium carbonate concretions 1 cm in diameter or larger, decreasing with depth. pH=8.3 (Sample No. 7585).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
7582	P3	0- 10	Ap	46	29	25	L	1.52	tr.	7.6	17.5	59	11.28	0.10
7583A		10- 20	B/A	41	26	33	CL	0.96	-	7.3	11.5	20	13.75	0.10
7583		20- 72	Bt	35	18	47	C	0.52	-	7.3	6.5	8	20.90	0.20
7584		72- 80	B/C	33	16	51	C	0.52	2.9	7.8	4.0	8	24.75	0.20
7585		80-120	Ck	47	20	33	SCL	0.29	23.1	8.3	4.0	9	13.20	0.15

Pedon P4 (Plate 4B)

Classification: USDA (1975): Typic Xerofluvent
FAO (1988): Calcaric Fluvisol
1 1 2
Pedon code: A------ Efxt   Mapping unit: AE2
A 0 3
Location: Map Sheet 4380/4, Larissa, Thessaly, Greece. 2,8 km southwest of the village of Platanoulia, 350 m. east of the Peneios river (branch of river flowing in a N-S direction, 30 m. north of the nearest field road. Coordinates: 39°39'22.5''N., 22°16'47''E.
Physiographic position: Peneios river flood plain, 76.5 m. elevation.
Topography: Flat;
Drainage: Excessively drained; high permeability.
Cultivation: Vegetables (onions, etc.)
Parent material: Recent, calcareous, coarse textured alluvium of Peneios river.
Examined by: N.G. Danalatos and J. Sgouras, September 4, 1987.

Ap 0-10 cm. Brown (10 YR 4/3) moist, brown (10 YR 5/3) dry, sandy loam; very weak to weak medium to coarse granular structure; loose (hard), loose (moist), non sticky (wet); common very fine and few fine tubular pores; many very fine and fine roots; calcareous; clear smooth boundary. pH=8.0 (Sample No. 7586).

C1 10-60 cm. Brown (10 YR 4/3) loamy sandy loam; very weak to weak coarse subangular blocky breaking down to medium subangular blocky structure; soft (dry), friable (moist), non sticky (wet); common very fine and few fine interstitial pores; common very fine and fine roots; calcareous to very calcareous; clear smooth boundary. pH=8.4 (Sample No. 7587).

C2 60-110 cm. Brown (10 YR 4/3) sandy loam; structureless; soft (dry), loose (moist), non sticky (wet); common very fine and few fine interstitial pores, very few medium pores; few very fine to fine roots; calcareous; clear smooth boundary. pH=8.4 (Sample No. 7588).

C3 110-131 cm. Dark yellowish brown (10 YR 4/4) loamy sand; structureless; loose (dry), loose (moist), non sticky (wet); common very fine and few fine intertitial pores, very few medium tubular pores; very calcareous; clear smooth boundary.

C4 131+ cm. Dark yellowish brown (10 YR 4/4) sandy loam; stuctureless; soft (dry), very friable (moist), non sticky (wet); common very fine and few fine interstitial pores, very few medium tubular pores; very calcareous.

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C	exch. Na^+
													<--cmol(+)/lt-->	
7586	P4	0- 10	Ap	75	10	15	SL	0.88	7.4	8.0	8.0	11	9.35	0.13
7587		10- 60	C1	75	8	17	SL	0.49	4.8	8.4	7.5	8	10.45	0.10
7588		60-110	C2	75	8	17	SL	0.05	10.5	8.4	6.5	6	9.63	0.10

Pedon P5 (Plate 5C)

Classification: USDA (1975): Calcixerollic Xerochrept
FAO (1988): Haplic Calcisol
4 3 4
Pedon code: B------ Ioxc   Mapping unit: F1Ic
B 3 3
Location: Map Sheet 4380/4, Larissa, Thessaly, Greece. 1,350 m southwest of Platanoulia village, 1,525 m north of the northern Peneios river bank in the point that the stream flows into the river, 100 m. SSE of the main field road to Platanoulia. Coordinates: 39°40'04''N., 22°17'22''E.
Physiographic postition: On the upper part of a 70 m. long, straight slope of the Pleistocene terrace (higher level), 88 m. elevation.
Topography: 3% south-facing slope.
Drainage: Well drained; slow permeability.
Cultivation: Irrigated cotton with very low yields.
Parent material: Pleistocene, calcareous, fine textured alluvium.
Examined by: N.G. Danalatos and J. Sgouras, September 7, 1987.

Ap 0-27 cm. Brown (10 YR 4/3) clayloam to clay; moderate coarse subangular blocky structure; hard to very hard (dry), firm (moist), very sticky (wet); common very fine interstitial pores; common fine and very fine roots; calcareous; clear irregular boundary. pH=7.8 (Sample No. 7593).

A/C 27-50 cm. Yellowish brown (10 YR 5/6) clay; moderate coarse subangular blocky structure; very hard (dry), friable (moist), sticky (wet); common very fine interstitial pores; common very fine roots; very calcareous; common large carbonate nodules; clear wavy boundary. pH=7.9 (Sample No. 7594).

Ck 50-75 cm. Light yellowish brown (10 YR 6/4) clay; weak to moderate coarse subangular blocky structure; very hard (dry), friable (moist), sticky (wet); very calcareous; common large carbonate nodules; clear wavy boundary. pH=8.0 (Sample No. 7595).

C 75-150 cm. Light yellowish brown (10 YR 6/4) clayloam; structureless; very hard (dry), friable (moist), sticky (wet); very calcareous. pH=8.1 (Sample No. 7596).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
7593	P5	0- 27	Ap	33	27	40	C/CL	1.55	3.8	7.8	16.0	16	20.35	0.20
7594		27- 50	A/C	31	23	46	C	0.77	31.1	7.9	7.5	8	18.70	0.20
7595		50- 75	Ck	29	27	44	C	0.46	39.9	8.0	5.5	4	15.40	0.23
7596		75-150	C	27	39	34	CL	0.29	40.3	8.1	5.0		12.65	0.18

Pedon P6 (Plate 5A)

Classification: USDA (1975): Typic Palexeralf
FAO (1988): Eutric Planosol
4 3 3
Pedon code: B------ Axpt Mapping unit: F1Ap1w
A 0 1
Location: Map Sheet 4380/2, Larissa, Thessaly, Greece. 940 m north of Platanoulia village, 30 meters west of the paved road to Agia Sophia. Coordinates: 39°40'57.3''N, 22°18'37.3''E.
Physiographic position: Pleistocene terrace, 87 m. elevation.
Topography: Nearly level (slope <1%).
Drainage: Well drained; moderately slow permeability.
Cultivation: none; the surrounding parcels were under orchards (pears).
Parent material: Pleistocene, calcareous alluvium of the Xerias river.
Examined by: Th. Kariotis and N.G. Danalatos, September 9, 1986.

Ah	0 - 3 cm. Pale brown (10 YR 6/3) moist, loam; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky (wet); common very fine and fine interstitial pores; common roots; abrupt smooth boundary. pH=6.7.
E	3 - 26 cm. Pale brown (10 YR 6/3) moist, dark yellowish brown (10 YR 4/4) moist, loam; moderate medium subangular blocky structure; very hard (dry), firm (moist), non sticky (wet); common very fine interstitial pores; few very fine and very few fine roots; clear smooth boundary. pH=6.2.
E/B	26 - 42 cm. Reddish yellow (7.5 YR 6/6) dry and strong brown (7.5 YR 4/6) moist, clayloam; moderate coarse angular blocky structure; very hard (dry), firm (moist), sticky (wet); patchy thin and moderately thick cutans on some ped surfaces; common very fine interstitial pores; roots as above; gradual smooth boundary. pH=6.0.
Bt1	42 - 63 cm. Brown (7.5 YR 4/4) dry and dark reddish brown (5 YR 3/4) moist, clayloam; strong coarse angular blocky structure; very hard (dry), firm (moist), very sticky (wet); brocken, moderately thick cutans of vlay minerals with iron oxides on most ped faces; common very fine interstitial pores; very few very fine roots; clear smooth boundary. pH=6.2.
Bt2	63 - 101 cm. Reddish brown (5 YR 4/4) moist, clay; strong medium to coarse angular blocky structure; very hard (dry), firm (moist), very sticky (wet); continuous, thick clay skins; common very fine interstitial pores; no roots; gradual smooth boundary. pH=6.4.
B/C	101 - 125 cm. Brownish yellow (10 YR 6/6) dry and yellowish brown (10 YR 5/6) clay; moderate medium subangular blocky structure; very hard (dry), friable (moist), very sticky (wet); common very fine interstitial pores; strongly calcareous; clear smooth boundary. pH=7.4.
Ck	125-150 cm. Pale brown (10 YR 6/3) moist, silty clayloam; weak medium subangular blocky structure; hard (dry), firm (moist), very sticky (wet); strongly calcareous with secondary lime as nodules; pH=7.8

Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
P6	0- 3	Ah	36	47	17	L	4.95	tr.	6.7			13.65	0.18
	3- 26	E	44	41	15	L	0.55	tr.	6.2			7.63	0.14
	26- 42	E/B	38	36	26	CL	0.50	tr.	6.0			13.20	0.16
	42- 63	Bt1	24	36	40	CL	0.57	-	6.2			24.75	0.26
	63-101	Bt2	20	40	41	C	0.63	-	6.4			29.70	0.32
	101-125	B/C	16	48	36	C	0.56	3.4	7.4			29.15	0.30
	120-150	Ck	11	65	24	SiCL	0.36	13.4	7.8			18.70	0.35

Pedon P7

Classification: USDA (1975): Calcic Palexeralf
FAO (1988): Eutric Planosol

4 3 3
Pedon code: C------ Axpc Mapping unit: F1Ap1m
A 0 1

Location: Map Sheet 4380/2, Larissa, Thessaly, Greece. 1,925 m north of the center of Platanoulia village, some meters east of the field road. Coordinates: 39°41'30.3''N., 22°18'06.2''E.
Physiographic position: Pleistocene terrace, 94 m. elevation.
Topography: Nearly level (slope <1%).
Drainage: Moderately well drained; very slow permeability.
Cultivation: Grapes grown in "palmetes", i.e. in parallel lanes. Drip irrigation is applied.
Parent material: Pleistocene, calcareous alluvium of the Xerias river.
Examined by: N.G. Danalatos and J. Sgouras, September 25, 1987.

Ap 0 - 35 cm. Very pale brown (10 YR 7/4) loam; massive; very hard (dry), very firm (moist), slightly sticky (wet); common very fine and few fine interstitial pores, few fine tubular pores; common roots; clear smooth boundary. pH=7.1 (Sample No. 7597).

B/A 35-44 cm. Brown (7.5 YR 5/4) clayloam; moderate medium to coarse angular blocky structure; very hard (dry), very firm (moist), very sticky and plastic (wet); broken, moderately thick clay skins on ped faces; common, small, spherical, black Mn concretions; few, small, quartz gravel (5% by volume); common very fine interstitial pores; few, small (1/2 cm), vertical cracks are visible; common fine roots; clear smooth boundary. pH=6.2 (Sample No. 7598).

Bt 44-120 cm. Dark brown to brown (7.5 YR 4/4) clay; strong coarse (>5 cm) angular blocky breaking to medium (2 cm) angular blocky structure; very hard (dry), very firm (moist), very sticky and plastic (wet); continuous thick clay skins; common, small, spherical, black Mn concretions; gravel as above; few, small cracks are visible; common very fine interstitial pores; roots are found down to 100 cm; clear smooth boundary. pH=7.0 (Sample No. 7599).

B/C 120+ cm. Brown (7.5 YR 5/4) clay; strong coarse angular blocky structure; very hard (dry), very firm (moist), very sticky (wet); common very fine interstitial pores; gravel as above; calcareous with broken, thick calcium carbonate concretions.

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
7597	P7	0- 35	Ap	47	34	19	L	0.74	-	7.1	33.0		5.50	0.10
7598		35- 44	B/A	41	26	33	CL	0.40	-	6.2	5.8		10.45	0.15
7599		44-120	Bt	35	22	43	C	0.35	-	7.0	4.0		17.05	1.00

Pedon P8

Classification: USDA (1975): Calcic Haploxeralf
FAO (1988): Calcic Luvisol
4 3 3
Pedon code: B------ Axhc   Mapping unit: F2Ah
A 0 1

Location: Map Sheet 4370/8, Larissa, Thessaly, Greece. 4 km NNW of Platanoulia and 3.4 km NW of Ag. Sophia villages, 400 m NE of the Tsalmas summit and some 10 m. from the field road (eastern side); the shortest distance to the Xerias river is 1 km (to the north-west). Coordinates: 39°42’30.5’’N., 22°17’01.3’’E.

Physiographic position: Pleistocene terrace (middle level, F2), 90 m. elevation.

Topography: Flat.

Drainage: Well drained; moderate permeability.

Cultivation: Pears grown in "palmetes", i.e. in parallel lanes. Drip irrigation is applied.

Parent material: Holocene, moderately fine textured, calcareous alluvium of Xerias river.

Examined by: N.G. Danalatos and J. Sgouras, September 22, 1987.

Ap	0-20 cm. Brown (10 YR 5/3) loam, light yellowish brown (10 YR 6/4) if dry; weak medium to coarse subangular blocky structure; hard (dry), friable (moist), sticky (wet); many very fine and very few fine interstitial pores; common fine and medium roots; gradual wavy boundary. pH=7.6 (Sample No. 8067).
B/A	20-29 cm. Brown (10 YR 4.5/3) clayloam; weak medium to coarse subangular blocky structure; hard (dry), friable (moist), sticky (wet); broken thin clay skins; many very fine and few fine interstitial pores; common fine and medium roots; gradual wavy boundary. pH=7.7 (Sample No. 8068).
Bt	29-71 cm. Dark brown to brown (10 YR 4/3) clayloam; moderate medium to coarse subangular blocky structure breaking to granular structure; hard (dry), friable (moist), sticky (wet); continuous moderately thick clay cutans; many very fine and few fine interstitial pores; common fine and medium roots; clear smooth boundary. pH=7.5 (Sample No. 8069).
B/C	71-87 cm. Dark yellowish brown (10 YR 4/4) clayloam; weak medium to coarse subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); broken moderately thick clay skins; calcareous with secondary lime in soft forms and as continuous carbonatic concretions 1/2 cm in diameter; many very fine and few fine interstitial pores; common fine roots; gradual irregular boundary. pH=7.9 (Sample No. 8070).
Ck	87-130 cm. Yellowish brown (10 YR 5/4) clayloam; structureless; hard (dry), friable (moist), slightly sticky to sticky (wet); many fine interstitial pores; few fine roots to a depth of 120 cm; very calcareous with secondary lime as common carbonatic nodules. pH=8.1 (Sample No. 8071).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na^+
8067	P8	0- 20	Ap	37	37	26	L	1.43	tr.	7.6	20.5		10.45	0.13
8068		20- 29	B/A	30	40	30	CL	0.91	tr.	7.7	5.5		14.30	0.13
8069		29- 71	Bt	35	31	34	CL	0.65	-	7.5	5.5		15.95	0.10
8070		71- 87	B/C	31	33	36	CL	0.52	5.0	7.9	5.5		18.15	0.13
8071		87-130	Ck	37	33	30	CL	0.37	25.2	8.1	5.0		12.65	0.10

Pedon P9

Classification: USDA (1975): Fluventic Xerochrept
FAO (1988): Calcaric Cambisols
4 3 3
Pedon code: B------ Ioxf Mapping unit: F2If
A 0 2

Location: Map Sheet 4370/8, Larissa, Thessaly, Greece. 5.1 km NNW of Platanoulia and 4.1 km NW of Ag. Sophia villages, 1 km north of Tsalmas hill and some 10 m. from the field road (western side); the shortest distance to Xerias river is 500 m (to the north-west). Coordinates: 39°42’57.4’’N., 22°16’52.9’’E.
Physiographic position: Pleistocene terrace (middle level, F2), 89.5 m. elevation.
Topography: Flat.
Drainage: Well drained; moderate permeability.
Cultivation: Pears grown in "palmetes", i.e. in parallel lanes. Drip irrigation is applied.
Parent material: Holocene, moderately fine textured, calcareous alluvium of Xerias river.
Examined by: N.G. Danalatos and J. Sgouras, September 23, 1987.

Ap	0-30 cm. Brown (10 YR 5/3) loam; weak medium to coarse subangular blocky structure; hard (dry), friable (moist), sticky (wet); many very fine and very few fine interstitial pores; slight calcareous; common fine and medium roots; gradual wavy boundary. pH=7.7 (Sample No. 8062).
B/A	30-41 cm. Brown (10 YR 4/3) sandy clayloam; weak medium to coarse subangular blocky structure; hard (dry), friable (moist), sticky (wet); many very fine and few fine interstitial pores; common fine and medium roots; gradual wavy boundary. pH=7.5 (Sample No. 8063).
Bw	41-76 cm. Dark brown to brown (10 YR 4/3) sandy clayloam; moderate medium to coarse subangular blocky structure; hard (dry), friable (moist), sticky (wet); many very fine and few fine interstitial pores; common fine and medium roots; calcareous; clear smooth boundary. pH=7.9 (Sample No. 8064).
B/C	76-91 cm. Dark yellowish brown (10 YR 4/4) loam; weak medium to coarse subangular blocky structure; slightly hard (dry), friable (moist), sticky (wet); very calcareous; many very fine and few fine interstitial pores; common fine roots; gradual irregular boundary. pH=7.9 (Sample No. 8065)
Ck	91-120 cm. Yellowish brown (10 YR 5/4) sandy loam; structureless; hard (dry), friable (moist), slightly sticky to sticky (wet); many fine interstitial pores; few fine roots to a depth of 120 cm; very calcareous with lime present as soft powdery forms. pH=8.0 (Sample No. 8066).

Sample no.	Profile no.	Depth (cm)	Horizon code	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	CaCO$_3$ tot.(%)	pH	P-Olsen (ppm)	K20 (ppm)	C.E.C <--cmol(+)/lt-->	exch. Na$^+$
8062	P9	0- 30	Ap	47	29	24	L	1.59	1.7	7.7	37.0		9.63	0.15
8063		30- 41	B/A	51	25	24	SCL	0.64	-	7.5	14.8		11.00	0.35
8064		41- 76	Bw	56	24	20	SCL	0.34	3.8	7.9	9.5		8.80	0.10
8065		76- 91	C/B	47	29	24	L	0.59	tr.	7.7	9.0		12.65	0.10
8066		91-120	Ck	56	28	16	SL	0.29	5.9	8.0	5.5		7.43	0.10

A.3 Peneios delta (pilot) area

Pedon P1

Classification: USDA (1975): Aeric Fluvaquent
FAO (1988): Calcaric Fluvisol
D 224
Pedon code: --- -----Eafa
F A02
Location: Map Sheet 4354/6 (Rapsani), Thessaly, Greece. 1.5 km NE of the Kouloura village, between the forest and the river channel. Coordinates: 39°56’33’’N., 22°16’23.5’’E.
Physiographic position: Meandering river belt, 0.8 m. elevation.
Topography: Flat.
Drainage: Poorly drained, moderately slow permeability. The ground-water table is shallow in the wet months (60 cm from the soil surface) and drops to about 130-140 cm in the summer (100 cm deep upon examination).
Cultivation: Beans.
Parent material: Holocene, calcareous stratified fine over coarse textured alluvium of Peneios river.
Examined by: N.G. Danalatos and L. Toulios, April 13, 1989.

Ap 0-29 cm. Dark greyish brown (10 YR 4/2), light yellowish brown (10 YR 6/4) dry, clayloam; weak to moderate medium subangular blocky structure; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores; few minute fragments of unweathered mica; calcareous; common very fine and few fine roots; clear wavy boundary; pH=7.6 (Sample No. 14359).

Bw 29-41 cm. Brown (10 YR 4/3) clayloam; few fine faint yellowish brown (10 YR 5/7) mottles; moderate medium angular blocky structure; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores; few fine tubular pores; few minute fragments of unweathered mica; few small soft manganese concretions; strong effervescence; common very fine and few fine roots; clear smooth boundary; pH=7.4 (Sample No. 14360).

2Cg1 41-51 cm. Yellowish brown (10 YR 5/4) sandy loam; common medium faint yellowish brown (10 YR 5/7) mottles; weak medium angular blocky structure; soft (dry), friable (moist), slightly sticky (wet); few manganese concretions; common very fine and few fine interstitial pores; few fine tubular pores; few to common minute fragments of fresh mica; very strong effervescence; some biological activity (earthworms 3mm long were found); common very fine and few fine roots; clear smooth boundary; pH=7.4 (Sample No. 14361).

3Cg2 51-62 cm. Brown (10 YR 5/3) loam; many medium prominent strong brown (7.5 YR 5/6) mottles; weak medium angular blocky structure; soft (dry), friable (moist), slightly sticky (wet); common very fine and few fine interstitial pores; few fine tubular pores (1.5 mm in diameter); common minute fragments of fresh mica; very strong effervescence; common very fine and few fine roots; clear smooth boundary; pH=7.5 (Sample No. 14362).

3Cg3 62-71 cm. Mottled brown (10 YR 5/3) and olive (5 Y 5/3) loam with additionally frequent medium prominent strong brown (7.5 YR 5/6) mottles; weak medium angular blocky structure; soft (dry), friable (moist), slightly sticky (wet); common very fine and few fine interstitial pores; few fine tubular pores and worm channels; frequent minute fragments of fresh mica; very strong effervescence; common very fine and few fine roots; clear smooth boundary; pH=7.5 (Sample No. 14363).

Pedon 1 (continued)

4Cg4 71-83 cm. Mottled brown (10 YR 5/3) olive (5 Y 5/3) and strong brown (7.5 YR 5/6) silt loam; weak medium angular blocky structure; slightly hard (dry), friable (moist), sticky (wet); common manganese concretions; common very fine and few fine interstitial pores; few fine tubular pores; frequent minute fragments of fresh mica; very strong effervescence; few very fine and fine roots; clear smooth boundary; pH=7.8 (Sample No. 14364).

4Cg5 83-95 cm. Mottled brown (10 YR 5/3) olive (5 Y 5/3) and strong brown (7.5 YR 5/6) silt loam; weak medium angular blocky structure; slightly hard (dry), friable (moist), sticky (wet); common manganese concretions; very few carbonate filaments; common very fine and few fine interstitial pores; few fine tubular pores (1.5 mm in diameter) and worm channels; frequent minute fragments of fresh mica; very strong effervescence; few very fine roots; clear smooth boundary; pH=7.9 (Sample No. 14365).

5Cg6 95-108 cm. Dark greyish brown (2.5 Y 4/3), loam; common medium prominent strong brown (7.5 YR 5/6) mottles; weak medium angular blocky structure; slightly hard (dry), friable (moist), slightly sticky (wet); few carbonate filaments; common very fine and few fine interstitial pores; few fine tubular pores (1.5 mm in diameter) and earth-worm channels; frequent minute fragments of fresh mica; very strong effervescence; few very fine roots; clear smooth boundary; pH=7.9 (Sample No. 14366).

6Cg7 108-122 cm. Olive brown (2.5 Y 4/4), sandy loam; structureless; common medium distinct strong brown (7.5 YR 5/6) mottles; weak medium angular blocky structure; loose (dry), loose (moist), non sticky (wet); common manganese concretions; few very fine interstitial pores; frequent minute fragments of fresh mica; strong effervescence; no roots; clear smooth boundary; pH=8.0 (Sample No. 14367).

6Cg8 122-132+ cm. Olive brown (2.5 Y 4/4), sandy loam; structureless; common medium distinct strong brown (7.5 YR 5/6) mottles; weak medium angular blocky structure; loose (dry), loose (moist), non sticky (wet); frequent minute fragments of fresh mica; common small black manganese concretions; very strong effervescence; pH=8.0 (Sample No. 14368).

Pedon P2 (Plate 6A)

Classification: USDA (1975): Typic Xerofluvent
FAO (1988): Calcaric Fluvisol
133
Pedon code: B-----Efxt
A03
Location: Map Sheet 4354/6 (Rapsani). 850 m west of the Kouloura village, Thessaly, Greece. Coordinates: 39°55’45’’N., 22°14’’51’’E.
Physiographic position: Meandering river belt, 3.0 m. elevation.
Topography: Flat.
Drainage: Well drained, very slow permeability (Ib<0.1 cm/hour). Ground water fluctuates between 1.5 m. in the winter and 2.5-3.0 m. in the summer (1.5 m. upon examination).
Cultivation: Maize; neighbouring fields were under beans, sugar beets and alfalfa.
Parent material: Recent calcareous stratified alluvium of Peneios river.
Examined by: N.G. Danalatos, Th. Trigas and L. Toulios, June 16, 1989.

Ap1 0-16 cm. Brown (10 YR 5/3) loam; weak medium angular blocky structure; hard (dry), friable (moist), sticky (wet); few very fine interstitial pores; frequent minute fragments of fresh mica; strongly effervescent; common roots; diffuse smooth boundary. pH=8.0 (Sample No. 14459).

Ap2 16-31 cm. Brown (10 YR 4.5/3) loam; weak medium angular blocky structure; hard (dry), firm (moist), sticky (wet); common very fine and few fine interstitial pores; few medium (3 mm diam.) tubular pores; frequent minute fragments of fresh mica; biological activity (worm casts are present); strong effervescence; abundant roots and root remnants; clear wavy boundary. pH=8.1 (Sample No. 14460).

C1 31-47 cm. Pale brown to light yellowish brown (10 YR 5.5/3.5), light yellowish brown (10 YR 6/4) dry, sandy loam; structureless; soft (dry), very friable (moist), slightly sticky (wet); many very fine and common fine (0.5 cm in diam.) interstitial pores; frequent minute fragments of fresh mica; strong effervescence; frequent very fine and fine roots; clear smooth boundary. pH=8.4 (Sample No. 14461).

C2 47-58 cm. Pale brown to light yellowish brown (10 YR 5.5/3.5), light yellowish brown (10 YR 6/4) dry, sandy loam to loamy sand; structureless; soft (dry), very friable (moist), slightly sticky (wet); many very fine and few fine interstitial pores; frequent minute fragments of fresh mica; strong effervescence; common very fine and fine roots; clear smooth boundary. pH=8.4 (Sample No. 14462).

C3 58-68 cm. Pale brown to light yellowish brown (10 YR 5.5/3.5), light yellowish brown (10 YR 6/4) dry, sandy loam; few fine faint brownish yellow (10 YR 6/6) mottles; weak medium angular blocky structure; soft (dry), very friable (moist), slightly sticky (wet); many very fine and common fine interstitial pores; frequent minute fragments of fresh mica; strong effervescence; common very fine and few fine roots; clear smooth boundary; pH=8.3 (Sample No. 14463).

2Bwb 68-92 cm. Brown (10 YR 3.5/3) clayloam; few fine faint yellowish brown to light yellowish brown (10 YR 5.5/4) mottles; moderate medium angular blocky structure; slightly hard (dry), friable (moist), sticky (wet); many very fine and common fine (up to 1 mm in diam.) interstitial pores; frequent minute fragments of fresh mica; strong effervescence; some worm casts are present; common very fine and fine roots; clear wavy boundary; pH=8.3 (Sample No. 14464).

2C4 92-114 cm. Brown (10 YR 4/3) loam; structureless; slightly hard (dry), friable (moist), sticky (wet); many very fine and common fine (up to 1 mm in diam.) interstitial pores; frequent minute fragments of fresh mica; common small soft black Mn nodules; very few carbonate filaments; strong effervescence; common very fine and fine roots; clear smooth boundary; pH=8.2 (Sample No. 14465).

Pedon 2 (continued)

2C5 114-150 cm. Pale brown to light yellowish brown (10 YR 5.5/3.5) sandy loam; structureless; slightly hard (dry), friable (moist), slightly sticky (wet); few carbonate filaments; common fine interstitial pores; frequent minute fragments of fresh mica; strong effervescence; common very fine roots; clear smooth boundary; pH=8.3 (Sample No. 14466).

2C6 150-180+ cm. Dark brown (10 YR 3.5/3) silty clayloam; common fine prominent yellowish brown (10 YR 5/6) mottles; structureless; very friable (moist), non sticky (wet); common very fine interstitial pores; frequent minute fragments of fresh mica; few small soft black manganese concretions; strong effervescence; few very fine and fine roots; pH=8.3 (Sample No. 14467).

Pedon P3 (Plate 6D)

Classification: USDA (1975): Vertic Xerochrept
FAO (1988): Vertic Cambisol
425
Pedon code: D------Ioxv
A02

Location: Map Sheet 4354/5 (Rapsani). 500 m. west of Papapouli railway station, Thessaly, Greece. Coordinates: 39°56’41.4” N., 22°13’18” E.
Physiographic position: Backswamps, 3.3 m. elevation.
Topography: Flat.
Drainage: Imperfectly drained; permeability is moderate. Ground-water table occurs at some depth below the control section. The soil was moist throughout.
Cultivation: Irrigated sugar beets performing well (3-4 irrigations with overhead methods).
Parent material: Holocene, calcareous, stratified fine over medium textured alluvium of Peneios river.
Examined by: N.G. Danalatos, T. Trigas and L. Toulios, May 5, 1989.
Remarks: In summer, cracks of 1 cm extend from the (dry) soil surface down to 50 cm.

Ap	0-27 cm. Dark brown (10YR 3/3), yellowish brown (10YR 5/4) dry, clay; massive; hard (dry), firm to very firm (moist), very sticky and plastic (wet); common very fine interstitial pores; barely calcareous; abundant roots; clear wavy boundary; pH=7.5 (Sample No. 14414).
Bw1	27-47 cm. Dark greyish brown (10YR 4/2 to 2.5Y 4/2) clay; few fine faint yellowish brown (10 YR 5/5) oxidation mottles; moderate medium subangular blocky structure; firm (moist), sticky and plastic (wet); many very fine and few fine interstitial pores; very few minute fragments of unweathered mica; very slightly effervescent; common very fine and few fine roots; gradual smooth boundary; pH=7.7 (Sample No. 14415).
Bw2	47-63 cm. Brown (10YR 4/3) clay; few fine faint yellowish brown (10 YR 5/5) oxidation mottles; moderate medium subangular blocky structure; firm (moist), sticky to very sticky (wet); many very fine and few fine interstitial pores; few minute fragments of unweathered mica; slight effervescence; common very fine roots; clear wavy boundary; pH=7.7 (Sample No. 14416).
CBk	63-79 cm. Brown (10YR 5/3) clayloam; many fine faint yellowish brown (10YR 5/6) oxidation mottles; structureless; friable (moist), sticky (wet); patchy thin calcitans; many very fine and few fine interstitial pores; common minute fragments of unweathered mica; strong effervescence; few very fine roots; clear wavy boundary; pH=7.9 (Sample No. 14417).
C1	79-105 cm. Yellowish brown (10YR 5/4) loam; many fine faint yellowish brown (10 YR 5/6) oxidation mottles; structureless; very friable (moist), slightly sticky (wet); patchy thin calcitans; common very fine and few fine interstitial pores; frequent minute fragments of unweathered mica; strong to very strong effervescence; very few very fine roots; clear smooth boundary; pH=8.0 (Sample No. 14418).
C2	105-121 cm. Brown (10YR 5/3) silt loam; many fine faint yellowish brown (10YR 5/6) oxidation mottles; structureless; very friable to friable (moist), slightly sticky (wet); many very fine interstitial pores; common minute fragments of unweathered mica; strong effervescence; very few very fine; clear smooth boundary; pH=8.3 (Sample No. 14419).
C3	121-140 cm. Brown (10YR 5/3) silty clayloam; many fine faint yellowish brown (10YR 5/6) oxidation mottles; structureless; friable (moist), sticky (wet); common very fine interstitial pores; common minute fragments of unweathered mica; strong to very strong effervescence; few very fine roots; pH=8.1 (Sample No. 14420).

Pedon P4 (Plate 6E)

Classification: USDA (1975): Vertic Haplaquept
FAO (1988): Gleyic Cambisol
E 435
Pedon code: --- -----Iahv
F A03

Location: Map Sheet 4354/5 (Rapsani). 1,550 m SW of the Papapouli railway station, 800 m NE of the crossing of the field road the highway Larissa-Thessaloniki, 50 m from the southern road-site, Thessaly, Greece. Coordinates: 39°55'56.2''N., 22°14'10.5''E.
Physiographic position: Low depression of backswamps, 3.0 m. elevation.
Topography: Flat.
Drainage: Very poorly drained. Ground-water table at 80-100 cm depth in the summer and at the surface in the winter.
Cultivation: Corn, beans and sugar beet. Corn produces 17.5 tons grain per hectare. Corn cv. ARIS is normally avoided. Supplementary irrigation is applied (2-3 applications).
Parent material: Recent calcareous alluvium.
Examined by: N.G. Danalatos and T. Trigas, June 14, 1989.
Remarks: When examined the soil was wet. Later in the summer, cracks of 1 cm extend from the (dry) soil surface down to 50 cm.

Ap 0-12 cm. Dark greyish brown (2.5Y 3.5/2) moist, light grey (2.5Y 7/2) dry, clay; massive to very weak coarse angular blocky structure; hard to very hard (dry), firm to very firm (moist), very sticky (wet); few very fine interstitial pores; strong effervescent; common fine roots and root remnants; very few shells; clear wavy boundary; pH=7.9 (Sample No.14468).

AB 12-36 cm. Dark greyish brown (2.5Y 4/2) moist, light grey (2.5Y 7/2) dry, clay; weak coarse angular blocky breaking to moderate medium angular blocky structure; very hard (dry), friable to firm (moist), very sticky (wet); many very fine interstitial and common fine tubular pores; strong effervescence; frequent fine and medium roots; few shells; clear smooth boundary; pH=8.0 (Sample No.14469).

Bg1 36-59 cm. Dark greyish brown (2.5Y 3.5/2) moist, light brownish grey (2.5Y 6/2) dry, clay; common fine faint strong brown (7.5YR 4/6) mottles; moderate medium breaking to weak fine angular blocky structure; very firm (moist), very sticky (wet); patchy thin cutans of iron oxides and hydroxides; abundant very fine interstitial and common fine interstitial and tubular pores; effervescent; some biological activity; frequent very fine and fine roots; few shells; clear smooth boundary; pH=8.1 (Sample No.14470).

Bg2 59-76 cm. Dark greyish brown to greyish brown (2.5Y 4.5/2) moist, light brownish grey (2.5Y 6/2) dry, clay; few fine faint strong brown (7.5YR 4/6) mottles; moderate medium breaking to weak fine angular blocky structure; very firm (moist), very sticky (wet); patchy (less than in the horizon above) thin iron coatings on ped surfaces; abundant very fine interstitial and common fine interstitial and tubular pores; effervescent; frequent very fine and fine roots; biological activity (earth worms), frequent shell remnants; gradual smooth boundary; pH=8.1 (Sample No. 14471).

B/C 76-90 cm. Olive grey (5Y 4.5/2) moist, light brownish grey (2.5Y 6/2) dry, clay; few fine faint strong brown (7.5YR 4/6) mottles; moderate medium breaking to weak fine angular blocky structure; firm to very firm (moist), very sticky (wet); broken thin iron coatings on ped surfaces; carbonate filaments; common very fine interstitial and few fine tubular pores; strong effervescence; increased biological activity; common fine and some medium roots; many shell remnants; clear smooth boundary; pH=8.1 (Sample No. 14472).

Cg 90-120 cm. Olive grey (5Y 5/2) moist, light grey (2.5Y 7/2) dry, clayloam; few fine faint strong brown (7.5YR 4/6) mottles; weak coarse angular blocky structure; firm (moist), very sticky (wet); continuous moderately thick iron coatings on ped surfaces; secondary lime in soft and concretional forms; common very fine and few fine interstitial, and few fine tubular pores; very strong effervescence; few very fine roots; frequent shell remnants; clear smooth boundary; pH=8.4 (Sample No. 14473).

Pedon P5 (Plate 6B)

Classification: USDA (1975): Aquic Xerofluvent
FAO (1988): Calcaric Fluvisol
213
Pedon code: C------Efxa
A03

Location: Map Sheet 4364/2 (Rapsani), 2.1 km E of the crossing of the Omolio-Stomio road the shortest field road to Peneios, 170 m from the northern road side. Thessaly, Greece. Coordinates: 39°52'40''N., 22°16'01''E.
Physiographic position: Meandering river belt, 0.8 m. elevation.
Topography: Flat.
Drainage: Moderately well drained. Ground-water table upon examination was at 140 cm; in August it goes deeper by 50-100 cm whereas in winter it rises to within 100 cm from the surface.
Cultivation: Irrigated maize cv. Pioneer producing 12-15 t/ha; fertilization: 1.5 tons $(NH_4)_3PO_4$/ha (20-10-0) or 1 ton (20-10-0)/ha + 500 kg/ha of Ca-NH_4NO_3 (33-0-0). The maize cv. ARIS lodges and is generally avoided.
Parent material: Recent, calcareous, stratified alluvium of the Peneios river.
Examined by: N.G. Danalatos and Ch. Tsandilas, June 13, 1989.

Ap	0-25 cm. Dark yellowish brown (10YR 4/4), light yellowish brown to pale brown (10YR 6/3.5) dry, loam; weak medium subangular blocky structure; soft (dry), friable (moist), slightly sticky (wet); common very fine and few fine interstitial pores; frequent minute fragments of unweathered mica; strongly effervescent; common very fine and few fine roots; gradual smooth boundary; pH=7.8 (Sample No. 14443).
C1	25-53 cm. Dark yellowish brown (10YR 3/4) loam; weak medium subangular blocky structure; firm (moist), slightly sticky (wet); common very fine to fine interstitial pores; frequent minute fragments of unweathered mica; strong effervescence; common very fine and few fine roots; clear smooth boundary; pH=8.3 (Sample No. 14444).
C2	53-69 cm. Yellowish to dark yellowish brown (10YR 4.5/4) sandy loam; structureless; friable (moist), slightly sticky (wet); common very fine and fine interstitial pores; very frequent minute fragments of unweathered mica; strong effervescence; few fine roots; clear smooth boundary; pH=8.5 (Sample No. 14445).
2C3	69-98 cm. Yellowish brown (10YR 5/4) sand; structureless; loose (moist), non sticky (wet); very frequent small fragments of unweathered mica; strong effervescence; clear smooth boundary; pH=8.3 (Sample No. 14446).
3C4	98-130+ cm. Dark yellowish brown (10YR 4/4) loam; common medium distinct strong brown (7.5YR 4/6) mottles of iron oxides; weak medium subangular blocky structure; firm (moist), slightly sticky (wet); common very fine and fine (up to 1.5 mm diam.) interstitial pores; abundant small (0.5 mm diam.) fragments of unweathered mica; strong effervescence; no roots; pH=8.0 (Sample No. 14447).

Pedon P6 (Plate 6C)

Classification: USDA (1975): Aquic Xerofluvent
FAO (1988): Calcaric Fluvisol
D 213
Pedon code: --- -----Efxa
F A03
Location: Map Sheet 4364/2 (Rapsani), 350 m SE of the last meander of the southernmost Peneios active distributary. Thessaly, Greece. Coordinates: 39°53’08’’N., 22°16’43.5’’E.
Physiographic position: Backswamps, 1.3 m. elevation.
Topography: Flat.
Drainage: Poorly drained. Ground-water table at 100 cm depth; it may rise to 42 cm for a short time in the winter and reaches 150 cm or deeper in August.
Cultivation: Irrigated beans. Possibly emergence problems due to slaking of the surface soil.
Parent material: Recent, calcareous, stratified alluvium of the Peneios river.
Examined by: N.G. Danalatos and Ch. Tsandilas, June 14, 1989.

Ap	0-28 cm. Dark yellowish brown (10YR 4/4), pale brown (10YR 6/3) dry, loam; weak medium subangular blocky structure; soft (dry), friable (moist), slightly sticky (wet); many very fine and few fine interstitial pores; few minute fragments of unweathered mica; calcareous; many fine and very fine roots; abrupt smooth boundary; pH=8.2 (Sample No. 14448).
C1	28-42 cm. Yellowish brown to dark yellowish brown (10YR 4.5/4) pale brown (10YR 6/3) dry, loamy sand; structureless; loose (dry, moist), slightly sticky (wet); no pores; common minute fragments of unweathered mica; calcareous; common very fine and few fine roots; abrupt smooth boundary (Sample No. 14449).
2C2	42-54 cm. Dark yellowish brown (10YR 4/4) silt loam; common medium prominent mottles of iron oxides (7YR 4/6); weak to moderate, medium to coarse, subangular blocky structure; friable (moist), slightly sticky (wet); common very fine and fine interstitial pores; common minute fragments of unweathered mica; calcareous; few fine roots; clear wavy boundary; pH=8.4 (Sample No. 14450).
2C3	54-82 cm. Yellowish to dark yellowish brown (10YR 4.5/4) silt loam; many, medium, prominent mottles of iron oxides (7.5YR 4/6); partly weakly to moderately structured with medium to coarse subangular blocks; friable (moist), slightly sticky (wet); common very fine and few fine interstitial pores; few to common small fragments of unweathered mica; strong effervescence; few fine roots; clear wavy boundary; pH=8.4 (Sample No. 14451).
2C4	82-100 cm. Dark yellowish brown (10YR 3.5/4) silt loam; common, distinct, medium, mottles of iron oxides (7YR 4/6); structureless to weak, moderate, subangular blocky structure; friable (moist), slightly sticky (wet); common very fine and few fine interstitial pores; common small fragments of unweathered mica; very calcareous; no roots; clear wavy boundary; pH=8.2 (Sample No. 14452).
3C5	100-130+ cm. Olive grey (5Y 5.5/2) sandy clayloam; structureless; slightly friable (moist), slightly sticky to sticky) (wet); common very fine and few fine interstitial pores; common small fragments of unweathered mica; strong effervescence; no roots; pH=8.2 (Sample No. 14453).

Pedon P7

Classification: USDA (1975): Typic Xerofluvent
FAO (1988): Calcaric Fluvisol
123
Pedon code: B------Efxt
A03
Location: Map Sheet 4354/7 (Rapsani), 2 km west of the Paliopirgos village, along the road connecting the village with the highway Larissa-Thessaloniki, Thessaly, Greece. Coordinates: 39°55’05’’N, 22°39’30’’E.
Physiographic position: Channel belt adjacent to the meander belt, about 5 m. ASL.
Topography: Flat.
Drainage: Well drained. Very slow permeability (0.3 cm/h). Ground-water table at great depth (> >150 cm).
Cultivation: Fallow after maize. The neighbouring parcels were under alfalfa.
Parent material: Recent, calcareous, stratified alluvium of the Peneios river.
Sampled by: L. Toulios, December 5, 1989.

Ap 0-28 cm. Dark yellowish brown (10YR 4/4), loam; structureless; very friable (moist); common very fine and few fine interstitial pores; calcareous; many roots; gradual smooth boundary; pH=8.0 (Sample No. 15770).

C1 28-43 cm. Dark yellowish brown (10YR 4/4) loam; weak medium angular blocky structure; very friable (moist); common very fine and few fine interstitial pores; calcareous; many roots; clear smooth boundary; pH=7.8 (Sample No. 15771).

2C2 43-73 cm. Yellowish brown (10YR 5/4) sandy loam; structureless; loose (moist); common very fine and few fine interstitial pores; calcareous; very few roots; abrupt smooth boundary; pH=8.0 (Sample No. 15772).

3C3 73-103 cm. Light yellowish brown (10YR 6/4) sandy loam; structureless; loose (moist); common very fine and few fine interstitial pores; calcareous; no roots; abrupt smooth boundary; pH=8.4 (Sample No. 15773).

4C4 103-143 cm. Brown (10YR 4/3) silt loam; structureless; very friable (moist); common very fine and few fine interstitial pores; calcareous; no roots; pH=8.0 (Sample No. 15774).

Pedon P8

Classification: USDA (1975): Aquic Xerochrepts
FAO (1988): Eutric Cambisols
434
Pedon code: D------Ioxa
A01
Location: Map Sheet 4354/6 (Rapsani), Kalorizia area, 1,650 m NNW of the Kouloura village, Thessaly, Greece. Coordinates: 39°56'50''N, $22^{o40'48''E.}$
Physiographic position: Depression in backswamps, 1 m. ASL.
Topography: Flat.
Drainage: Poorly drained. The ground-water table may be very shallow for some time in the winter and drop below the control section in the end of the summer.
Cultivation: Alfalfa.
Parent material: Recent, calcareous, stratified alluvium of the Peneios river.
Sampled by: L. Toulios, November 29, 1989.

Ap	0-35 cm. Dark yellowish brown (10YR 4/4), sandy clayloam; weak medium subangular blocky structure; friable (moist); few very fine interstitial pores; non calcareous; few roots; clear smooth boundary; pH=7.6 (Sample No. 15791).
Bw	35-65 cm. Dark brown (10YR 3/3) clay; moderate medium angular blocky structure; firm (moist); many very fine and common fine interstitial pores; common spherical manganese concretions; non calcareous; few roots; abrupt boundary; pH=7.8 (Sample No. 15792).
C1	65-90 cm. Dark yellowish brown (10YR 4/4) clayloam; weak medium subangular blocky structure; firm (moist); common very fine and few fine interstitial pores; common spherical manganese concretions; calcareous; very few roots; gradual smooth boundary; pH=8.1 (Sample No. 15793).
C2	90-111 cm. Yellowish brown (10YR 5/4) clayloam; weak moderate subangular blocky structure; firm (moist); common very fine and few fine interstitial pores; calcareous; very few roots; gradual smooth boundary; pH=8.1 (Sample No. 15794).
C3	111-135 cm. Yellowish brown (10YR 5/4) clayloam; weak moderate subangular blocky structure; firm (moist); common very fine and few fine interstitial pores; calcareous; no roots; pH=7.9 (Sample No. 15795).

Analytical data of the selected soil profiles (Peneios delta area)

Sample	Profile	Depth	Horizon	Sand	Silt	Clay	Text.	O.M.	CaCO3	pH	ECe	CEC	exch.K	exch.Na
no.	no.	(cm)	code	(%)	(%)	(%)	code	(%)	tot.(%)		(mmhos)	<-----	cmol(+)/kg	--->
14359	P1	0- 29	Ap	29	41	30	CL	1.64	2.52	7.6		24.8	0.31	0.65
14360		29- 41	B	24	42	34	CL	1.64	1.68	7.4		24.8	0.27	0.40
14361		41- 51	2Cg1	59	29	12	SL	0.60	5.46	7.6		10.5	0.08	0.30
14362		51- 62	3Cg2	37	49	14	L	0.54	5.04	7.5		9.4	0.08	0.35
14363		62- 71	3Cg3	45	41	17	L	0.62	6.93	7.5		12.1	0.08	0.40
14364		71- 83	4Cg4	23	52	25	SiL	0.57	8.4	7.8		18.2	0.12	0.50
14365		83- 95	4Cg5	27	52	21	SiL	0.59	12.18	7.9		18.7	0.12	0.45
14366		95-108	5Cg6	37	42	21	L	0.56	9.24	7.9		16.5	0.10	0.35
14367		108-122	6Cg7	75	17	8	SL	0.39	4.62	8.0		7.7	0.08	0.20
14368		122-132+	6Cg8	61	29	10	SL	0.26	5.46	7.9		9.9	0.08	0.20
14459	P2	0- 16	Ap1	36	42	22	L	1.27	6.09	8.0	<3	10.5	0.21	0.15
14460		16- 31	Ap2	43	37	20	L	1.25	6.09	8.1	<3	16.0	0.19	0.10
14461		31- 47	C1	59	31	10	SL	0.33	8.82	8.4	<3	12.1	0.11	0.10
14462		47- 58	C2	78	14	8	SL	0.23	8.61	8.4	<3	8.3	0.08	0.15
14463		58- 68	C3	53	33	14	SL	0.40	8.19	8.3	<3	12.7	0.11	0.10
14464		68- 92	2Bwb	21	47	32	CL	1.24	5.67	8.3	<3	30.3	0.19	0.15
14465		92-114	2C4	35	43	22	L	0.67	8.40	8.2	<3	14.9	0.13	0.15
14466		114-150	2C5	55	35	10	SL	0.27	7.56	8.3	<3	8.8	0.06	0.10
14467		150-180+	2C6	17	49	34	SiCL	0.60	4.62	8.3	<3	19.3	0.21	0.10
14414	P3	0- 27	Ap	25	31	44	C	2.71	0.	7.5	<3			
14415		27- 47	Bw1	25	23	52	C	1.90	0.	7.7	<3			
14416		47- 63	Bw2	17	33	50	C	1.39	3.36	7.7	<3			
14417		63- 79	CBk	21	45	34	CL	0.88	4.41	7.9	<3			
14418		79-105	C1	45	41	14	L	0.24	4.62	8.0	<3			
14419		105-121	C2	23	53	24	SiL	1.35	8.40	8.3	<3			
14420		121-140	C3	14	54	32	SiCL	0.41	8.40	8.1	<3			
14468	P4	0- 27	Ap	19	33	48	C	2.49	6.93	7.9	<3			
14469		27- 47	AB	15	36	49	C	2.39	6.93	8.0	<3			
14470		47- 63	Bg1	19	25	56	C	1.36	2.73	8.1	<3			
14471		63- 79	Bg2	19	25	56	C	1.57	2.31	8.1	<3			
14472		79-105	B/C	25	27	48	C	1.97	5.25	8.1	<3			
14473		105-120	Cg	29	33	38	CL	1.10	11.13	8.47	<3			
14443	P5	0- 25	Ap	46	37	17	L	1.12	8.19	7.8	<3			
14444		25- 53	C1	46	37	17	L	0.71	8.82	8.3	<3			
14445		53- 69	C2	66	21	13	SL	0.32	8.82	8.5	<3			
14446		69- 98	2C3	92	3	5	S	0.13	10.71	8.3	<3			
14447		98-130+	3C4	44	43	13	L	0.29	10.71	8.0	<3			
14448	P6	0- 28	Ap	38	43	19	L	1.41	6.72	8.2	<3			
14449		28- 42	C1	80	13	7	LS	0.16	7.98	9.0	<3			
14450		42- 54	2C2	25	50	25	SiL	0.92	8.61	8.4	<3			
14451		54- 82	2C3	26	55	19	SiL	0.58	10.50	8.4	<3			
14452		82-100	2C4	22	53	25	SiL	0.72	10.08	8.2	6			
14453		100-130	3C5	54	23	23	SCL	0.34	12.39	8.2	4			
15770	P7	0- 28	Ap	47	30	17	L	0.70	5.25	8.6	<3	11.0	0.35	0.10
15771		28- 43	C1	31	48	21	L	0.84	6.93	7.8	3	13.8	0.16	0.25
15772		43- 73	2C2	77	7	16	SL	0.27	6.30	8.5	<3	5.5	0.04	0.10
15773		73-103	3C3	71	22	7	SL	0.17	5.46	8.4	<3	6.1	0.04	0.10
15774		103-143	4C4	33	51	16	SiL	0.47	6.83	8.8	<3	18.7	0.16	0.25
15791	P8	0- 35	Ap	55	19	26	SCL	1.27	tr.	7.6	<3	18.2	0.27	0.35
15792		35- 65	Bw	25	31	44	C	1.27	0.00	7.8	<3	40.7	0.33	0.60
15793		65- 90	C1	25	39	36	CL	0.57	5.46	8.1	<3	39.6	0.29	0.80
15794		90-110	C2	21	40	39	CL	0.54	7.56	8.1	<3	39.6	0.29	1.35
15795		110-135	C3	21	44	35	CL	0.44	9.24	7.9	<3	29.7	0.23	0.80

Analytical data of the additional soil sites (Peneios delta area)

Sample no.	Site no. (soil unit)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Text. code	O.M. (%)	$CaCO_3$ tot.(%)	pH	ECx1000 milimhos	CEC	exch.K^+	exch.Na^+
											<-----cmol(+)/kg----->		
14369	T1	0- 20	34	38	28	L	1.84	1.68	7.4		23.1	0.31	0.15
14370	(AcEx2)	20- 40	30	46	24	L	1.17	5.46	7.9		21.5	0.16	0.25
14371		40- 60	78	12	10	SL	0.27	7.14	8.4		6.6	0.03	0.20
14372		60- 80	78	14	8	LS	0.20	5.46	8.1		6.1	0.08	0.20
14373		80-100	94	0	6	S	0.17	4.20	8.0		3.3	0.04	0.05
15827	T2	0- 28	26	39	35	CL	1.88	2.10	7.9	<3	27.5	0.27	0.40
15828	(AmEx3)	28- 60	16	63	21	SiL	0.54	5.88	8.1	<3	16.5	0.10	0.35
15829		60- 85	19	56	25	SiL	0.47	6.30	8.0	<3	18.7	0.21	0.35
15830		85-110	20	37	43	C	0.64	6.09	8.1	<3	23.1	0.23	0.40
15831		110-135	24	19	57	C	1.14	2.52	8.0	<3	29.2	0.35	0.40
15832	T3	0- 30	34	44	22	L	1.47	4.62	8.3		15.4	0.42	1.95
15833	(EEae)	30- 60	34	48	18	L	0.80	5.88	8.2		13.8	0.27	1.25
15834		60- 90	62	27	11	SL	0.23	7.14	8.2		8.3	0.16	0.40
15835		90-120	90	5	5	S	0.07	5.04	8.7		3.9	0.10	0.30
15836		120-150	94	1	5	S	0.23	3.78	8.7		2.8	0.04	
15837	T4	0- 30	20	53	27	CL	2.04	3.36	7.7		20.9	0.33	2.05
15838	(EI/Exa)	30- 60	20	52	28	SiCL	0.84	7.56	7.9		20.9	0.23	4.15
15839		60- 90	20	54	26	SiCL	0.50	7.98	8.0		18.2	0.23	4.40
15840		90-120	24	44	32	CL	0.44	10.08	8.2		18.7	0.23	3.55
15841		120-150	32	46	22	L	0.40	10.08	8.0		15.4	0.23	2.25
15842	T5	0- 30	32	42	26	L	2.08	2.94	7.8		24.2	0.33	3.25
15843	(EI/Exa)	30- 60	18	54	28	SiCL	1.07	9.66	7.7		21.5	0.23	4.75
15844		60- 90	29	50	22	SiL	0.50	11.76	8.0		15.4	0.21	5.65
15845		90-120	28	52	20	SiL	0.40	14.28	8.3		14.9	0.23	6.30
15846		120-150	18	52	30	SiCL	0.44	7.98	8.0		19.2	0.40	7.40
15847	T6	0- 30	26	45	29	CL	1.47	5.88	8.0		24.2	0.35	0.35
15848	(AmEx3)	30- 60	24	46	30	CL	1.11	5.88	8.0		24.2	0.29	0.30
15849		60- 90	38	37	25	L	0.67	6.72	8.1		22.6	0.21	0.30
15850		90-120	32	39	29	CL	0.74	6.72	8.1				
15851		120-150	42	43	15	L	0.37	7.98	8.2				
15752	T7	0- 30	26	41	33	CL	1.81	6.09	7.6	<3	29.7	0.29	0.30
15753	(AbIxv)	30- 60	22	39	39	CL	1.61	5.67	7.7	<3	25.3	0.35	0.35
15754		60- 80	20	39	41	C	0.84	6.51	7.9	<3	24.8	0.23	0.30
15755		80-110	18	35	47	C	0.97	4.83	8.0	<3	31.9	0.33	0.30
15756		110-150	18	41	41	SiC	0.87	5.46	8.0	<3	27.0	0.33	0.30
15757	T8	0- 30	58	19	23	SCL	1.54	2.73	7.9	<3	17.6	0.23	0.30
15758	(AmEx3)	30- 60	20	43	37	SiCL	1.00	2.10	8.0	<3	27.5	0.21	0.20
15759		60- 85	26	51	23	SiL	0.70	5.04	8.0	<3	16.5	0.10	0.15
15760		85-110	38	39	23	L	0.74	1.89	8.0	<3	13.8	0.10	0.20
15761		110-140	20	53	27	SiCL		8.19	8.1	<3	19.8	0.10	0.25
15762	T9	0- 23	51	34	15	L	0.84	6.09	8.1	<3	8.8	0.10	0.35
15763	(AcEx2)	23- 48	49	37	14	L	0.80	6.09	8.0	<3	9.4	0.40	0.30
15764		48- 75	59	30	11	SL	0.23	6.93	8.2	<3	8.3	0.38	0.25
15765		75- 90	37	42	21	L	0.60	6.30	8.3	<3	11.6	0.16	0.20
15766		90-110	35	48	17	L	0.67	5.04	8.2	<3	14.3	0.27	0.20
15767		110-120	63	28	9	SL	0.17	5.67	8.3	<3	8.3	0.23	0.15
15768		120-130	38	45	17	L	0.57	5.85	7.9	<3	14.3	0.21	0.20
15769		130-150	30	57	13	SiL	0.40	6.09	7.8	<3	10.5	0.16	0.15
15775	T10	0- 30	40	43	17	L	1.00	4.41	7.9	<3	11.6	0.27	0.10
15776	(AmExa)	30- 50	30	38	16	L	0.67	4.62	8.0	<3	12.7	0.21	0.15
15777		50- 70	46	34	20	L	1.21	2.52	7.9	<3	16.5	0.23	0.20
15778		70-100	47	33	19	L	0.84	1.26	7.9	<3	17.5	0.27	0.15
15779		100-130	48	33	19	L	0.74	3.78	7.9	<3	14.9	0.27	0.20

A.4 Pedon TEI/L

Classification: USDA (1975): Thapto-Calcic Haploxeralfic Entic Chromoxerert
FAO (1988): Calcic Vertisol
435
Pedon code: B--------Vxce
A01
Location: Experimental farm TEI-Larissa
Physiographic position: Peneios river meandering plain.
Topography: Level (slope 0.5%).
Drainage: Well to moderately well drained.
Cultivation: Maize, cotton, sugar beet, wheat, alfalfa.
Parent material: Alluvium of the Peneios river.
Sampled by: N.G. Danalatos, Th. Mitsimbonas and P. Giolas, September 10, 1987.
Remarks: Cracks wider than 1 cm extend deeper than 50 cm from the (dry) surface.

Ap	0-33 cm. Strong brown (7.5 YR 4/6) clayloam; moderate to strong coarse subangular blocky structure; hard to very hard (dry), firm (moist), very sticky (wet); abundant fine and very fine roots; common very fine interstitial pores; clear and smooth boundary.
Bw	33-58 cm. Strong brown (7.5 YR 4/6) clay; strong coarse angular blocky structure; common slickensides; hard to very (dry), firm (moist), very sticky (wet); common fine and very fine roots; common very fine interstitial pores; clear smooth boundary.
2Bt1kb	58-95 cm. Brown (7.5 YR 4/4) clay; strong coarse angular blocky structure; very hard (dry), very firm (moist), very sticky (wet); continuous moderate thick clay skins; few medium distinct red iron mottles; broken moderate thick concretions of calcium carbonate; common very fine and few fine roots; common very fine interstitial pores; calcareous; irregular wavy boundary.
2Bt2kb	95-165 cm. Strong brown (7.5 YR 4.5/6) clay; moderate coarse subangular blocky breaking down to medium to fine subangular blocky structure; very hard (dry), friable (moist), sticky (wet) ; common coarse prominent red iron mottling; broken moderate thick clay, iron and calcium carbonate cutans; few very fine roots; common very fine interstitial pores; calcareous.
2C	165-190 cm. Reddish yellow (7.5 YR 6.5/6) clayloam; structureless; broken iron- and calcicutans; very calcareous; irregular wavy boundary.
3R	190+ cm. Light brown (10 YR 6.5/4) marl.

Soil moisture characteristics (% vol)

depth	<---------------	---------------	pF	---------------	--------------->	SMfield	BD
(cm)	1.00	2.52	3.00	3.43	4.20	(% vol)	(kg/lt)
0-30	43.17	41.57	39.61	37.48	27.42	35.26	1.567
0-30	42.37	41.05	39.60	37.94	28.34	35.38	1.610
30-60	45.93	42.20	39.18	36.94	33.45	34.16	1.500
30-60	44.13	37.91	36.68	35.65	25.70	32.75	1.436

B. CLIMATOLOGICAL DATA FILES

B.1 Larissa 1987 (Note: SD=sunshine duration ratio; RH=rel. air humidity).

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH	DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
91	19.0	8.0	0.000	4.08	2.01	0.92	138	27.5	10.5	0.622	0.00	1.63	0.68
92	17.5	2.5	0.590	0.16	2.01	0.74	139	28.0	12.0	0.884	0.00	0.76	0.64
93	19.0	1.5	0.901	0.00	2.01	0.72	140	29.5	13.5	0.642	0.00	2.26	0.53
94	22.0	3.0	0.765	0.00	2.01	0.74	141	29.0	12.0	0.441	0.43	1.19	0.67
95	20.5	2.5	0.132	0.00	2.01	0.80	142	25.0	9.5	0.887	0.00	3.50	0.47
96	20.5	5.0	0.589	0.00	2.01	0.78	143	25.0	7.0	0.721	0.00	3.57	0.42
97	22.5	7.5	0.858	0.00	2.01	0.66	144	27.5	10.5	0.865	0.00	2.44	0.40
98	22.5	5.5	0.832	0.00	2.01	0.73	145	24.0	11.5	0.548	0.02	1.63	0.65
99	22.5	7.5	0.683	0.00	2.01	0.71	146	25.0	11.5	0.595	0.48	1.13	0.76
100	19.0	8.5	0.505	0.00	2.01	0.72	147	24.0	9.0	0.670	0.00	1.13	0.76
101	19.5	12.5	0.381	0.26	2.89	0.67	148	26.0	9.0	0.771	0.00	1.25	0.67
102	19.0	10.0	0.623	0.03	1.82	0.69	149	24.5	10.5	0.307	0.00	1.06	0.64
103	17.0	6.0	0.250	0.06	4.33	0.83	150	25.5	14.0	0.197	0.18	0.76	0.74
104	14.0	8.5	0.000	0.00	2.89	0.73	151	21.5	9.5	0.292	0.92	0.81	0.84
105	14.0	4.0	0.526	0.00	1.63	0.74	152	24.5	14.0	0.170	0.06	0.81	0.76
106	13.0	7.5	0.367	0.83	1.50	0.81	153	23.5	13.5	0.509	0.00	0.78	0.70
107	18.0	8.0	0.351	0.00	0.50	0.75	154	26.0	10.0	0.826	0.00	0.76	0.63
108	21.0	3.5	0.872	0.00	0.50	0.73	155	29.0	12.0	0.839	0.00	1.12	0.59
109	25.5	6.0	0.863	0.00	0.99	0.67	156	30.0	12.0	0.892	0.00	2.18	0.50
110	24.0	7.5	0.794	0.00	1.20	0.78	157	30.0	13.0	0.890	0.00	0.62	0.50
111	21.0	5.5	0.510	0.00	1.89	0.66	158	30.5	15.5	0.930	0.00	1.37	0.50
112	23.0	7.5	0.472	0.09	2.33	0.64	159	33.5	16.5	0.915	0.00	0.99	0.52
113	10.5	4.5	0.000	0.07	1.82	0.83	160	34.5	17.0	0.887	0.00	1.12	0.57
114	10.0	3.0	0.492	0.06	1.45	0.77	161	37.0	14.5	0.671	0.00	1.12	0.58
115	19.5	4.0	0.556	0.00	2.47	0.74	162	35.5	16.0	0.824	0.00	1.06	0.54
116	24.5	4.5	0.708	0.00	0.76	0.71	163	35.0	18.0	0.857	0.00	1.42	0.51
117	22.0	4.5	0.400	0.00	1.76	0.70	164	36.0	17.0	0.842	0.00	0.76	0.56
118	18.0	7.0	0.000	1.75	6.59	0.82	165	36.5	17.5	0.854	0.00	1.19	0.54
119	17.0	6.5	0.753	0.08	3.96	0.60	166	36.5	17.0	0.587	0.00	1.19	0.53
120	18.0	6.0	0.448	0.00	1.70	0.61	167	36.0	19.0	0.874	0.00	1.81	0.42
121	19.5	7.0	0.072	0.00	0.00	0.74	168	34.5	19.0	0.915	0.00	4.92	0.21
122	20.0	9.5	0.517	0.00	0.75	0.77	169	31.5	16.5	0.835	0.00	3.05	0.47
123	22.0	11.0	0.745	0.34	0.75	0.82	170	30.0	17.0	0.695	0.00	1.62	0.54
124	22.5	7.5	0.707	0.00	1.70	0.79	171	29.5	17.0	0.401	0.00	0.78	0.58
125	22.0	11.5	0.285	0.00	2.70	0.81	172	28.5	16.0	0.629	0.00	2.43	0.56
126	20.0	13.0	0.718	0.13	2.51	0.70	173	30.5	13.5	0.784	0.00	1.93	0.46
127	19.0	6.0	0.681	0.00	3.64	0.63	174	29.0	13.5	0.670	0.06	1.99	0.60
128	18.0	8.0	0.544	0.00	1.32	0.58	175	27.5	14.0	0.684	0.00	1.37	0.66
129	18.5	11.0	0.712	0.00	2.76	0.47	176	31.5	14.0	0.819	0.00	1.12	0.55
130	21.5	7.0	0.921	0.00	0.88	0.58	177	31.0	15.0	0.719	0.00	1.49	0.52
131	22.5	9.0	0.688	0.00	0.69	0.67	178	31.0	15.0	0.632	0.06	1.81	0.56
132	23.0	9.0	0.749	0.00	1.89	0.63	179	28.0	19.0	0.108	0.01	1.86	0.60
133	23.0	7.0	0.684	0.00	1.75	0.72	180	31.0	18.0	0.821	0.00	2.18	0.50
134	22.5	6.5	0.808	0.00	0.76	0.62	181	31.0	16.0	0.808	0.00	1.81	0.48
135	22.5	11.0	0.111	0.00	1.01	0.79	182	29.0	15.0	0.842	0.00	2.11	0.47
136	25.0	12.0	0.652	0.34	1.06	0.79	183	27.0	14.0	0.843	0.00	1.62	0.46
137	26.0	12.0	0.796	0.00	0.69	0.69	184	29.0	17.0	0.493	0.00	0.99	0.47

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH	DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
185	32.5	18.5	0.162	0.00	0.81	0.65	237	28.5	16.0	0.864	0.00	1.56	0.65
186	31.5	16.0	0.547	0.01	1.12	0.67	238	29.5	15.5	0.859	0.00	1.81	0.60
187	26.5	14.0	0.210	0.11	2.98	0.70	239	30.0	17.0	0.824	0.00	1.49	0.57
188	28.0	15.0	0.372	0.00	1.24	0.61	240	30.5	17.0	0.826	0.00	1.24	0.56
189	17.5	13.0	0.623	0.00	1.49	0.59	241	34.0	18.5	0.274	0.00	3.60	0.57
190	30.0	12.0	0.881	0.00	1.24	0.55	242	30.0	19.0	0.808	0.00	4.35	0.37
191	31.0	13.5	0.854	0.00	1.19	0.52	243	30.0	14.5	0.879	0.00	1.19	0.53
192	31.5	18.5	0.156	0.00	1.49	0.51	244	30.5	14.5	0.920	0.00	1.74	0.56
193	31.5	19.0	0.706	0.00	0.62	0.52	245	30.0	15.5	0.854	0.00	2.55	0.63
194	34.0	16.5	0.788	0.00	1.12	0.51	246	29.5	15.5	0.632	0.00	1.49	0.68
195	34.5	17.5	0.755	0.00	1.44	0.50	247	30.0	15.0	0.851	0.00	1.99	0.67
196	35.5	17.5	0.646	0.00	1.44	0.47	248	31.0	14.0	0.830	0.00	1.74	0.58
197	37.0	19.0	0.729	0.00	1.74	0.46	249	30.0	14.5	0.771	0.00	2.11	0.59
198	37.0	15.5	0.820	0.00	1.93	0.44	250	28.5	13.0	0.718	0.00	1.99	0.69
199	36.5	17.0	0.808	0.00	1.31	0.49	251	28.5	14.0	0.775	0.00	2.31	0.64
200	39.0	19.0	0.844	0.00	1.49	0.50	252	28.0	15.0	0.809	0.00	0.62	0.58
201	41.0	19.0	0.819	0.00	1.44	0.46	253	28.0	14.5	0.804	0.00	1.44	0.53
202	41.0	21.0	0.724	0.00	1.74	0.45	254	28.5	13.0	0.703	0.00	1.99	0.61
203	41.0	21.0	0.774	0.00	1.12	0.45	255	29.0	16.0	0.690	0.00	1.37	0.66
204	40.0	21.0	0.803	0.00	0.94	0.44	256	33.0	24.5	0.795	0.00	1.12	0.57
205	41.0	22.0	0.826	0.00	0.99	0.48	257	30.0	16.0	0.845	0.00	0.62	0.47
206	41.5	21.0	0.779	0.00	0.69	0.49	258	32.0	17.0	0.840	0.00	0.50	0.41
207	43.0	22.0	0.809	0.00	0.75	0.45	259	37.0	18.0	0.835	0.00	1.37	0.38
208	43.5	18.5	0.852	0.00	2.31	0.38	260	35.0	17.5	0.781	0.00	1.31	0.47
209	33.0	19.0	0.553	0.00	2.24	0.51	261	37.5	18.5	0.776	0.00	2.18	0.59
210	31.0	21.5	0.653	0.00	2.68	0.47	262	37.5	16.5	0.795	0.00	1.12	0.59
211	31.5	19.5	0.816	0.00	1.44	0.50	263	35.5	18.5	0.757	0.00	0.25	0.53
212	34.5	17.5	0.804	0.00	1.81	0.58	264	35.0	16.0	0.742	0.00	2.38	0.59
213	33.5	20.5	0.537	0.01	2.06	0.60	265	27.0	18.0	0.653	0.00	3.00	0.55
214	32.0	18.0	0.843	0.00	1.44	0.54	266	25.0	14.0	0.370	0.00	1.81	0.65
215	34.0	18.0	0.902	0.00	1.49	0.50	267	26.5	15.0	0.278	0.00	1.63	0.77
216	35.0	17.0	0.882	0.00	1.24	0.47	268	27.0	16.0	0.483	0.00	2.69	0.79
217	39.0	17.0	0.927	0.00	1.12	0.44	269	29.0	16.0	0.714	0.00	1.81	0.80
218	39.0	17.0	0.922	0.00	1.74	0.42	270	29.0	18.5	0.512	0.00	1.63	0.81
219	40.0	17.5	0.874	0.00	3.11	0.53	271	28.0	15.0	0.120	0.00	2.19	0.75
220	38.5	18.0	0.811	0.00	0.99	0.58	272	20.0	14.0	0.129	0.00	3.50	0.69
221	35.0	20.0	0.878	0.00	1.99	0.55	273	16.5	14.0	0.000	1.21	5.38	0.81
222	39.0	20.0	0.880	0.00	1.19	0.56	274	14.2	13.6	0.000	2.35	1.75	0.92
223	38.0	21.0	0.846	0.00	2.24	0.61	275	15.8	12.4	0.000	0.00	0.81	0.87
224	36.0	20.0	0.696	0.00	3.67	0.61	276	18.2	13.6	0.036	0.00	1.75	0.70
225	36.0	20.5	0.603	0.19	1.74	0.69	277	18.0	14.0	0.320	0.00	3.31	0.87
226	35.5	19.5	0.648	0.03	3.80	0.61	278	18.8	8.8	0.196	0.00	0.81	0.71
227	35.0	19.0	0.839	0.00	1.86	0.67	279	21.0	6.8	0.679	0.00	1.19	0.76
228	31.0	14.5	0.644	0.00	4.92	0.49	280	21.4	7.4	0.321	0.00	0.63	0.72
229	32.0	16.5	0.925	0.00	2.80	0.36	281	21.0	14.4	0.098	0.29	0.81	0.89
230	32.5	14.0	0.920	0.00	1.86	0.53	282	25.0	12.2	0.563	0.00	1.25	0.85
231	31.5	13.0	0.856	0.00	1.44	0.59	283	23.8	13.2	0.438	0.00	2.69	0.79
232	31.5	13.5	0.570	0.04	1.56	0.65	284	23.8	13.4	0.446	0.00	1.13	0.81
233	25.5	18.5	0.656	0.00	2.68	0.71	285	22.4	13.2	0.304	0.04	0.81	0.83
234	25.5	17.0	0.544	0.58	0.50	0.73	286	21.0	15.4	0.429	0.94	1.13	0.85
235	28.5	13.0	0.866	0.00	1.37	0.67	287	25.0	11.0	0.803	0.00	2.00	0.66
236	29.0	15.0	0.854	0.00	1.44	0.67	288	24.2	9.0	0.723	0.00	0.88	0.69

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
289	21.2	9.0	0.179	0.00	0.00	0.83
290	21.4	9.4	0.179	0.00	0.69	0.81
291	22.4	12.0	0.518	0.00	1.00	0.79
292	18.0	11.2	0.107	0.23	0.00	0.90
293	20.0	12.4	0.196	0.00	1.06	0.85
294	20.6	11.2	0.428	0.00	0.75	0.83
295	21.4	8.0	0.642	0.00	1.38	0.81
296	20.4	12.2	0.411	0.00	1.56	0.79
297	21.0	11.8	0.457	0.00	1.06	0.75
298	19.0	14.4	0.019	0.00	1.00	0.81
299	22.0	8.4	0.610	0.00	0.31	0.84
300	17.2	10.2	0.000	0.35	1.75	0.88
301	10.8	8.8	0.010	0.29	1.38	0.91
302	9.6	5.4	0.000	0.40	0.88	0.95
303	9.6	7.8	0.000	1.33	0.00	0.93
304	9.6	7.4	0.000	0.20	0.00	0.97
305	9.8	8.2	0.000	0.00	1.25	0.86
306	13.2	1.0	0.600	0.00	0.00	0.86
307	9.4	6.4	0.000	1.85	0.50	0.98
308	9.2	7.6	0.000	1.53	4.19	0.85
309	10.6	7.0	0.480	0.00	3.88	0.64
310	12.8	0.1	0.870	0.00	0.44	0.75
311	14.2	-0.4	0.790	0.00	0.00	0.80
312	15.0	-0.2	0.790	0.00	0.00	0.82
313	15.8	0.0	0.550	0.00	0.00	0.84
314	16.2	2.8	0.060	0.00	0.25	0.88
315	14.6	10.0	0.000	0.68	0.63	0.98
316	16.4	10.6	0.000	0.00	0.00	0.96
317	18.0	9.2	0.410	0.00	0.00	0.93
318	19.4	7.0	0.400	0.00	0.00	0.90
319	20.4	9.0	0.190	0.00	0.88	0.88
320	20.0	8.8	0.480	0.00	0.00	0.90
321	17.6	9.4	0.230	0.00	0.00	0.96
322	12.4	9.0	0.180	0.95	3.13	0.84
323	12.0	6.8	0.010	1.05	2.00	0.89
324	12.0	3.4	0.150	0.00	0.00	0.87
325	14.6	8.0	0.080	1.05	2.13	0.90
326	14.2	5.0	0.510	0.07	0.00	0.83
327	11.4	2.8	0.150	0.00	0.25	0.94
328	13.4	4.0	0.050	0.00	0.00	0.93
329	16.8	2.4	0.140	0.00	0.25	0.93
330	17.6	7.6	0.020	0.00	0.94	0.91
331	19.8	11.6	0.450	0.39	1.50	0.83
332	13.8	5.2	0.240	0.00	0.50	0.89
333	15.8	2.2	0.510	0.00	0.00	0.93
334	12.4	7.6	0.160	0.00	0.25	0.95

B.2 Larissa 1988

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH	DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
91	20.00	7.20	0.474	0.00	1.90	0.62	140	30.80	12.00	0.517	4.20	1.90	0.69
92	18.60	2.20	0.417	0.00	1.00	0.62	141	29.20	11.00	0.668	0.00	2.40	0.59
93	16.40	0.40	0.031	0.00	0.00	0.74	142	28.40	9.80	0.777	0.00	0.80	0.56
94	18.00	7.40	0.133	0.00	1.50	0.78	143	26.60	12.80	0.550	0.00	1.60	0.56
95	19.40	6.20	0.537	0.00	1.10	0.81	144	24.80	12.40	0.535	0.00	2.30	0.57
96	18.20	8.20	0.155	0.00	1.90	0.83	145	19.20	14.00	0.000	0.00	0.80	0.82
97	17.40	9.60	0.100	0.00	3.40	0.82	146	26.00	12.60	0.390	0.00	1.00	0.72
98	21.20	4.40	0.431	0.00	0.40	0.82	147	27.80	10.60	0.581	0.00	1.40	0.68
99	23.40	4.20	0.844	0.00	1.30	0.66	148	29.00	11.20	0.696	0.00	0.90	0.68
100	24.60	4.40	0.719	0.00	0.60	0.66	149	30.20	12.40	0.688	0.00	2.00	0.64
101	18.40	6.80	0.572	0.00	4.00	0.81	150	30.40	11.40	0.783	0.00	2.30	0.47
102	19.80	9.20	0.775	0.00	1.40	0.74	151	31.80	10.40	0.884	0.00	1.90	0.49
103	21.00	3.80	0.500	0.00	1.00	0.71	152	29.40	13.20	0.048	0.00	0.30	0.66
104	16.20	9.20	0.000	4.70	2.90	0.81	153	26.80	14.40	0.603	1.70	2.50	0.59
105	11.00	2.60	0.797	0.90	4.00	0.44	154	27.00	12.40	0.792	0.00	2.60	0.44
106	10.00	4.60	0.392	0.00	1.50	0.57	155	30.80	9.20	0.886	0.00	1.80	0.45
107	8.20	2.40	0.000	2.90	1.00	0.86	156	31.40	11.20	0.459	0.00	0.90	0.47
108	13.40	0.40	0.343	0.00	0.60	0.82	157	31.70	14.80	0.526	0.00	1.70	0.43
109	17.20	3.80	0.521	0.00	1.30	0.80	158	32.60	14.00	0.822	0.00	2.40	0.52
110	17.60	5.20	0.579	0.00	1.00	0.81	159	33.20	12.00	0.471	0.00	1.10	0.40
111	20.00	3.20	0.762	0.00	1.30	0.74	160	29.20	18.80	0.060	0.00	0.90	0.59
112	23.60	2.40	0.620	0.00	1.00	0.73	161	32.60	15.40	0.698	0.00	1.90	0.57
113	24.40	4.80	0.875	0.00	0.60	0.68	162	35.40	16.20	0.771	0.00	1.50	0.46
114	26.00	6.60	0.624	0.00	1.80	0.58	163	36.40	15.80	0.562	0.00	1.60	0.46
115	24.80	8.00	0.534	0.00	2.90	0.65	164	35.40	19.60	0.655	0.00	3.20	0.44
116	17.40	12.80	0.000	2.90	4.10	0.91	165	35.40	17.00	0.834	0.00	2.90	0.42
117	18.20	10.00	0.138	0.00	1.60	0.87	166	36.20	18.40	0.680	0.00	2.90	0.39
118	16.40	10.80	0.087	0.00	1.50	0.87	167	32.00	19.80	0.807	0.00	3.00	0.35
119	15.00	8.00	0.007	2.70	1.60	0.91	168	34.00	15.20	0.587	0.00	2.40	0.39
120	13.60	10.60	0.000	15.60	1.50	0.88	169	34.40	18.20	0.728	0.00	2.40	0.40
121	16.60	9.60	0.590	0.00	2.60	0.77	170	32.40	17.40	0.394	0.00	2.60	0.49
122	18.80	5.00	0.718	0.00	0.80	0.77	171	28.80	16.20	0.655	3.60	1.00	0.69
123	23.20	1.80	0.723	0.00	0.50	0.68	172	29.40	15.40	0.555	2.70	1.30	0.68
124	25.60	5.20	0.357	0.00	0.50	0.69	173	29.40	12.60	0.717	0.00	1.50	0.62
125	27.40	10.40	0.178	0.00	0.00	0.74	174	31.40	14.40	0.710	0.00	2.40	0.45
126	35.60	12.20	0.640	0.00	2.10	0.47	175	31.60	14.00	0.376	0.00	2.00	0.45
127	29.40	11.00	0.829	0.00	2.80	0.51	176	31.80	15.80	0.382	0.00	3.30	0.56
128	26.00	12.60	0.410	0.00	1.00	0.63	177	24.60	14.20	0.537	0.00	6.10	0.65
129	24.80	12.00	0.395	0.00	1.80	0.69	178	34.80	16.00	0.732	0.00	2.30	0.53
130	25.20	10.00	0.549	0.00	1.60	0.71	179	33.20	18.80	0.753	0.00	3.50	0.54
131	28.40	9.40	0.786	0.00	2.10	0.71	180	37.40	18.20	0.807	0.00	2.10	0.46
132	24.00	15.00	0.371	0.00	5.00	0.74	181	35.60	19.40	0.815	0.00	3.00	0.31
133	22.60	16.00	0.006	0.00	3.80	0.71	182	36.00	20.00	0.822	0.00	2.80	0.38
134	22.40	12.40	0.091	0.00	1.90	0.75	183	38.40	21.40	0.587	0.00	2.60	0.40
135	24.00	13.20	0.451	0.00	2.10	0.73	184	37.20	18.40	0.810	0.00	2.80	0.38
136	28.20	9.40	0.596	0.00	1.60	0.66	185	38.60	19.00	0.790	0.00	1.60	0.44
137	29.00	11.00	0.755	0.00	1.40	0.56	186	39.60	20.20	0.804	0.00	2.10	0.42
138	29.80	12.20	0.768	0.00	1.60	0.48	187	40.60	21.60	0.696	0.00	1.50	0.43
139	30.00	11.00	0.856	0.00	1.80	0.54	188	44.80	22.60	0.589	0.00	1.60	0.40

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
189	41.60	23.00	0.562	0.00	2.50	0.39
190	42.20	23.80	0.650	0.00	2.50	0.39
191	34.80	26.20	0.827	0.00	6.40	0.27
192	33.00	21.00	0.855	0.00	3.30	0.29
193	31.40	21.00	0.835	0.00	3.90	0.32
194	34.40	15.40	0.781	0.00	2.00	0.47
195	37.60	18.00	0.768	0.00	2.00	0.44
196	38.20	20.00	0.755	0.00	1.90	0.48
197	39.80	20.00	0.798	0.00	1.40	0.42
198	36.40	21.00	0.820	0.00	2.10	0.43
199	32.60	22.80	0.527	0.00	3.80	0.46
200	32.00	21.00	0.412	0.90	2.30	0.65
201	33.40	18.00	0.702	0.00	1.60	0.53
202	33.40	21.20	0.772	0.00	4.00	0.42
203	32.60	18.00	0.843	0.00	2.40	0.53
204	34.20	18.00	0.838	0.00	1.90	0.47
205	34.40	19.20	0.826	0.00	1.90	0.44
206	35.50	19.00	0.807	0.00	2.00	0.48
207	36.80	21.20	0.593	0.00	2.00	0.46
208	33.20	21.60	0.286	0.00	0.50	0.52
209	35.80	20.20	0.777	0.00	2.50	0.44
210	35.60	22.60	0.737	0.00	2.40	0.47
211	36.40	20.80	0.753	0.00	2.30	0.53
212	34.40	22.80	0.656	0.00	3.50	0.59
213	33.20	20.80	0.586	0.00	2.40	0.57
214	33.80	21.00	0.772	0.00	1.60	0.57
215	36.20	18.00	0.795	0.00	1.80	0.47
216	36.80	17.40	0.847	0.00	1.90	0.43
217	36.20	16.80	0.827	0.00	2.30	0.46
218	36.80	16.80	0.765	0.00	2.40	0.53
219	31.80	17.80	0.351	0.00	3.80	0.55
220	29.40	21.00	0.266	0.00	1.50	0.64
221	23.80	15.80	0.619	0.00	1.90	0.57
222	33.20	14.20	0.765	0.00	2.50	0.53
223	35.20	14.00	0.767	0.00	1.50	0.50
224	35.00	16.40	0.763	0.00	1.90	0.48
225	35.00	18.00	0.785	0.00	2.40	0.42
226	35.80	16.60	0.830	0.00	1.90	0.40
227	36.00	18.00	0.854	0.00	2.00	0.43
228	36.40	17.40	0.593	0.00	1.90	0.40
229	35.20	20.20	0.470	0.80	2.10	0.52
230	33.80	18.20	0.700	0.70	1.60	0.61
231	31.80	22.40	0.546	0.00	2.80	0.55
232	32.20	20.20	0.659	0.00	1.60	0.57
233	33.80	22.40	0.780	0.00	1.50	0.61
234	36.40	20.40	0.789	0.00	1.30	0.58
235	36.80	18.40	0.683	0.00	2.40	0.42
236	33.00	19.20	0.891	0.00	2.40	0.35
237	34.20	14.80	0.901	0.00	1.20	0.46
238	33.80	16.60	0.791	0.00	2.40	0.45
239	31.20	18.40	0.914	0.00	3.10	0.40
240	30.40	14.80	0.917	0.00	3.40	0.44
241	33.00	12.40	0.904	0.00	1.50	0.53
242	36.40	15.00	0.831	0.00	0.90	0.44
243	34.60	18.40	0.841	0.00	2.60	0.51
244	34.60	17.60	0.836	0.00	1.90	0.46
245	33.20	18.20	0.615	0.00	2.40	0.67
246	37.80	18.60	0.862	0.00	2.80	0.50
247	32.40	19.40	0.866	0.00	3.00	0.44
248	31.80	16.80	0.885	0.00	1.30	0.54
249	35.40	15.00	0.716	0.00	6.40	0.45
250	25.80	20.80	0.367	0.00	2.40	0.40
251	26.60	12.00	0.619	0.00	2.30	0.42
252	26.60	9.60	0.801	0.00	2.30	0.42
253	28.60	14.40	0.788	0.00	2.50	0.47
254	28.60	15.60	0.790	0.00	3.10	0.35
255	29.00	11.60	0.785	0.00	2.00	0.53
256	30.40	11.80	0.763	0.00	1.50	0.58
257	31.60	13.20	0.463	0.00	1.60	0.51
258	32.60	16.20	0.488	0.00	2.10	0.57
259	34.60	19.80	0.706	0.00	2.00	0.48
260	31.00	14.80	0.338	0.00	1.80	0.47
261	31.00	15.00	0.800	0.00	1.40	0.42
262	28.60	15.60	0.673	0.00	3.50	0.51
263	28.00	14.60	0.619	0.00	1.30	0.65
264	25.60	14.20	0.139	0.00	1.10	0.65
265	25.20	16.80	0.303	5.40	1.30	0.76
266	25.60	18.00	0.362	5.40	0.90	0.74
267	28.20	15.40	0.677	0.00	0.90	0.72
268	27.80	14.60	0.663	0.00	1.50	0.73
269	28.80	12.80	0.699	0.00	0.30	0.63
270	27.60	13.20	0.668	0.00	1.60	0.57
271	27.20	13.20	0.586	0.00	1.50	0.60
272	26.80	12.80	0.555	0.00	1.60	0.66
273	26.80	11.60	0.709	0.00	1.10	0.65
274	26.20	10.20	0.589	0.00	0.75	0.62
275	26.20	13.00	0.545	0.00	1.75	0.50
276	21.00	15.00	0.143	0.00	0.63	0.74
277	21.40	10.60	0.187	1.90	0.38	0.79
278	22.40	8.40	0.670	0.00	0.63	0.81
279	26.60	9.40	0.723	0.00	0.75	0.70
280	29.60	12.40	0.857	0.00	1.75	0.64
281	28.60	12.80	0.446	0.00	1.75	0.60
282	24.00	13.00	0.884	0.00	3.38	0.51
283	24.20	6.60	0.866	0.00	0.63	0.62
284	25.20	10.40	0.795	0.00	1.00	0.70
285	25.60	11.20	0.813	0.00	1.25	0.72
286	25.00	10.80	0.777	0.00	1.63	0.71
287	25.00	10.60	0.768	0.00	1.25	0.64
288	23.20	10.20	0.813	0.00	1.13	0.64
289	20.20	11.00	0.339	0.00	1.38	0.63
290	20.20	7.20	0.830	0.00	1.00	0.67
291	21.80	4.80	0.776	0.00	1.25	0.64
292	24.80	3.60	0.768	0.00	0.00	0.58

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
293	24.60	9.00	0.748	0.00	3.13	0.65
294	16.00	15.40	0.000	0.00	6.38	0.69
295	16.20	14.80	0.000	0.00	6.25	0.70
296	16.00	12.40	0.000	0.00	2.88	0.75
297	19.40	8.60	0.536	0.00	0.63	0.77
298	19.20	9.80	0.045	0.00	1.88	0.68
299	18.80	12.40	0.259	1.00	7.38	0.52
300	11.00	7.80	0.714	0.00	4.75	0.49
301	13.20	0.40	0.795	0.00	0.25	0.55
302	15.80	2.00	0.824	0.00	0.00	0.62
303	20.80	0.20	0.781	0.00	1.00	0.63
304	16.60	6.00	0.000	0.75	1.19	0.84
305	9.60	6.40	0.000	0.39	3.75	0.74
306	11.80	-0.60	0.820	0.00	0.40	0.74
307	14.60	-0.80	0.780	0.00	0.00	0.79
308	10.40	5.80	0.000	0.45	2.45	0.88
309	8.60	6.00	0.000	1.81	1.50	0.94
310	10.00	3.20	0.660	0.00	3.65	0.75
311	11.80	-1.20	0.850	0.00	0.25	0.77
312	14.20	-1.00	0.600	0.00	0.50	0.75
313	14.00	-1.00	0.790	0.00	0.50	0.77
314	9.80	1.40	0.000	0.00	2.50	0.80
315	9.00	5.20	0.020	0.00	2.75	0.78
316	11.60	4.00	0.370	0.00	0.00	0.82
317	12.80	-1.00	0.600	0.00	0.00	0.82
318	9.00	0.00	0.000	0.72	1.25	0.93
319	11.60	4.00	0.290	0.16	1.00	0.80
320	10.80	0.00	0.790	0.11	2.15	0.63
321	8.80	0.00	0.890	0.00	3.15	0.53
322	9.20	-4.40	0.820	0.00	0.25	0.72
323	12.00	-4.00	0.840	0.00	0.00	0.73
324	15.00	2.60	0.080	0.86	1.25	0.88
325	16.40	2.40	0.460	0.00	0.40	0.86
326	20.80	12.00	0.260	0.54	5.50	0.63
327	15.80	9.40	0.130	1.53	1.75	0.88
328	9.40	4.80	0.000	2.18	1.90	0.93
329	4.80	2.40	0.000	1.81	0.50	0.96
330	5.20	0.80	0.000	1.70	2.00	0.94
331	8.20	-0.40	0.820	0.00	0.00	0.88
332	8.40	-1.00	0.220	0.00	0.00	0.91
333	11.20	-2.00	0.760	0.00	0.55	0.87
334	16.20	2.60	0.770	0.00	2.00	0.67
335	13.00	4.00	0.300	0.00	0.00	0.84
336	19.20	8.00	0.470	0.30	1.90	0.85
337	20.00	6.80	0.840	0.46	1.25	0.77
338	15.60	5.80	0.140	0.00	0.15	0.86
339	12.00	6.00	0.010	0.02	0.00	0.97
340	16.40	3.00	0.830	0.00	0.45	0.83
341	14.40	7.00	0.380	0.00	1.40	0.72
342	10.20	6.00	0.000	0.75	1.90	0.87
343	6.40	4.20	0.000	0.51	8.80	0.77
344	7.40	5.20	0.000	0.00	7.50	0.68
345	8.60	3.00	0.750	0.00	1.00	0.69
346	10.50	-2.00	0.710	0.00	0.00	0.83
347	9.20	-0.60	0.260	0.00	0.00	0.90
348	10.60	-1.20	0.700	0.00	0.00	0.82
349	9.20	-1.20	0.500	0.00	0.90	0.74
350	4.40	-1.80	0.000	3.67	3.50	0.96
351	1.20	-8.20	0.000	2.78	2.25	0.97
352	1.60	-1.00	0.100	0.00	1.75	0.86
353	-1.00	-16.00	0.420	0.00	0.00	0.93
354	-2.40	-17.50	0.000	0.00	0.00	0.94
355	1.20	-2.40	0.000	1.00	0.00	0.98
356	3.40	-0.80	0.070	0.20	0.00	0.99
357	-0.80	-3.60	0.000	0.00	0.00	1.00
358	-2.80	-7.40	0.000	0.00	0.00	1.00
359	-1.40	-7.40	0.350	0.00	0.40	0.98
360	4.00	-5.40	0.880	0.00	1.15	0.81
361	4.00	-7.20	0.760	0.00	0.00	0.89
362	4.60	-6.00	0.690	0.00	0.00	0.91
363	7.20	-1.80	0.840	0.00	1.15	0.82
364	5.60	-5.00	0.760	0.00	0.00	0.93
365	5.00	-4.00	0.760	0.00	0.00	0.93

B.3 Larissa 1989

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH	DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
1	9.40	-4.40	0.710	0.00	0.40	0.93	50	12.80	-3.60	0.670	0.00	1.05	0.75
2	6.00	-3.40	0.220	0.03	0.65	0.90	51	16.40	-3.00	0.830	0.00	0.00	0.72
3	3.60	0.00	0.350	0.15	2.75	0.83	52	20.20	-1.40	0.830	0.00	0.15	0.67
4	4.00	-4.40	0.700	0.00	0.75	0.87	53	24.20	1.00	0.670	0.00	0.90	0.60
5	5.40	-6.00	0.630	0.00	0.00	0.88	54	14.80	5.40	0.150	0.00	3.25	0.84
6	7.00	-5.60	0.580	0.00	0.00	0.91	55	17.20	4.20	0.300	0.00	0.25	0.81
7	7.20	-4.40	0.380	0.00	0.00	0.90	56	20.60	6.00	0.740	0.00	5.75	0.61
8	5.40	-1.00	0.000	0.00	0.25	0.93	57	20.40	9.20	0.560	0.28	4.25	0.65
9	7.20	-2.60	0.870	0.00	2.25	0.68	58	17.40	9.00	0.530	0.00	4.15	0.63
10	9.20	-4.60	0.890	0.00	0.00	0.80	59	16.00	2.50	0.550	0.04	2.15	0.69
11	10.60	-4.00	0.760	0.00	0.00	0.86	60	20.80	1.40	0.880	0.00	3.00	0.57
12	11.80	-3.20	0.730	0.00	0.90	0.86	61	19.00	7.00	0.560	0.31	3.75	0.60
13	11.40	3.60	0.380	0.00	0.65	0.89	62	17.40	3.80	0.670	0.00	2.15	0.49
14	11.40	-2.40	0.550	0.00	2.00	0.78	63	16.40	4.00	0.380	0.00	1.40	0.68
15	11.80	-4.00	0.880	0.00	0.00	0.66	64	11.00	7.40	0.000	0.35	2.45	0.80
16	13.00	-3.60	0.890	0.00	0.00	0.68	65	11.80	7.00	0.000	0.00	2.25	0.71
17	15.20	-3.60	0.880	0.00	0.25	0.77	66	12.20	6.00	0.150	0.00	1.65	0.77
18	14.60	-2.80	0.740	0.00	0.00	0.77	67	15.60	2.00	0.700	0.00	0.50	0.77
19	13.40	-1.40	0.670	0.00	0.25	0.74	68	16.60	-0.60	0.380	0.00	1.75	0.78
20	11.40	-4.30	0.800	0.00	0.25	0.80	69	17.20	3.80	0.460	0.00	1.50	0.71
21	10.80	-4.20	0.690	0.00	0.25	0.83	70	11.20	6.00	0.000	0.86	1.25	0.89
22	9.00	-4.80	0.370	0.00	0.00	0.89	71	10.40	6.80	0.000	0.03	1.50	0.80
23	11.40	-4.60	0.630	0.00	0.00	0.84	72	13.00	5.00	0.220	0.00	0.00	0.79
24	7.40	-4.20	0.000	0.00	1.70	0.79	73	15.60	1.00	0.750	0.00	0.90	0.73
25	5.20	1.80	0.000	0.00	4.15	0.63	74	17.40	1.40	0.710	0.00	0.50	0.73
26	6.40	2.00	0.000	0.00	1.65	0.62	75	21.00	2.60	0.790	0.00	1.40	0.70
27	9.20	2.00	0.220	0.00	1.15	0.68	76	20.60	2.80	0.850	0.00	1.45	0.75
28	6.60	2.80	0.000	0.00	0.50	0.74	77	20.20	4.20	0.670	0.00	1.40	0.80
29	9.20	2.40	0.230	0.00	0.90	0.66	78	20.40	6.60	0.500	0.00	2.00	0.85
30	9.20	-1.00	0.470	0.00	1.40	0.68	79	20.20	7.60	0.500	0.00	1.65	0.81
31	11.40	-6.60	0.670	0.00	0.00	0.71	80	15.00	5.40	0.040	0.03	2.15	0.85
32	12.60	-2.80	0.770	0.00	1.15	0.71	81	18.00	5.00	0.280	0.00	0.75	0.84
33	12.20	-3.60	0.810	0.00	0.25	0.75	82	15.20	7.60	0.000	0.26	0.25	0.91
34	14.40	-5.20	0.790	0.00	0.00	0.71	83	13.20	10.80	0.000	1.65	2.65	0.87
35	14.60	-4.40	0.770	0.00	0.00	0.73	84	12.00	10.20	0.000	0.00	2.75	0.79
36	15.40	-3.40	0.700	0.00	0.00	0.75	85	19.60	4.00	0.840	0.00	0.90	0.78
37	14.20	2.60	0.640	0.00	1.75	0.65	86	18.80	4.40	0.920	0.00	1.40	0.61
38	12.20	3.60	0.450	0.00	1.75	0.63	87	20.00	2.00	0.830	0.00	1.75	0.72
39	8.80	-3.60	0.000	0.00	1.65	0.76	88	21.40	3.20	0.880	0.00	0.25	0.76
40	12.40	5.00	0.490	0.00	2.50	0.61	89	24.40	5.00	0.840	0.00	0.40	0.68
41	10.00	-0.60	0.000	0.00	0.40	0.73	90	26.00	6.40	0.820	0.00	0.50	0.65
42	7.60	0.00	0.750	0.08	5.40	0.57	91	26.20	6.40	0.840	0.00	0.00	0.62
43	10.20	-7.60	0.850	0.00	0.00	0.66	92	24.00	7.00	0.750	0.00	2.00	0.52
44	13.40	-8.40	0.850	0.00	0.00	0.64	93	22.80	5.60	0.750	0.00	0.75	0.62
45	8.80	-1.60	0.000	0.14	1.50	0.75	94	22.40	9.80	0.800	0.00	1.75	0.73
46	7.80	2.40	0.000	0.00	1.90	0.86	95	25.20	8.40	0.560	0.00	1.65	0.77
47	10.40	2.60	0.480	0.00	0.00	0.84	96	28.00	9.20	0.680	0.00	1.15	0.55
48	12.60	-0.80	0.130	0.00	0.75	0.74	97	23.80	7.00	0.950	0.00	1.95	0.40
49	12.40	5.80	0.320	0.00	0.00	0.69	98	23.00	4.00	0.860	0.00	1.25	0.55

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
99	22.40	4.80	0.710	0.00	1.15	0.58
100	23.40	4.80	0.910	0.00	1.50	0.57
101	21.20	4.40	0.470	0.00	1.00	0.64
102	19.00	7.80	0.160	0.00	0.40	0.66
103	20.60	6.00	0.630	0.00	2.15	0.72
104	18.40	9.00	0.440	1.10	1.50	0.83
105	17.00	3.00	0.330	0.00	1.65	0.76
106	22.00	3.20	0.590	0.00	3.15	0.65
107	23.20	5.00	0.940	0.00	1.00	0.63
108	26.40	6.50	0.820	0.00	0.75	0.61
109	25.00	8.80	0.710	0.00	1.50	0.68
110	23.20	7.20	0.640	0.00	1.50	0.67
111	22.40	8.00	0.560	0.00	0.75	0.64
112	23.40	6.00	0.650	0.00	0.65	0.57
113	24.00	8.40	0.650	0.00	0.50	0.66
114	24.80	9.80	0.920	0.00	1.25	0.50
115	23.20	4.80	0.700	0.00	2.00	0.60
116	25.60	7.00	0.880	0.00	1.15	0.66
117	25.20	8.20	0.700	0.00	1.75	0.59
118	22.80	10.60	0.280	0.00	2.40	0.72
119	24.80	7.40	0.720	0.00	1.65	0.66
120	19.40	7.00	0.340	0.00	3.90	0.58
121	21.40	6.40	0.650	0.00	2.40	0.62
122	22.00	6.00	0.580	0.00	1.51	0.63
123	20.00	6.20	0.450	0.00	2.90	0.67
124	18.20	11.60	0.050	0.15	1.75	0.78
125	19.60	10.00	0.330	0.09	1.40	0.79
126	23.60	8.40	0.700	0.00	0.50	0.70
127	22.40	9.00	0.400	0.00	1.90	0.73
128	20.80	5.20	0.700	0.00	0.90	0.64
129	23.00	4.40	0.920	0.00	1.75	0.51
130	25.40	8.60	0.780	0.00	1.70	0.56
131	29.00	7.00	0.900	0.00	1.50	0.56
132	30.60	8.80	0.800	0.00	1.30	0.56
133	31.00	14.20	0.500	0.00	1.90	0.61
134	34.20	14.00	0.390	0.00	1.75	0.57
135	35.20	14.80	0.900	0.00	2.25	0.47
136	28.80	11.60	0.750	0.00	4.90	0.56
137	25.80	17.60	0.480	0.00	2.90	0.55
138	25.40	16.20	0.410	0.00	2.50	0.56
139	23.80	13.20	0.170	0.00	2.15	0.58
140	27.20	11.00	0.680	0.00	1.75	0.57
141	29.20	12.00	0.700	1.53	1.40	0.66
142	23.80	14.00	0.320	0.41	1.65	0.78
143	17.20	13.20	0.010	0.41	2.05	0.88
144	17.60	11.60	0.110	0.23	0.90	0.79
145	19.80	8.60	0.390	0.12	1.40	0.70
146	21.00	5.00	0.530	0.00	1.50	0.66
147	22.40	6.80	0.600	0.00	2.25	0.67
148	23.00	9.20	0.610	0.00	1.45	0.65
149	26.60	9.60	0.750	0.00	1.75	0.60
150	29.80	10.00	0.840	0.00	2.00	0.54
151	28.80	13.20	0.570	0.00	2.25	0.63
152	26.40	16.20	0.513	1.42	2.81	0.77
153	27.80	18.00	0.440	0.30	0.75	0.67
154	29.80	12.20	0.893	0.00	1.63	0.53
155	29.40	15.00	0.747	0.00	1.88	0.66
156	28.20	17.40	0.447	0.00	3.75	0.64
157	26.00	15.00	0.393	0.02	1.50	0.68
158	29.00	15.60	0.887	0.00	4.25	0.42
159	30.00	11.40	0.893	0.00	1.88	0.40
160	29.80	13.80	0.800	0.00	1.44	0.43
161	29.20	17.60	0.860	0.00	2.13	0.39
162	28.00	14.20	0.813	0.00	2.75	0.37
163	24.80	18.00	0.000	0.10	1.38	0.55
164	24.00	14.80	0.300	0.20	0.50	0.80
165	26.40	13.20	0.500	0.19	0.50	0.73
166	29.00	11.00	0.773	0.00	2.00	0.58
167	28.00	18.20	0.687	0.00	3.75	0.36
168	28.40	17.20	0.447	0.00	2.25	0.53
169	25.20	9.50	0.673	0.00	2.38	0.47
170	28.80	11.00	0.840	0.00	2.00	0.47
171	30.20	11.80	0.773	0.00	1.88	0.51
172	30.80	13.20	0.573	0.00	1.81	0.51
173	21.80	15.20	0.767	0.00	1.88	0.44
174	34.20	13.40	0.780	0.00	2.00	0.43
175	33.60	14.80	0.533	0.00	1.50	0.46
176	32.80	15.20	0.860	0.00	2.69	0.52
177	31.00	17.20	0.473	0.16	1.69	0.58
178	30.00	13.20	0.433	1.11	1.00	0.68
179	34.00	18.20	0.646	0.00	1.31	0.54
180	34.40	17.40	0.840	0.00	1.38	0.48
181	34.00	17.00	0.793	0.00	1.62	0.50

B.4 Thessaloniki 1987

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
91	13.00	6.00	0.000	2.68	4.63	0.84
92	15.00	5.00	0.377	0.44	0.88	0.75
93	16.00	4.00	0.887	0.00	2.06	0.62
94	18.00	5.00	0.780	0.00	1.69	0.69
95	15.00	6.00	0.079	0.00	0.94	0.80
96	22.00	6.00	0.395	0.00	0.94	0.81
97	22.00	10.00	0.867	0.00	2.75	0.68
98	18.00	7.00	0.880	0.00	2.25	0.70
99	20.00	9.00	0.736	0.00	1.56	0.74
100	20.00	9.00	0.640	0.00	2.44	0.84
101	17.00	12.00	0.054	0.36	3.94	0.79
102	18.00	9.00	0.705	0.00	1.81	0.51
103	16.00	10.00	0.039	0.12	1.25	0.79
104	11.00	8.50	0.000	0.05	0.44	0.81
105	16.00	5.00	0.253	0.04	1.38	0.79
106	17.00	7.50	0.421	0.21	1.94	0.73
107	19.00	6.00	0.458	0.00	2.44	0.68
108	21.00	6.00	0.783	0.00	2.25	0.64
109	25.00	9.00	0.879	0.00	4.06	0.54
110	20.00	8.00	0.733	0.00	1.69	0.78
111	17.00	9.00	0.474	0.00	1.69	0.74
112	19.00	15.00	0.450	0.19	5.00	0.63
113	18.00	11.00	0.022	0.35	4.19	0.76
114	15.00	10.00	0.381	0.55	1.25	0.75
115	14.00	12.00	0.744	0.00	2.50	0.70
116	20.00	14.00	0.719	0.00	1.81	0.71
117	24.00	18.00	0.495	0.38	3.25	0.77
118	11.00	6.00	0.000	1.46	4.38	0.86
119	19.00	4.00	0.801	0.00	2.81	0.52
120	20.00	6.00	0.381	0.00	4.69	0.50
121	20.00	9.00	0.183	0.01	1.94	0.69
122	18.00	11.00	0.372	0.05	1.94	0.74
123	20.00	9.00	0.618	0.00	1.56	0.78
124	20.00	10.00	0.478	0.00	1.94	0.85
125	21.00	11.00	0.282	0.00	2.06	0.84
126	20.00	13.00	0.404	0.37	2.00	0.80
127	18.00	9.00	0.575	0.00	2.75	0.56
128	19.00	9.00	0.732	0.05	9.31	0.52
129	19.00	10.00	0.766	0.00	8.44	0.43
130	21.00	8.00	0.828	0.00	2.69	0.49
131	20.00	6.00	0.733	0.00	1.88	0.64
132	21.50	10.00	0.639	0.00	1.81	0.73
133	21.00	9.00	0.709	0.00	2.69	0.82
134	23.00	10.00	0.707	0.06	1.88	0.75
135	22.00	11.50	0.282	0.02	1.94	0.78
136	22.00	13.00	0.739	0.50	1.63	0.77
137	27.00	13.00	0.723	0.00	2.25	0.69
138	27.00	15.00	0.596	0.00	1.44	0.67
139	28.00	14.00	0.797	0.00	1.88	0.63
140	29.00	13.00	0.837	0.00	1.63	0.57
141	22.00	13.00	0.348	1.06	2.31	0.68
142	23.00	11.00	0.820	0.00	5.81	0.46
143	24.50	10.00	0.881	0.00	2.19	0.53
144	26.00	13.00	0.858	0.00	3.44	0.49
145	26.00	14.00	0.228	0.16	1.06	0.69
146	25.50	14.00	0.448	0.00	2.06	0.72
147	25.00	12.00	0.799	0.00	2.44	0.69
148	23.00	12.00	0.770	0.00	1.94	0.74
149	24.00	13.00	0.302	0.00	1.94	0.69
150	22.00	14.00	0.000	0.01	2.31	0.70
151	21.00	14.00	0.000	0.78	4.31	0.74
152	24.00	14.00	0.349	0.00	3.94	0.57
153	25.00	12.00	0.362	0.00	3.19	0.56
154	26.00	13.00	0.729	0.00	1.81	0.64
155	26.00	12.00	0.762	0.00	2.00	0.64
156	26.00	15.00	0.632	0.00	1.56	0.68
157	28.00	16.00	0.876	0.00	4.63	0.48
158	29.00	13.00	0.909	0.00	2.13	0.51
159	28.00	14.00	0.888	0.00	2.81	0.57
160	29.00	15.00	0.847	0.00	2.06	0.58
161	29.00	16.00	0.751	0.00	1.19	0.60
162	35.00	17.00	0.778	0.00	1.94	0.56
163	34.00	19.00	0.851	0.00	2.94	0.56
164	32.00	18.00	0.810	0.00	2.19	0.61
165	31.00	19.00	0.810	0.00	2.22	0.61
166	32.50	19.50	0.688	0.00	1.50	0.61
167	33.00	20.00	0.762	0.00	2.38	0.63
168	32.00	17.00	0.856	0.00	6.25	0.32
169	26.00	18.00	0.438	0.00	4.44	0.56
170	26.00	13.00	0.829	1.03	3.00	0.65
171	27.00	17.00	0.121	0.04	2.00	0.64
172	25.00	15.00	0.701	0.76	4.94	0.69
173	28.00	15.50	0.802	2.60	4.25	0.62
174	27.00	16.00	0.754	0.00	3.56	0.55
175	28.00	14.80	0.808	0.00	3.38	0.57
176	29.50	14.80	0.761	0.00	2.06	0.63
177	30.00	18.00	0.661	0.00	2.25	0.63
178	28.00	17.00	0.499	0.00	2.50	0.66
179	29.00	19.00	0.182	0.04	1.75	0.70
180	32.00	19.40	0.790	0.00	2.06	0.57
181	33.00	19.00	0.750	0.00	1.69	0.56
182	31.00	20.00	0.757	0.00	2.38	0.56
183	31.00	17.00	0.859	0.00	2.38	0.55
184	33.00	19.00	0.697	0.00	2.50	0.52
185	31.00	19.00	0.169	0.69	1.25	0.69
186	31.00	19.00	0.766	0.00	3.75	0.63
187	28.00	20.00	0.516	0.27	3.25	0.62
188	29.00	16.00	0.672	0.09	2.81	0.64

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
189	25.00	17.00	0.646	0.00	3.31	0.61
190	26.00	14.00	0.831	0.00	2.31	0.62
191	30.00	15.00	0.777	0.00	1.88	0.66
192	32.00	20.00	0.403	0.00	2.56	0.55
193	32.00	20.00	0.704	0.00	2.25	0.59
194	30.00	17.50	0.835	0.00	2.13	0.60
195	32.00	18.50	0.781	0.00	2.19	0.61
196	35.00	20.50	0.714	0.00	2.63	0.58
197	30.00	22.00	0.729	0.00	2.00	0.58
198	34.00	18.00	0.771	0.00	2.56	0.59
199	33.00	20.50	0.780	0.00	2.94	0.60
200	32.00	21.00	0.829	0.00	2.06	0.59
201	35.00	21.00	0.810	0.00	1.56	0.55
202	34.00	20.00	0.770	0.00	2.56	0.54
203	38.00	20.00	0.771	0.00	2.44	0.54
204	38.00	21.00	0.780	0.00	1.94	0.50
205	37.00	22.00	0.830	0.00	1.81	0.54
206	35.00	21.00	0.790	0.00	2.19	0.55
207	36.00	21.00	0.799	0.00	1.94	0.59
208	34.00	20.00	0.793	0.00	2.88	0.57
209	32.50	20.00	0.647	0.00	3.94	0.55
210	32.00	19.00	0.762	0.00	4.19	0.49
211	28.00	17.00	0.636	0.03	2.25	0.59
212	28.00	17.00	0.779	0.16	3.00	0.63
213	27.00	17.00	0.391	0.27	2.63	0.72
214	32.00	17.00	0.869	0.00	4.81	0.46
215	30.00	16.00	0.864	0.00	2.00	0.56
216	30.00	17.00	0.859	0.00	2.19	0.57
217	29.00	17.00	0.875	0.00	2.56	0.49
218	30.00	17.00	0.892	0.00	4.75	0.46
219	29.00	18.00	0.757	0.00	1.88	0.57
220	30.00	18.00	0.839	0.00	2.13	0.61
221	32.00	18.00	0.841	0.00	1.56	0.58
222	30.00	18.00	0.843	0.00	1.88	0.61
223	34.00	20.00	0.787	0.00	2.06	0.60
224	33.00	19.50	0.738	0.00	4.75	0.57
225	30.00	17.00	0.814	0.15	3.00	0.63
226	28.00	18.00	0.838	1.21	2.81	0.59
227	28.00	18.00	0.833	0.00	2.38	0.67
228	27.00	16.00	0.732	0.00	8.56	0.49
229	29.00	19.00	0.883	0.00	5.25	0.41
230	29.00	16.00	0.855	0.00	2.63	0.55
231	28.00	15.00	0.821	0.00	2.38	0.68
232	30.00	16.00	0.674	0.00	4.44	0.61
233	29.00	16.00	0.563	1.36	4.25	0.65
234	27.00	16.00	0.806	0.55	1.50	0.70
235	29.00	16.00	0.801	0.00	2.44	0.69
236	29.00	15.00	0.849	0.00	1.50	0.70
237	29.00	15.00	0.813	0.00	1.56	0.72
238	28.00	17.50	0.793	0.00	2.44	0.68
239	29.00	22.00	0.811	0.00	2.25	0.68
240	28.00	16.00	0.767	0.00	1.50	0.67
241	29.00	17.00	0.146	0.00	5.13	0.57
242	29.00	17.00	0.842	0.00	4.81	0.45
243	30.00	17.50	0.829	0.00	2.25	0.61
244	31.00	16.00	0.832	0.00	2.19	0.62
245	28.00	13.00	0.780	0.00	2.19	0.68
246	27.00	15.50	0.493	0.00	2.06	0.69
247	28.00	16.00	0.699	0.00	1.81	0.69
248	29.00	16.00	0.749	0.00	1.75	0.61
249	27.00	15.00	0.617	0.00	1.88	0.64
250	26.00	15.00	0.563	0.00	2.31	0.71
251	27.00	16.00	0.693	0.00	2.06	0.66
252	31.00	16.00	0.703	0.00	2.31	0.65
253	31.00	14.00	0.625	0.00	2.31	0.66
254	28.00	15.00	0.410	0.00	1.81	0.71
255	30.00	16.00	0.565	0.00	1.63	0.70
256	32.00	16.00	0.713	0.00	1.94	0.63
257	34.50	15.00	0.781	0.00	1.75	0.55
258	36.00	15.00	0.775	0.00	2.06	0.46
259	38.00	16.00	0.729	0.00	2.25	0.43
260	35.00	16.00	0.691	0.00	2.63	0.58
261	27.00	15.00	0.586	0.00	2.13	0.71
262	32.00	14.00	0.530	0.00	2.00	0.68
263	32.00	15.00	0.731	0.00	1.13	0.58
264	35.00	16.00	0.742	0.00	2.38	0.59
265	27.00	18.00	0.653	0.00	3.00	0.55
266	25.00	14.00	0.370	0.00	1.81	0.65
267	26.50	15.00	0.278	0.00	1.63	0.77
268	27.00	16.00	0.483	0.00	2.69	0.79
269	29.00	16.00	0.714	0.00	1.81	0.80
270	29.00	18.50	0.512	0.00	1.63	0.81
271	28.00	15.00	0.120	0.00	2.19	0.75
272	20.00	14.00	0.129	0.00	3.50	0.69
273	16.50	14.00	0.000	1.21	5.38	0.81

B.5 Thessaloniki 1988

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
91	18.40	6.80	0.347	0.00	1.20	0.76
92	18.80	4.40	0.692	0.00	1.90	0.60
93	17.80	4.40	0.180	0.00	1.90	0.69
94	17.20	9.60	0.078	0.00	1.10	0.82
95	19.40	9.20	0.545	0.00	1.00	0.77
96	15.60	9.00	0.054	0.00	1.10	0.86
97	16.40	8.40	0.147	0.00	1.40	0.86
98	18.90	6.60	0.427	0.00	1.40	0.86
99	22.80	5.60	0.706	0.00	1.80	0.69
100	21.60	6.00	0.757	0.00	1.70	0.74
101	15.90	9.60	0.008	0.90	2.50	0.82
102	18.40	10.40	0.668	0.00	2.00	0.76
103	20.20	5.40	0.537	0.00	2.30	0.68
104	12.40	9.60	0.000	4.80	5.90	0.71
105	11.00	5.20	0.842	0.00	13.30	0.37
106	10.40	3.40	0.697	0.00	3.80	0.49
107	10.40	1.00	0.351	0.00	2.10	0.73
108	12.60	3.40	0.082	0.00	4.40	0.68
109	17.00	3.00	0.840	0.00	1.90	0.64
110	16.80	6.00	0.616	0.00	2.10	0.74
111	19.40	5.80	0.821	0.00	1.40	0.72
112	24.00	6.60	0.819	0.00	2.30	0.62
113	24.00	11.20	0.817	0.00	2.30	0.58
114	24.20	9.40	0.602	0.00	2.10	0.69
115	22.00	10.40	0.527	0.00	1.60	0.77
116	18.00	14.00	0.066	2.90	1.30	0.84
117	19.00	12.60	0.022	0.00	1.30	0.81
118	16.20	9.20	0.000	0.00	0.70	0.79
119	15.00	9.00	0.579	3.60	1.30	0.88
120	14.60	12.20	0.000	4.00	1.20	0.84
121	16.40	10.40	0.662	0.00	2.10	0.64
122	18.40	7.20	0.819	0.00	2.20	0.70
123	21.00	5.40	0.666	0.00	2.20	0.63
124	22.00	7.40	0.500	0.00	1.40	0.67
125	18.80	10.80	0.086	0.00	1.10	0.82
126	29.00	12.00	0.533	0.00	1.40	0.70
127	26.60	14.20	0.844	0.00	3.90	0.54
128	25.60	12.80	0.665	0.00	1.70	0.62
129	23.00	14.20	0.317	0.00	1.90	0.63
130	24.80	10.40	0.485	0.00	2.10	0.65
131	25.60	10.40	0.652	0.00	2.00	0.64
132	23.20	13.60	0.273	0.00	1.40	0.76
133	20.60	15.00	0.007	0.00	1.60	0.77
134	20.60	13.00	0.042	0.00	1.80	0.76
135	23.40	13.40	0.403	0.00	1.30	0.76
136	25.00	12.20	0.735	0.00	2.70	0.72
137	26.00	14.80	0.776	0.00	2.10	0.69
138	28.00	12.60	0.795	0.00	1.90	0.64
139	29.00	13.00	0.836	0.00	2.30	0.61
140	28.00	13.60	0.600	0.00	1.60	0.67
141	29.00	13.20	0.703	4.20	2.90	0.63
142	26.00	12.60	0.736	0.00	2.60	0.59
143	24.20	15.00	0.543	0.00	3.80	0.54
144	23.60	11.60	0.782	0.00	2.40	0.59
145	24.40	11.40	0.418	8.20	1.60	0.75
146	24.60	14.80	0.246	3.40	1.50	0.77
147	26.00	12.00	0.752	0.00	2.10	0.67
148	26.40	14.80	0.744	0.00	2.60	0.71
149	26.80	15.20	0.538	20.50	1.00	0.74
150	27.40	12.60	0.844	0.00	1.70	0.59
151	28.60	14.40	0.898	0.00	2.20	0.58
152	23.60	14.80	0.102	0.00	2.00	0.77
153	23.00	17.20	0.529	4.60	8.00	0.62
154	23.40	17.00	0.799	0.00	10.60	0.43
155	27.80	13.40	0.929	0.00	3.30	0.47
156	28.20	13.40	0.567	0.00	1.80	0.60
157	29.00	16.40	0.560	0.00	2.00	0.64
158	30.00	15.80	0.808	0.00	2.60	0.65
159	28.70	15.40	0.546	0.00	2.00	0.60
160	30.20	20.00	0.383	0.00	2.10	0.56
161	31.00	14.40	0.550	0.00	2.00	0.57
162	31.00	17.40	0.797	0.00	1.30	0.59
163	33.20	18.00	0.596	1.30	2.50	0.57
164	29.00	18.00	0.515	1.00	2.30	0.67
165	31.40	17.00	0.808	0.00	2.00	0.49
166	31.00	16.80	0.693	0.00	1.40	0.53
167	30.60	19.60	0.874	0.00	4.20	0.43
168	31.00	18.20	0.354	0.00	1.70	0.55
169	31.00	20.00	0.715	0.00	1.90	0.55
170	30.00	18.40	0.535	0.00	3.20	0.61
171	27.60	17.00	0.629	2.80	2.40	0.63
172	28.60	15.20	0.401	0.00	3.90	0.54
173	27.60	17.60	0.797	0.00	3.90	0.43
174	29.00	19.80	0.818	0.00	3.10	0.45
175	29.00	15.60	0.584	0.00	2.20	0.40
176	28.60	19.60	0.329	1.40	2.40	0.66
177	28.60	17.60	0.450	0.00	2.30	0.76
178	31.40	18.00	0.759	0.00	2.40	0.65
179	30.40	20.00	0.679	0.00	1.40	0.66
180	33.80	19.20	0.693	0.00	2.30	0.60
181	32.60	22.80	0.882	0.00	3.90	0.47
182	34.80	19.00	0.863	0.00	3.00	0.45
183	34.40	21.80	0.688	0.00	2.40	0.67
184	36.00	20.00	0.796	0.00	2.10	0.63
185	36.20	20.60	0.804	0.00	2.20	0.58
186	38.60	22.60	0.824	0.00	2.10	0.62
187	38.00	23.00	0.690	0.00	2.60	0.61
188	42.00	23.60	0.690	0.00	1.50	0.62

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
189	39.80	24.20	0.711	0.00	1.80	0.59
190	36.60	24.40	0.752	0.00	2.60	0.62
191	33.20	25.00	0.827	0.00	7.80	0.67
192	30.60	23.20	0.889	0.00	7.90	0.71
193	31.40	18.60	0.889	0.00	2.70	0.69
194	32.40	18.00	0.707	0.00	2.30	0.67
195	34.60	18.60	0.823	0.00	2.00	0.66
196	35.60	19.80	0.816	0.00	2.20	0.66
197	35.60	20.60	0.845	0.00	2.90	0.64
198	33.00	21.00	0.854	0.00	4.20	0.66
199	31.00	23.00	0.671	0.00	3.60	0.66
200	32.00	23.20	0.714	0.00	2.40	0.62
201	32.40	19.60	0.757	0.00	2.70	0.62
202	32.40	22.20	0.793	0.00	3.60	0.67
203	31.00	19.00	0.843	0.00	3.10	0.63
204	33.40	20.00	0.824	0.00	2.10	0.62
205	34.40	21.20	0.840	0.00	4.90	0.61
206	34.20	21.60	0.779	0.00	1.90	0.60
207	32.40	23.80	0.509	0.00	2.60	0.56
208	32.00	23.00	0.510	0.00	2.00	0.63
209	34.20	21.00	0.798	0.00	2.50	0.62
210	33.80	21.60	0.821	0.00	2.30	0.62
211	33.20	21.40	0.830	0.00	2.40	0.62
212	32.20	21.00	0.663	32.20	3.30	0.63
213	31.40	24.00	0.594	0.00	1.80	0.61
214	32.00	22.00	0.772	0.00	2.30	0.59
215	33.60	20.80	0.774	0.00	1.90	0.61
216	34.80	20.20	0.704	0.00	2.20	0.61
217	34.20	20.80	0.792	0.00	2.30	0.62
218	33.20	20.00	0.680	0.00	2.30	0.62
219	29.80	23.00	0.158	0.00	1.80	0.62
220	29.00	23.40	0.582	0.00	2.10	0.62
221	30.40	18.40	0.683	0.00	2.70	0.61
222	31.00	18.80	0.771	0.00	2.40	0.63
223	33.40	18.80	0.774	0.00	2.30	0.63
224	32.40	20.00	0.768	0.00	2.10	0.60
225	32.80	20.00	0.756	0.00	1.80	0.61
226	33.60	19.40	0.860	0.00	1.60	0.60
227	34.40	20.00	0.788	0.00	2.00	0.61
228	35.00	21.20	0.630	0.00	2.70	0.61
229	32.20	21.40	0.653	1.70	2.30	0.61
230	33.20	21.60	0.655	0.00	2.80	0.64
231	30.40	21.00	0.657	0.00	1.80	0.61
232	30.40	20.00	0.733	0.00	2.30	0.61
233	30.40	18.60	0.750	0.00	2.60	0.63
234	33.60	20.00	0.752	0.00	1.50	0.61
235	33.20	20.00	0.456	0.00	1.90	0.63
236	30.80	22.00	0.869	0.00	6.40	0.71
237	30.00	17.60	0.766	0.00	1.10	0.63
238	31.40	18.20	0.851	0.00	2.40	0.64
239	29.40	19.80	0.870	0.00	5.80	0.70
240	29.00	20.60	0.864	0.00	3.40	0.70
241	30.00	15.40	0.866	0.00	2.10	0.66
242	32.40	15.60	0.823	0.00	2.00	0.66
243	32.00	18.00	0.795	0.00	1.60	0.62
244	32.60	19.00	0.790	0.00	2.20	0.61
245	30.40	18.40	0.646	0.00	4.30	0.62
246	34.40	18.00	0.779	0.00	2.30	0.61
247	30.40	18.20	0.851	0.00	2.10	0.69
248	30.20	17.40	0.815	0.00	2.30	0.68
249	31.80	17.00	0.747	0.00	2.40	0.67
250	29.60	20.00	0.515	1.10	11.90	0.66
251	23.20	17.40	0.767	0.00	11.50	0.65
252	25.40	18.00	0.801	0.00	6.00	0.69
253	26.00	13.40	0.788	0.00	2.00	0.69
254	27.20	14.60	0.822	0.00	2.10	0.70
255	26.20	14.00	0.793	0.00	2.00	0.65
256	27.00	14.00	0.771	0.00	2.30	0.62
257	29.00	14.00	0.686	0.00	1.70	0.62
258	30.40	15.40	0.616	0.00	2.30	0.62
259	30.00	20.20	0.650	0.00	1.90	0.54
260	27.40	18.20	0.338	0.00	2.50	0.62
261	29.00	16.00	0.800	0.00	2.20	0.64
262	26.20	18.60	0.430	0.00	4.50	0.65
263	26.60	14.20	0.692	0.00	1.40	0.62
264	25.00	15.40	0.253	0.00	1.20	0.60
265	24.80	17.20	0.057	1.00	2.60	0.53
266	27.20	15.80	0.584	1.00	1.80	0.54
267	26.60	18.20	0.677	0.00	2.40	0.62
268	27.60	15.40	0.696	0.00	2.10	0.60
269	28.00	14.20	0.707	0.00	2.50	0.58
270	27.00	13.80	0.776	0.00	1.30	0.64
271	25.00	16.40	0.410	0.00	1.30	0.61
272	25.40	15.40	0.673	0.00	1.60	0.63
273	24.60	15.00	0.717	0.00	1.90	0.63

B.6 Aliartos 1988

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
91	22.00	13.00	0.813	0.00	9.50	0.42
92	19.20	5.00	0.810	0.00	3.30	0.46
93	18.40	4.40	0.125	0.00	0.00	0.57
94	19.40	8.20	0.187	0.00	4.30	0.49
95	24.00	8.00	0.541	0.00	5.50	0.52
96	19.80	11.00	0.031	0.00	1.00	0.65
97	18.40	11.20	0.093	0.00	1.60	0.77
98	24.00	9.00	0.524	0.00	1.60	0.69
99	25.80	10.00	0.721	0.00	2.60	0.47
100	25.80	6.00	0.757	0.00	0.40	0.46
101	20.40	7.80	0.412	0.00	3.50	0.61
102	18.20	9.80	0.684	0.00	2.00	0.58
103	23.00	4.80	0.696	0.00	0.50	0.46
104	20.60	13.00	0.189	0.00	4.30	0.66
105	14.40	6.80	0.594	4.20	4.80	0.41
106	6.80	4.80	0.090	5.60	1.50	0.78
107	11.20	2.00	0.179	2.80	1.40	0.67
108	13.60	3.00	0.477	5.90	1.40	0.59
109	14.80	6.40	0.201	0.00	0.80	0.72
110	16.40	7.00	0.438	0.00	1.80	0.63
111	19.20	4.00	0.451	0.00	1.00	0.63
112	23.50	6.00	0.679	0.00	2.40	0.55
113	24.00	7.60	0.633	0.00	0.40	0.56
114	24.00	6.40	0.587	0.00	3.50	0.49
115	24.80	9.80	0.827	0.00	3.00	0.40
116	21.80	14.00	0.438	0.00	1.50	0.67
117	18.00	11.40	0.131	0.00	4.00	0.72
118	17.00	8.60	0.109	0.00	5.60	0.68
119	19.80	9.00	0.427	2.80	2.00	0.74
120	15.00	11.40	0.000	1.90	3.00	0.79
121	15.00	10.80	0.461	0.00	3.60	0.61
122	17.20	4.00	0.804	0.00	4.30	0.48
123	23.60	3.00	0.867	0.00	2.30	0.37
124	27.80	7.00	0.786	0.00	2.60	0.42
125	31.40	10.80	0.527	0.00	1.00	0.45
126	35.80	13.00	0.718	0.00	2.40	0.30
127	27.00	17.40	0.844	0.00	3.60	0.44
128	27.00	12.00	0.735	0.00	1.60	0.49
129	26.00	12.00	0.494	0.00	5.40	0.47
130	20.00	13.00	0.753	0.00	2.80	0.51
131	27.20	11.20	0.596	0.00	5.00	0.55
132	28.00	15.20	0.448	0.00	5.00	0.49
133	21.80	15.40	0.091	0.00	4.30	0.73
134	22.00	12.80	0.209	0.00	1.50	0.71
135	26.00	13.60	0.583	0.00	1.20	0.65
136	28.00	14.00	0.694	0.00	1.40	0.51
137	28.20	13.00	0.838	0.00	3.00	0.41
138	30.60	12.40	0.885	0.00	2.40	0.35
139	29.00	12.20	0.905	0.00	2.10	0.41
140	30.20	13.20	0.890	0.00	1.50	0.43
141	29.40	13.00	0.902	0.00	3.50	0.35
142	27.40	12.40	0.839	0.00	1.00	0.40
143	26.00	12.60	0.605	0.00	1.00	0.46
144	23.00	11.20	0.405	0.00	2.80	0.57
145	16.40	15.20	0.000	9.20	2.00	0.90
146	24.00	14.00	0.520	0.00	3.60	0.63
147	27.60	12.00	0.649	0.00	2.00	0.50
148	28.90	12.00	0.771	0.00	3.00	0.47
149	29.80	13.00	0.723	0.00	1.60	0.43
150	28.80	12.60	0.878	0.00	1.90	0.44
151	30.80	13.60	0.918	0.00	2.50	0.43
152	30.20	15.40	0.109	0.00	1.50	0.44
153	28.20	16.40	0.631	0.00	3.30	0.55
154	26.20	14.20	0.853	0.00	2.80	0.36
155	29.40	12.60	0.893	0.00	1.00	0.40
156	25.60	14.00	0.594	0.00	2.50	0.40
157	29.40	14.00	0.304	0.00	1.80	0.38
158	33.00	14.20	0.835	0.00	4.00	0.37
159	32.60	16.00	0.343	0.00	2.40	0.34
160	30.00	19.60	0.054	0.00	1.60	0.51
161	30.90	17.00	0.235	0.00	1.80	0.52
162	33.20	15.80	0.777	0.00	2.00	0.42
163	34.80	17.00	0.723	0.00	1.40	0.38
164	34.60	18.80	0.602	0.00	4.90	0.33
165	33.20	16.80	0.661	0.00	3.00	0.32
166	35.20	16.80	0.747	0.00	3.50	0.30
167	33.20	18.40	0.874	0.00	2.50	0.30
168	33.20	15.20	0.681	0.00	7.00	0.33
169	33.40	16.40	0.688	0.00	1.50	0.30
170	33.40	18.40	0.334	0.00	3.70	0.36
171	28.00	17.90	0.455	10.50	2.40	0.75
172	29.00	14.20	0.716	0.00	3.40	0.65
173	27.20	15.20	0.656	1.40	1.20	0.56
174	29.50	13.80	0.764	0.00	1.60	0.45
175	31.90	15.60	0.644	0.00	2.80	0.40
176	34.00	16.00	0.658	0.00	2.60	0.41
177	32.80	19.20	0.792	0.00	5.00	0.40
178	35.20	16.80	0.901	0.00	3.50	0.34
179	34.60	18.40	0.854	0.00	1.90	0.45
180	37.20	17.80	0.882	0.00	3.50	0.37
181	33.00	19.60	0.909	0.00	2.50	0.34
182	34.00	18.00	0.896	0.00	3.00	0.33
183	38.00	20.40	0.587	0.00	0.50	0.42
184	38.80	18.60	0.891	0.00	1.00	0.31
185	37.20	18.60	0.878	0.00	2.50	0.38
186	36.80	19.80	0.885	0.00	3.60	0.39
187	37.80	22.40	0.798	0.00	3.00	0.37
188	42.90	21.80	0.792	0.00	1.40	0.34

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
189	42.00	22.60	0.724	0.00	1.60	0.34
190	44.60	22.20	0.854	0.00	0.80	0.35
191	32.80	22.50	0.725	0.00	3.00	0.47
192	30.80	20.00	0.848	0.00	2.40	0.35
193	30.80	17.80	0.869	0.00	2.20	0.39
194	34.90	15.40	0.896	0.00	1.80	0.30
195	37.20	18.20	0.877	0.00	3.50	0.32
196	37.80	19.40	0.878	0.00	3.70	0.30
197	38.80	18.80	0.886	0.00	1.50	0.28
198	35.00	20.80	0.902	0.00	2.00	0.39
199	31.40	20.60	0.781	0.00	4.70	0.45
200	30.90	20.80	0.727	0.00	2.40	0.49
201	32.00	16.90	0.825	0.00	2.60	0.45
202	32.00	17.60	0.751	0.00	1.00	0.47
203	30.80	17.20	0.871	0.00	3.70	0.44
204	31.80	17.20	0.879	0.00	3.60	0.43
205	32.00	18.10	0.826	0.00	3.20	0.46
206	32.80	18.20	0.904	0.00	4.60	0.42
207	32.90	20.20	0.739	0.00	3.80	0.46
208	31.20	21.00	0.566	0.00	3.20	0.52
209	32.60	18.80	0.770	0.00	2.80	0.46
210	32.60	18.80	0.828	0.00	2.00	0.46
211	33.20	20.00	0.830	0.00	1.00	0.48
212	32.80	20.00	0.783	0.00	2.50	0.50
213	31.20	19.20	0.742	0.00	4.50	0.51
214	32.00	19.20	0.843	0.00	3.50	0.45
215	33.00	17.40	0.838	0.00	3.30	0.50
216	34.80	17.40	0.854	0.00	2.00	0.36
217	35.60	16.40	0.870	0.00	2.00	0.35
218	33.80	16.40	0.865	0.00	2.00	0.48
219	30.00	22.00	0.659	0.00	4.50	0.56
220	28.20	21.80	0.790	0.00	5.50	0.46
221	29.60	16.40	0.870	0.00	4.20	0.42
222	30.80	15.50	0.765	0.00	2.80	0.44
223	33.00	16.20	0.832	0.00	1.30	0.37
224	33.60	17.00	0.819	0.00	3.50	0.42
225	32.60	16.40	0.879	0.00	3.40	0.38
226	32.20	15.80	0.881	0.00	2.60	0.41
227	33.20	19.00	0.876	0.00	3.60	0.32
228	34.20	17.00	0.725	0.00	2.20	0.38
229	33.90	18.20	0.587	0.00	1.00	0.45
230	33.40	19.20	0.795	0.00	1.80	0.48
231	32.40	18.20	0.731	0.00	1.80	0.51
232	30.80	17.60	0.829	0.00	2.20	0.53
233	34.00	16.00	0.743	0.00	1.30	0.47
234	36.40	17.60	0.856	0.00	1.20	0.45
235	37.90	18.00	0.792	0.00	2.20	0.43
236	32.60	20.40	0.906	0.00	2.00	0.33
237	33.00	15.60	0.894	0.00	1.20	0.42
238	33.60	16.20	0.814	0.00	1.80	0.41
239	31.20	17.40	0.892	0.00	1.80	0.44
240	29.90	14.20	0.841	0.00	2.20	0.49
241	32.00	14.20	0.889	0.00	1.80	0.39
242	35.40	14.80	0.869	0.00	1.00	0.33
243	37.20	17.40	0.856	0.00	1.50	0.39
244	35.00	16.80	0.866	0.00	2.30	0.35
245	39.00	17.00	0.754	0.00	2.00	0.35
246	38.00	18.00	0.833	0.00	4.70	0.37
247	31.00	20.00	0.859	0.00	2.00	0.44
248	29.80	15.80	0.885	0.00	3.00	0.42
249	33.20	14.60	0.817	0.00	1.20	0.36
250	25.40	17.00	0.281	2.00	2.50	0.66
251	26.20	12.60	0.814	0.00	1.50	0.39
252	26.80	13.00	0.620	0.00	1.40	0.47
253	27.80	12.90	0.851	0.00	2.30	0.51
254	27.00	14.80	0.846	0.00	1.80	0.55
255	27.40	11.00	0.816	0.00	2.40	0.46
256	30.20	11.40	0.875	0.00	3.30	0.43
257	32.20	13.80	0.813	0.00	2.00	0.46
258	32.80	15.80	0.776	0.00	5.00	0.49
259	35.90	20.40	0.803	0.00	4.50	0.43
260	34.60	17.00	0.556	1.50	3.80	0.49
261	31.00	16.40	0.889	0.00	1.90	0.44
262	28.40	13.20	0.754	0.00	2.20	0.54
263	26.60	16.80	0.448	0.00	1.80	0.61
264	27.40	13.80	0.703	0.00	1.80	0.54
265	25.20	15.00	0.369	5.70	3.70	0.76
266	25.40	15.20	0.346	0.00	1.40	0.71
267	26.60	15.80	0.727	0.00	1.00	0.68
268	27.80	13.00	0.729	0.00	1.60	0.64
269	26.20	13.00	0.707	0.00	3.20	0.59
270	25.20	14.60	0.826	0.00	5.30	0.52
271	24.80	13.00	0.787	0.00	5.30	0.53
272	24.40	10.60	0.790	0.00	2.70	0.56
273	25.20	10.20	0.793	0.00	1.80	0.57

B.7 Spata 1990

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
305	27.00	17.00	0.760	0.00	2.80	0.62
306	27.80	17.80	0.490	0.00	2.90	0.60
307	27.00	14.40	0.610	0.00	1.20	0.66
308	27.60	14.60	0.330	0.00	1.75	0.70
309	26.00	17.00	0.140	0.00	1.75	0.81
310	20.60	15.40	0.700	0.00	3.00	0.57
311	16.20	14.00	0.220	0.00	2.50	0.71
312	14.60	10.40	0.000	3.08	4.00	0.82
313	12.00	8.00	0.470	0.00	4.00	0.71
314	12.80	8.00	0.300	0.00	3.50	0.57
315	11.60	6.80	0.040	0.00	1.75	0.70
316	13.60	1.00	0.610	0.00	1.50	0.72
317	13.80	4.00	0.080	0.00	0.75	0.70
318	14.80	10.80	0.000	0.00	2.50	0.72
319	17.80	13.20	0.040	0.20	1.75	0.85
320	18.60	14.60	0.000	0.30	5.60	0.84
321	18.60	12.00	0.320	0.98	0.00	0.87
322	22.20	11.80	0.790	0.00	1.00	0.69
323	22.00	10.20	0.810	0.00	2.60	0.69
324	20.60	8.20	0.620	0.00	0.00	0.80
325	21.00	8.20	0.720	0.00	1.80	0.81
326	21.40	9.00	0.700	0.00	2.00	0.75
327	20.60	9.20	0.440	0.00	1.50	0.85
328	21.00	10.40	0.510	0.08	4.20	0.76
329	21.00	13.60	0.790	0.35	2.75	0.69
330	21.60	7.60	0.720	0.00	3.20	0.70
331	20.40	6.80	0.710	0.00	5.40	0.75
332	21.80	16.40	0.720	0.00	3.20	0.80
333	19.60	10.60	0.020	0.00	0.60	0.87
334	21.00	12.40	0.680	0.30	9.60	0.48
335	18.40	8.60	0.400	0.00	2.00	0.68
336	14.00	9.00	0.060	4.24	2.10	0.89
337	12.40	10.40	0.000	3.03	4.00	0.82
338	11.40	9.40	0.010	0.77	3.20	0.75
339	13.60	3.00	0.730	0.00	0.80	0.77
340	16.80	5.40	0.330	0.98	4.20	0.83
341	16.60	12.60	0.060	1.03	5.30	0.77
342	15.80	7.00	0.780	0.00	2.10	0.61
343	15.00	2.60	0.650	0.00	0.00	0.73
344	16.00	4.00	0.200	0.00	2.00	0.84
345	18.00	13.00	0.110	0.00	6.10	0.73
346	16.80	11.40	0.000	3.13	3.70	0.91
347	15.80	5.60	0.480	0.00	2.40	0.72
348	15.00	7.00	0.140	0.58	1.40	0.78
349	16.60	8.00	0.810	0.01	3.30	0.65
350	16.00	7.40	0.840	0.20	2.00	0.70
351	14.00	4.20	0.000	0.00	1.00	0.90
352	13.80	9.40	0.000	1.21	0.60	0.92
353	13.80	6.60	0.000	0.42	2.20	0.82
354	15.00	9.20	0.290	0.13	1.50	0.78
355	14.20	3.20	0.760	0.00	0.50	0.84
356	12.80	4.80	0.030	0.00	0.75	0.80
357	11.80	3.40	0.290	0.00	1.75	0.59
358	9.00	5.00	0.170	0.07	6.75	0.54
359	9.00	6.00	0.020	0.00	4.00	0.60
360	9.80	5.40	0.060	0.00	3.50	0.64
361	11.20	4.00	0.190	0.00	0.00	0.72
362	15.00	3.60	0.670	0.02	1.75	0.81
363	15.20	8.40	0.220	0.00	1.20	0.75
364	14.00	8.40	0.560	0.00	2.25	0.72
365	13.60	3.20	0.840	0.00	2.25	0.78

B.8 Spata 1991

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
1	16.00	0.60	0.790	0.00	0.00	0.83
2	17.00	5.20	0.190	0.00	1.30	0.79
3	12.80	2.00	0.670	0.01	0.00	0.67
4	16.00	-1.20	0.800	0.00	0.00	0.77
5	16.40	0.40	0.850	0.00	1.00	0.84
6	17.00	5.00	0.660	0.00	0.00	0.80
7	17.00	3.00	0.770	0.00	0.00	0.85
8	16.80	2.40	0.820	0.00	1.00	0.84
9	16.80	2.20	0.850	0.00	0.00	0.83
10	15.60	3.00	0.760	0.00	1.80	0.79
11	16.30	4.00	0.850	0.00	2.80	0.71
12	16.00	0.00	0.820	0.00	0.00	0.81
13	14.80	0.40	0.780	0.00	0.00	0.87
14	15.00	3.20	0.270	0.00	2.00	0.87
15	11.60	8.00	0.000	2.62	5.30	0.83
16	7.60	5.20	0.400	0.03	8.30	0.71
17	6.60	3.80	0.440	0.00	7.30	0.64
18	5.40	3.60	0.010	0.00	4.00	0.59
19	6.00	4.20	0.000	0.00	7.30	0.58
20	8.80	5.00	0.690	0.00	5.70	0.67
21	6.60	4.00	0.000	0.40	4.00	0.83
22	6.20	3.40	0.000	0.02	4.00	0.72
23	8.20	5.20	0.460	0.00	6.00	0.61
24	8.00	2.20	0.250	0.00	2.00	0.72
25	5.80	-3.60	0.080	0.04	3.30	0.82
26	10.20	-0.50	0.580	0.00	2.20	0.76
27	10.40	-2.00	0.050	0.00	2.00	0.89
28	9.60	7.60	0.000	0.52	5.30	0.86
29	10.00	6.20	0.150	0.01	4.00	0.75
30	7.00	3.90	0.420	0.00	4.00	0.64
31	6.60	1.40	0.790	0.00	2.00	0.46
32	3.40	0.00	0.370	0.00	2.00	0.65
33	0.40	-2.50	0.080	0.11	2.00	0.81
34	2.80	-2.70	0.300	0.39	2.70	0.77
35	6.80	-5.60	0.530	0.00	2.00	0.76
36	9.00	-2.60	0.000	0.00	2.00	0.80
37	11.00	5.00	0.140	1.58	3.00	0.77
38	10.60	0.80	0.170	0.00	3.00	0.80
39	12.00	-0.60	0.310	0.00	2.00	0.81
40	15.20	3.00	0.190	0.00	1.30	0.84
41	16.00	4.60	0.610	0.00	2.00	0.85
42	16.00	3.20	0.520	0.29	1.30	0.87
43	16.60	4.60	0.040	0.00	5.70	0.81
44	16.20	8.20	0.180	0.00	5.00	0.62
45	16.20	4.40	0.620	0.00	7.00	0.67
46	19.00	9.30	0.560	0.01	12.50	0.62
47	11.80	6.00	0.550	0.00	9.30	0.43
48	18.60	3.40	0.770	0.00	6.00	0.62
49	15.60	5.60	0.130	0.09	3.00	0.77
50	14.20	7.60	0.480	0.33	4.00	0.81
51	13.80	8.00	0.750	0.00	4.70	0.69
52	11.40	8.40	0.020	0.54	3.30	0.84
53	11.60	9.40	0.000	0.45	3.00	0.91
54	12.00	9.00	0.000	0.15	4.00	0.82
55	10.00	7.80	0.000	0.01	3.00	0.71
56	7.60	5.80	0.000	0.03	5.30	0.79
57	11.40	3.30	0.160	0.10	3.20	0.77
58	16.20	-0.20	0.710	0.00	1.00	0.73
59	17.20	2.40	0.590	0.00	3.70	0.78
60	16.40	5.60	0.490	0.39	2.70	0.83
61	14.40	3.00	0.440	0.00	2.30	0.85
62	12.40	8.80	0.050	0.06	2.30	0.75
63	8.00	5.20	0.310	0.00	9.00	0.56
64	10.20	-0.10	0.750	0.00	5.70	0.57
65	17.00	-1.60	0.760	0.00	3.30	0.69
66	19.20	9.60	0.620	0.00	2.70	0.65
67	18.40	4.80	0.530	0.00	2.30	0.82
68	14.60	10.20	0.480	0.00	2.00	0.81
69	13.80	9.50	0.180	0.76	2.00	0.80
70	13.60	8.40	0.290	3.68	1.80	0.81
71	9.80	6.40	0.000	0.17	3.20	0.79
72	11.60	3.00	0.110	0.00	1.70	0.81
73	13.00	0.60	0.720	0.00	4.30	0.74
74	13.00	5.00	0.070	2.13	4.00	0.60
75	11.60	8.80	0.000	0.93	2.30	0.83
76	13.80	10.40	0.030	0.04	2.00	0.88
77	17.00	8.00	0.570	0.00	1.80	0.82
78	13.80	9.40	0.400	0.00	4.70	0.78
79	15.00	6.90	0.450	0.00	2.70	0.78
80	16.20	5.00	0.480	0.00	3.70	0.80
81	18.00	6.00	0.810	0.00	4.00	0.69
82	18.60	3.40	0.860	0.00	3.30	0.67
83	19.60	5.60	0.800	0.00	3.70	0.63
84	17.40	3.00	0.700	0.00	3.00	0.78
85	19.00	5.20	0.490	0.00	0.70	0.80
86	17.20	7.00	0.550	0.00	1.30	0.85
87	17.00	8.00	0.600	0.00	5.50	0.75
88	16.40	6.00	0.480	0.00	2.70	0.84
89	14.60	9.80	0.450	0.00	2.70	0.78
90	14.00	8.60	0.030	0.00	2.00	0.83
91	11.40	9.00	0.000	0.05	6.00	0.85
92	11.40	9.20	0.140	0.00	5.30	0.74
93	12.80	8.00	0.040	0.00	3.30	0.68
94	15.00	2.60	0.340	0.00	2.00	0.77
95	16.80	2.20	0.660	0.00	4.70	0.81
96	16.00	5.00	0.080	1.02	3.00	0.88
97	16.40	6.00	0.210	0.63	2.00	0.85
98	14.80	10.00	0.270	0.13	3.00	0.74

DAY	Tmax (oC)	Tmin (oC)	SD	PREC (cm)	WIND (m/s)	RH
99	18.00	5.60	0.340	0.03	3.00	0.72
100	18.40	8.70	0.440	0.00	3.30	0.53
101	17.60	4.00	0.740	0.00	2.30	0.80
102	18.00	4.40	0.380	0.00	1.30	0.80
103	16.20	10.50	0.060	0.03	2.00	0.85
104	18.40	6.20	0.590	0.55	2.00	0.84
105	15.60	6.50	0.550	0.86	2.00	0.80
106	17.20	3.40	0.480	12.30	2.20	0.81
107	18.40	5.40	0.740	0.00	4.00	0.81
108	20.60	7.00	0.370	0.00	4.30	0.85
109	22.80	13.20	0.540	0.00	5.30	0.72
110	20.80	11.40	0.820	0.00	3.30	0.55
111	20.00	5.20	0.770	0.00	4.70	0.74
112	19.40	9.60	0.570	0.00	4.30	0.70
113	18.20	12.20	0.620	0.00	6.00	0.67
114	19.40	8.50	0.790	0.00	5.00	0.58
115	18.60	7.00	0.790	0.00	5.00	0.57
116	18.40	3.00	0.560	0.00	4.30	0.73
117	18.60	6.00	0.180	0.25	1.00	0.80
118	20.80	5.40	0.300	0.41	1.70	0.75
119	17.40	11.50	0.300	0.46	3.50	0.83
120	17.40	9.00	0.350	2.93	1.70	0.85
121	20.00	8.40	0.760	0.01	4.00	0.78
122	21.40	6.40	0.810	0.00	5.30	0.73
123	21.20	6.60	0.750	0.00	4.00	0.81
124	24.60	10.40	0.710	0.00	3.70	0.62
125	26.00	15.60	0.450	0.00	4.00	0.70
126	23.60	13.20	0.770	0.00	3.30	0.59
127	23.40	12.20	0.440	0.61	3.70	0.79
128	21.00	13.00	0.850	0.00	5.70	0.45
129	21.80	6.00	0.490	0.00	3.80	0.62
130	19.00	11.80	0.000	0.40	0.70	0.80
131	21.60	14.40	0.380	1.33	2.00	0.88
132	22.80	12.60	0.730	0.00	2.30	0.80
133	23.40	11.20	0.560	0.00	3.00	0.75
134	21.20	10.60	0.350	0.06	1.30	0.74
135	15.40	11.30	0.000	0.00	3.20	0.85
136	21.60	8.40	0.730	1.63	4.30	0.76
137	22.80	12.00	0.650	0.00	6.30	0.69
138	22.60	8.40	0.730	0.00	2.70	0.68
139	20.40	10.30	0.600	0.00	2.00	0.62
140	19.00	8.60	0.350	0.44	1.50	0.74
141	21.40	7.00	0.750	0.00	1.40	0.69
142	24.20	8.00	0.710	0.00	2.20	0.69
143	24.60	13.00	0.520	0.00	3.20	0.70
144	18.60	10.70	0.120	0.42	3.70	0.85
145	21.20	9.80	0.660	0.00	3.70	0.63
146	20.80	10.40	0.820	0.00	3.30	0.53
147	21.60	8.60	0.790	0.00	4.00	0.57
148	20.80	13.80	0.580	0.00	7.30	0.46
149	19.40	12.00	0.510	0.00	3.30	0.63
150	20.00	11.60	0.180	0.09	2.80	0.79
151	21.80	8.40	0.460	0.00	1.80	0.75

C. LISTING OF SELECTED PROGRAM MODULES

C.1 (Crop) Constants and (forcing and rate) variables

Crop Constants

```
5010 '*****************************************
5020 'DEFAULT VALUES OF CROP FOR CROP CONSTANS
5030 '*****************************************
5040 '----------------------------
5050 '   MAIZE CONSTANTS
5060 '----------------------------
5070  TH = 8: AMAXOPT = 85: EFF = .5: DEPGR = 4: KE = .6: RD = 10: RRG = 2
5080  RL = .015 / .72: RS = .008 / .69: RR = .01 / .72: RSO = .015 / .72
5090 ECLEAF = .72: ECROOT = .72: ECSTEM = .69: ECSO = .72
5100 IF CR = 1 THEN TSUM(1) = 745: TSUM(2) = 770: THLLS = 9: TSUMLLS = 870
5110 IF CR = 2 THEN TSUM(1) = 760: TSUM(2) = 860: THLLS = 9: TSUMLLS = 870
5120 IF CR = 3 THEN TSUM(1) = 890: TSUM(2) = 865: THLLS = 9: TSUMLLS = 870
5130 IF CR = 4 THEN TSUM(1) = 660: TSUM(2) = 843: TH = 10.5: THLLS = 10.5: TSUMLLS = 1000
5140 IF CR = 5 THEN TSUM(1) = 780: TSUM(2) = 843: TH = 10.5: THLLS = 10.5: TSUMLLS = 1000
5150 IF CR = 6 THEN TSUM(1) = 725: TSUM(2) = 843: TH = 10.5: THLLS = 10.5: TSUMLLS = 1000
5160 RETURN
5162 '----------------------------
5164 ' WHEAT CONSTANTS
5166 '----------------------------
5168 RL = .015 / .72: RS = .01 / .69: RR = .01 / .72: RSO = .013 / .79
5170 ECLEAF = .72: ECROOT = .72: ECSTEM = .69: ECSO = .79
5172 AMAXOPT = 40: EFF = .5: DEPGR = 3: ke = .5: RD = 10: RRG = .8
5174 TH = 0: TSUM(1) = 920: TSUM(2) = 860: THLLS = 0: TSUMLLS = 1300
5176 RETURN
5178 '--------------------
5280 'COTTON CONSTANTS
5290 '--------------------
5300 '
5320  AMAXOPT = 50: FRAMAX = 1: EFF = .5: DEPGR = 4: KE = .6: RD = 10: RRG = 2
5330  RL = .01 / .72: RS = .008 / .69: RR = .01 / .72: RSO = .01 / .61
5340  ECLEAF = .72: ECROOT = .72: ECSTEM = .69: ECSO = .61
5350  TSUM(1) = 840: TSUM(2) = 600: TH = 15: THLLS = 15: TSUMLLS = 2450
5360 RETURN
```

(Note CR=4 for cv. ARIS, -5 for cv.P.3165, and -6 for cv.P.3183)

Rate variables (FRorgan and SLA)

Maize

```
'------------------------------------------------------------
' CALCULATIONS OF PARTITIONING FRACTIONS OF MAIZE cv. ARIS
'------------------------------------------------------------
' ROOTS
IF DVS >= 0 AND DVS <= .5 THEN FRROOT = .35 - .7 * DVS
IF DVS > .5 THEN FRROOT = 0
' LEAVES
IF DVS >= 0 AND DVS <= .075 THEN FRLEAF = .3
IF DVS > .075 AND DVS <= .375 THEN FRLEAF = .3575 - .1 * DVS
IF DVS > .375 AND DVS <= .5 THEN FRLEAF = .53 - .56 * DVS
IF DVS > .5 AND DVS <= .63 THEN FRLEAF = 1.25 - 1.95 * DVS
IF DVS > .64 THEN FRLEAF = 0

' SHEATHS
IF DVS >= 0 AND DVS <= .375 THEN FRSHEATH = .15
IF DVS > .375 AND DVS <= .5 THEN FRSHEATH = DVS * .4
IF DVS > .5 AND DVS <= .6 THEN FRSHEATH = 1.2 - 2 * DVS
IF DVS > .6 THEN FRSHEATH = 0
' Storage Organs
IF DVS >= 0 AND DVS <= .45 THEN FRSO = 0
IF DVS > .45 AND DVS <= .5 THEN FRSO = DVS - .45
IF DVS > .5 AND DVS <= .6 THEN FRSO = 5 * DVS - 2.45
IF DVS > .6 AND DVS <= .625 THEN FRSO = 4 * DVS - 1.85
IF DVS > .625 AND DVS <= .75 THEN FRSO = 2.8 * DVS - 1.1
IF DVS > .75 THEN FRSO = 1
' STEMS
IF DVS >= 0 AND DVS <= .075 THEN FRSTEM = .15
IF DVS > .075 AND DVS <= .45 THEN FRSTEM = .14 + .8 * DVS
IF DVS > .45 AND DVS <= .5 THEN FRSTEM = .5
IF DVS > .5 AND DVS <= .6 THEN FRSTEM = 1 - DVS
IF DVS > .6 AND DVS <= .75 THEN FRSTEM = 2 - 2.66 * DVS
IF DVS > .75 THEN FRSTEM = 0
GOTO 5940: ' jumb over DONA's partitionings to SLA calculation
'----------------------------------------------------------
' PARTITIONING FRACTIONS OF MAIZE cv. PIONEER (3183+3165)
'----------------------------------------------------------
' ROOTS
IF DVS >= 0 AND DVS <= .5 THEN FRROOT = .35 - .7 * DVS
IF DVS > .5 THEN FRROOT = 0
' LEAVES
IF DVS >= 0 AND DVS <= .075 THEN FRLEAF = .3
IF DVS > .075 AND DVS <= .375 THEN FRLEAF = .3575 - .1 * DVS
IF DVS > .375 AND DVS <= .5 THEN FRLEAF = .32
IF DVS > .5 AND DVS <= .65 THEN FRLEAF = .32 - 2.133 * (DVS - .5)
IF DVS > .65 THEN FRLEAF = 0
' SHEATHS
IF DVS >= 0 AND DVS <= .375 THEN FRSHEATH = .15
IF DVS > .375 AND DVS <= .5 THEN FRSHEATH = DVS * .4
IF DVS > .5 AND DVS <= .6 THEN FRSHEATH = 1.2 - 2 * DVS
IF DVS > .6 THEN FRSHEATH = 0
```

```
' Storage Organs
IF DVS >= 0 AND DVS <= .45 THEN FRSO = 0
IF DVS > .45 AND DVS <= .5 THEN FRSO = DVS - .45
IF DVS > .5 AND DVS <= .65 THEN FRSO = 6.33 * DVS - 3.117
IF DVS > .65 THEN FRSO = 1
' STEMS
IF DVS >= 0 AND DVS <= .075 THEN FRSTEM = DVS * 2.67
IF DVS > .075 AND DVS <= .375 THEN FRSTEM = .14 + .8 * DVS
IF DVS > .375 AND DVS <= .5 THEN FRSTEM = .44
IF DVS > .5 AND DVS <= .65 THEN FRSTEM = .44 - 2.933 * (DVS - .5)
IF DVS >= .65 THEN FRSTEM = 0
'--------------------
5940 'SLA of MAIZE
'--------------------
IF DVS <= .5 THEN SLA = 35 - 38 * DVS
IF DVS > .5 THEN SLA = 16
IF CR >= 4 AND CR <= 6 THEN IF DVS < .07 THEN SLA = 29 ELSE SLA = 17.4 - LOG(DVS * 2) * 5.9: 'Greek
cultivars of maize
RETURN
```

Cotton

```
'---------------------------------------------
' PARTITIONING FRACTIONS FOR COTTON
' --------------------------------------------
' ROOTS
IF DVS >= 0 AND DVS <= .5 THEN FRROOT = .4 - DVS * .2
IF DVS > .7 THEN FRROOT = 0
' LEAVES
IF DVS <= .5 THEN FRLEAF = (1 - FRROOT) * (.9 - (DVS * 1.2))
IF DVS > .5 AND DVS <= 1 THEN FRLEAF = (1 - FRROOT) * (.3 - (DVS - .5) * .45)
IF DVS > 1 THEN FRLEAF = .075
'STEMS
IF DVS <= .3 THEN FRSTEM = (1 - FRROOT) * (.1 + (DVS * 1.2))
IF DVS > .3 AND DVS <= .4 THEN FRSTEM = (1 - FRROOT) * (.46 + (DVS - .3) * .7)
IF DVS > .4 AND DVS <= .5 THEN FRSTEM = (1 - FRROOT) * (.53 + (DVS - .4) * .2)
IF DVS > .5 AND DVS <= .6 THEN FRSTEM = (1 - FRROOT) * (.55 - (DVS - .5) * .5)
IF DVS > .6 AND DVS <= .7 THEN FRSTEM = (1 - FRROOT) * (.5 - (DVS - .6) * .7)
IF DVS > .7 AND DVS <= .8 THEN FRSTEM = (1 - FRROOT) * (.43 - (DVS - .7) * .75)
IF DVS > .8 AND DVS <= 1 THEN FRSTEM = (1 - FRROOT) * (.355 - (DVS - .8) * 1.4)
IF DVS > 1 THEN FRSTEM = (1 - FRROOT) * .075
' STORAGE ORGANS
IF DVS <= .3 THEN FRSO = 0
IF DVS > .3 AND DVS <= .4 THEN FRSO = (1 - FRROOT) * (DVS - .3) * .5
IF DVS > .4 AND DVS <= .5 THEN FRSO = (1 - FRROOT) * (.05 + (DVS - .4))
IF DVS > .5 AND DVS <= .7 THEN FRSO = (1 - FRROOT) * (.15 + (DVS - .5))
IF DVS > .7 AND DVS <= .8 THEN FRSO = (1 - FRROOT) * (.35 + (DVS - .7) * 1.3)
IF DVS > .8 AND DVS <= 1 THEN FRSO = (1 - FRROOT) * (.48 + (DVS - .8) * 1.85)
IF DVS > 1 THEN FRSO = .85
'---------------------
' SLA OF COTTON
'---------------------
SLA = 20.4 - DVS * 7.01 - TA * .191 + LAI * 1.6
RETURN
```

3. Wheat

```
'-----------------------------------------------
' CALCULATION OF PARTITIONING FRACTIONS OF WHEAT
'-----------------------------------------------
'LEAVES
IF DVS <= .35 THEN FRLEAF = .4 - DVS * .14286
IF DVS > .35 AND DVS <= .52 THEN FRLEAF = .35 - (DVS - .35) * 2.0588
IF DVS > .52 THEN FRLEAF = 0'
'ROOT
IF DVS <= .15 THEN FRROOT = .6 - DVS * 2.6666
IF DVS > .15 AND DVS <= .7 THEN FRROOT = .2 - (DVS - .15) * .363636
IF DVS > .7 THEN FRROOT = 0'
' STORAGE ORGANS
IF DVS <= .45 THEN FRSO = 0
IF DVS > .45 AND DVS <= .7 THEN FRSO = (DVS - .45) * 4
IF DVS > .7 THEN FRSO = 1
' STEMS
FRSTEM = 1 - (FRROOT + FRLEAF + FRSO)
IF FRSTEM < 0 THEN FRSTEM = 0
IF FRSTEM > 1 THEN FRSTEM = 1
'
'---------------
' SLA OF WHEAT
'---------------
IF DVS <= .32 THEN SLA = 31.8
IF DVS > .32 THEN SLA = 15.16082 - 14.62284 * LOG(DVS)
RETURN
'
```

Temperature correction factors

```
6730' CFT FOR MAIZE
IF TPR <= 10 THEN FRAMAX = 0
IF TPR > 10 AND TPR <= 20 THEN FRAMAX = .056 * TPR - .56
IF TPR > 20 AND TPR <= 30 THEN FRAMAX = (TPR - 7) / (30 - 7)
IF TPR > 30 AND TPR <= 41 THEN FRAMAX = 1
IF TPR > 41 AND TPR <= 50 THEN FRAMAX = 1 - (TPR - 41) / (50 - 41)
IF TPR > 50 THEN FRAMAX = 0
RETURN
6740' CFT FOR COTTON
IF TCAN <= 15 THEN CFT = 0
IF TCAN > 15 AND TCAN <= 20 THEN CFT = (TCAN - 15) * .04
IF TCAN > 20 AND TCAN <= 28 THEN CFT = .2 + (TCAN - 20) * .0875
IF TCAN > 28 AND TCAN <= 30 THEN CFT = .9 + (TCAN - 28) * .05
IF TCAN > 30 THEN CFT = 1
RETURN
6750' CFT FOR C3 PLANTS (WHEAT)
IF TPR <= 0 THEN FRAMAX = 0
IF TPR >= 0 AND TPR <= 15 THEN FRAMAX = (TPR - 0) * .06666
IF TPR > 15 AND TPR <= 23 THEN FRAMAX = 1
IF TPR > 23 AND TPR <= 36 THEN FRAMAX = 1 - (TPR - 23) * .026923
IF TPR > 36 AND TPR <= 46 THEN FRAMAX = .65 - (TPR - 36) * .065
IF TPR > 46 OR TPR < 0 THEN FRAMAX = 0
RETURN
```

Irrigation water amounts per application day (INPIRR(DAY), in cm)

Maize experiments

```
'TEI/L, 1988, Treatment Y (wet)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(161) = 5.0: INPIRR(167) = 1.1
'INPIRR(168) = 3.8: INPIRR(171) = 3.0: INPIRR(172) = 3.0: INPIRR(173) = 3.0
'INPIRR(179) = 4.5: INPIRR(180) = 3.0: INPIRR(181) = 3.0: INPIRR(182) = 3.0
'INPIRR(185) = 3.2: INPIRR(186) = 5.5: INPIRR(188) = 3.0: INPIRR(189) = 1.5
'INPIRR(192) = 5.0: INPIRR(194) = 5.0: INPIRR(196) = 5.0: INPIRR(199) = 5.0
'INPIRR(201) = 1.5: INPIRR(202) = 1.5: INPIRR(203) = 5.0: INPIRR(206) = 2.5
'INPIRR(207) = 1.0: INPIRR(214) = 2.5: INPIRR(219) = 4.5: INPIRR(230) = 5.0
'INPIRR(231) = 5.0
'VO = 0.4 * 24 '(drip irrigation)
'
'TEI/L, 1988, Treatment PY (wet-dry after silking)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(161) = 5.0: INPIRR(167) = 1.1
'INPIRR(168) = 3.8: INPIRR(171) = 3.0: INPIRR(172) = 3.0: INPIRR(173) = 3.0
'INPIRR(179) = 4.5: INPIRR(180) = 3.0: INPIRR(181) = 3.0: INPIRR(182) = 3.0
'INPIRR(185) = 3.2: INPIRR(186) = 5.5: INPIRR(188) = 3.0: INPIRR(189) = 1.5
'INPIRR(192) = 5.0: INPIRR(207) = 1.0: INPIRR(219) = 4.5
'VO = 0.4 * 24
'
'TEI/L, 1988, Treatment K (normal)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(161) = 5.0: INPIRR(167) = 0.4
'INPIRR(168) = 1.2: INPIRR(171) = 1.6: INPIRR(172) = 0.0: INPIRR(173) = 1.8
'INPIRR(179) = 4.5: INPIRR(180) = 3.0: INPIRR(181) = 0.0: INPIRR(182) = 3.0
'INPIRR(185) = 3.2: INPIRR(186) = 0.0: INPIRR(188) = 0.0: INPIRR(189) = 1.5
'INPIRR(192) = 5.0: INPIRR(194) = 5.0: INPIRR(196) = 5.0: INPIRR(199) = 5.0
'INPIRR(201) = 1.5: INPIRR(202) = 1.5: INPIRR(203) = 5.0: INPIRR(206) = 2.5
'INPIRR(207) = 1.0: INPIRR(219) = 4.5: INPIRR(230) = 5.0: INPIRR(231) = 5.0
'VO = 0.4 * 24
'
'TEI/L, 1988, Treatment A (dry)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(161) = 5: VO = .4 * 24
'
'TEI/L, 1987, SSMAX=4.0
'INPIRR(146) = 3.15: INPIRR(156) = 4.2: INPIRR(164) =  7.7: INPIRR(170) = 7.7
'INPIRR(177) = 7.70: INPIRR(184) = 7.7: INPIRR(192) = 14.7: INPIRR(198) = 9.2
'INPIRR(205) = 7.60: INPIRR(212) = 7.6: INPIRR(220) =  7.6: INPIRR(232) = 7.6
'INPIRR(240) = 7.60: Vo = 2 * 24
'
'Vrachia/Thessaloniki, 1987
'INPIRR(168) = 12: INPIRR(184) = 8: INPIRR(196) = 8
'INPIRR(208) = 8: INPIRR(219) = 8: INPIRR(230) = 8
```

Cotton experiments

```
'TEI/L, 1988, Treatment K (normal)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(167) = 0.4
'INPIRR(168) = 1.2: INPIRR(179) = 4.5: INPIRR(195) = 5.0
'INPIRR(202) = 5.0: INPIRR(203) = 5.0: INPIRR(207) = 1.0
'INPIRR(219) = 4.5: INPIRR(237) = 2.8: INPIRR(238) = 2.8
'INPIRR(239) = 2.8: INPIRR(240) = 2.8: INPIRR(241) = 2.8
'INPIRR(242) = 2.8: INPIRR(230) = 5.0: INPIRR(231) = 5.0
'VO = 0.4 * 24 '(drip irrigation)
'
```

```
'TEI/L, 1988, Treatment Y (wet)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(167) = 1.1: INPIRR(168) = 3.8
'INPIRR(172) = 3.0: INPIRR(173) = 1.8: INPIRR(179) = 4.5: INPIRR(180) = 3.0
'INPIRR(181) = 3.0: INPIRR(182) = 3.0: INPIRR(185) = 3.0: INPIRR(186) = 5.5
'INPIRR(188) = 3.0: INPIRR(189) = 1.5: INPIRR(192) = 5.0: INPIRR(194) = 5.0
'INPIRR(196) = 5.0: INPIRR(199) = 5.0: INPIRR(201) = 1.5: INPIRR(202) = 1.5
'INPIRR(203) = 5.0: INPIRR(206) = 2.5: INPIRR(207) = 1.0: INPIRR(211) = 0.0
'INPIRR(219) = 4.5: INPIRR(237) = 2.8: INPIRR(238) = 2.8: INPIRR(239) = 2.8
'INPIRR(240) = 2.8: INPIRR(241) = 2.8: INPIRR(242) = 2.8
'VO = 0.4 * 24 '(drip irrigation)
'
'TEI/L, 1988, Treatment A (dry)
'INPIRR(130) = 3.6: INPIRR(140) = 4.8: INPIRR(207) = 1: INPIRR(219) = 4.5
'VO = 0.4 * 24 '(drip irrigation)
'
'
'Cotton evaluation (Chapt. 5): 2 irrigations till flowering; every 10 days thereafter
'note a first application of 3.5 cm upon the germination day: PSINI=1000
'INPIRR(120) = 0: INPIRR(150) = 0: INPIRR(170) = 4: INPIRR(190) = 4
'INPIRR(200) = 4: INPIRR(210) = 4: INPIRR(220) = 4: INPIRR(230) = 4: INPIRR(240) = 4
'INPIRR(270) = 5: vo = .4 * 24
```

Wheat experiment

```
' note irrigations wheat-TEI/L, 1989
'INPIRR(101) = .2: INPIRR(102) = 2.2: INPIRR(103) = 1.2
'INPIRR(112) = 2.2: INPIRR(114) = 1.2: INPIRR(115) = .8
'INPIRR(116) = 1.2: INPIRR(117) = 1.2: INPIRR(128) = 3
'INPIRR(129) = 3: VO = .4 * 24
'
' rain showers=half prec. at middle of each month with 10mm/h
' for an average-year scenario; and
INPIRR(350) = 2.86: INPIRR(15) = 1.87: INPIRR(45) = 1.75
INPIRR(75) = 1.88: INPIRR(105) = 1.45: INPIRR(135) = 1.87
VO = 1 * 24
```

C.2 Selected SO.CR.AT.E.S. modules

```
2850 'Subroutine ASTRO:
2860 'computation of daylength (DAYL), photoperiodic daylength (DAYLP) and
2870 'time of sunrise (RISE) from day number (DAY) and latitude (LAT).
2880 '------------------------------------------------------------------------
2890 '
2900 '
2910 '*-----conversion factor from degrees to radians and arcsin function.
2920 '
2930        PI = 3.1415926#
2940        RAD = PI / 180
2950        DEF FNASN (X) = ATN(X / SQR(-X * X + 1))
2960 '
2970 '
2980 '*-----declination of the sun (DEC) as function of daynumber (DAY)
2990 '
3000        ARG = SIN(23.45 * RAD) * COS(2 * PI * (day% + 10) / 365)
3010        DEC = -FNASN(ARG)
3020 '
3030 '
3040 '*-----SSIN, CCOS and AOB are intermidiate variables
3050 '
3060        SSIN = SIN(LAT * RAD) * SIN(DEC)
3070        CCOS = COS(LAT * RAD) * COS(DEC)
3080        AOB = SSIN / CCOS
3090 '
3100 '
3110 '*-----daylength (DAYL) and photoperiodic daylength (DAYLP) in hours
3120 '      and sunrise time (RISE)
3130 '
3140        DAYL = 12 * (1 + 2 * FNASN(AOB) / PI)
3150        ARG = (-SIN(8 * RAD) + SSIN) / CCOS
3160        DAYLP = 12 * (1 + 2 * FNASN(ARG) / PI)
3170        SUNRISE = 12 - DAYL / 2
3180        SUNSET = 12 + DAYL / 2
3190 '
3200 '      end of subroutine
3210        RETURN


3250 '************************************************************************
3260 'Subroutine TOTASS:
3270 'calculates gross assimilation (DTGA) by performing a Gaussian integration
3280 'over time. At three different times of the day, radiation is computed and
3290 'used to determine assimilation whereafter integration takes place.
3300 '------------------------------------------------------------------------
3310 '
3320 '
3330        PI = 3.1415926#
3340 '
3350 '*-----assimilation set to zero at three different times of the day (HOUR)
3360 '
```

```
3370        DTGA = 0
3380        FOR IT = -1 TO 1
3390        HOUR = 12 + DAYL * .5 * (.5 + IT * SQR(.15))
3400 '
3410 '
3420 '*-----at the specified HOUR the ambient temperature (TPR) is copmputed
3430 '      and used to compute FRAMAX and AMAX
3440 '
3450 '      call TWAVE subroutine
3460 '      GOSUB 934
3470 '
3480 '      call FRAMAX correction section
3490        IF CR <= 6 THEN GOSUB 6730: ' ***C4  plants
3500        IF CR > 6 AND CR < 10 THEN GOSUB 6750: ' ***C3  plants
3502        IF CR = 10 THEN GOSUB 6740:' ***COTTON
3510 '
3520        AMAX = AMAXOPT * FRAMAX
3530        IF AMAX = 0 THEN AMAX = .1' to avoid division by zero
3540 '
3550 '*-----at the specified HOUR, radiation is computed and used to compute
3560 '      assimilation.
3570 '
3580 '      call  RADIAT subroutine
3590        GOSUB 4150
3600 '
3610 '      call  ASSIM  subroutine
3620        GOSUB 4370
3630 '
3640 '
3650 '*-----integration of assimilation rate to a daily total (DTGA)
3660 '
3670        IF IT = 0 THEN FGROS = FGROS * 1.6
3680        DTGA = DTGA + FGROS
3690        NEXT IT
3700        DTGA = DTGA * DAYL / 3.6
3710 '
3720       IF DVS < .03 THEN DTGA = AMAX * SL * SLA * DAYL / 25000
3720 '
3730 '      end of subroutine
3740        RETURN
3750 '
3760 '
3780 '***************************************************************************


8760 '***************************************************************************
8770 ' Subroutine PENMAN.SUB / DANALATOS N. / 30-07-89
8780 '
8790 ' Calculates Penman equation according to Frere M.
8800 ' based on TMAX,TMIN,ALT,LAT,SD,RH,WIND,and DAY
8810 '-------------------------------------------
8815 wind = wind * 1.5' WIND IS HARDER IN THE DAY
8820 RESTORE 11310
8830 '
8840 '*-----PENX is intermidiate variable
```

```
8850 '
8860 FOR LL% = 0 TO 5: FOR MM% = 0 TO 35: READ PENX(LL%, MM%): NEXT: NEXT
8870 '
8880 FOR LL% = 0 TO 5
      IF ALT >= 200 * LL% AND ALT <= 200 * (LL% + 1) THEN ALTNO = LL%: ALT1 = 200 * LL%
     NEXT
8890 IF TPR <= 0 THEN PENX1 = PENX(ALTNO, 0): PENX2 = PENX(ALTNO + 1, 0)
8900 FOR MM% = 0 TO 35
8910 IF TPR >= MM% AND TPR < MM% + 1 THEN MM% = MM%: GOSUB 9300
8920 NEXT
8930 IF TPR > 35 THEN PENX1 = PENX(ALTNO, 35): PENX2 = PENX(ALTNO + 1, 35)
8940 PENX = PENX1 + (PENX1 - PENX2) * (ALT - ALT1) / (-200)
8950 '
8960 '
8970 '*-----WVAL is intermidiate variable
8980 '
8990        IF tmax - tmin <= 12 THEN WVAL = .54
9000        IF tmax - tmin > 12 AND tmax - tmin <= 13 THEN WVAL = .61
9010        IF tmax - tmin > 13 AND tmax - tmin <= 14 THEN WVAL = .68
9020        IF tmax - tmin > 14 AND tmax - tmin <= 15 THEN WVAL = .75
9030        IF tmax - tmin > 15 AND tmax - tmin <= 16 THEN WVAL = .82
9040        IF tmax - tmin > 16 THEN WVAL = .89
9050 '
9060 '
9070        EASAT = 6.11 * EXP(17.4 * TPR / (TPR + 239))' saturated vapour pressure
9080 '
9090        ATERM = (1 + WVAL * wind) * .26 * (EASAT - rh * EASAT)
9100 '
9110 '*----total radiation (RA in mm) calculated from the total flux (DSO)
9120 '     divided over the latent heat flux (2.45x10^6).-Short wave radiation
9130 '     (SHRA in mm) and infrared radiation (INRA in mm) are found and used
9140 '     to calculate net radiation for transp/tion and evap/tion NETRA and
9150 '     NETRAEO respectively (in cm)- .75 and .95 is related to albedos
9160 '
9170        RA = DSO / 2450000!
9180        SHRA = .75 * avrad / 2450000!
9190        SHRAEO = .95 * avrad / 2450000!
9200       INRA = 1.983952E-09 * (273 + TA) ^ 4 * (.56 - SQR(EASAT * rh) * 7.900001E-02) * (sd * .9 + .1)
9210       NETRA = SHRA - INRA
9220       NETRAEO = SHRAEO - INRA
9230       eto = .1 * (ATERM + (PENX * NETRA)) / (PENX + 1)
9240       EO = .1 * (ATERM + (PENX * NETRAEO)) / (PENX + 1)
9250 '
9260        RETURN
9270 '
9280 '*-----extrapolation subroutine for PENX (Penman equation)
9290 '
9300 PENX1 = (PENX(ALTNO, MM%) - PENX(ALTNO, MM% + 1)) / (-1) * (TPR - MM%) + PENX(ALTNO, MM%)
9310 PENX2 = (PENX(ALTNO + 1, MM%) - PENX(ALTNO + 1, MM% + 1)) / (-1) * (TPR - MM%) + PENX(ALTNO + 1, MM%)
9320 RETURN

11290 '*-----data on PENX with altitude for ALT=0-1000 m. (Penman Subroutine)
11300 '
11310  DATA  .67,.72,.76,.81,.87,.92,.98,1.04,1.11,1.17,1.25,1.32,1.4,1.48,1.57,1.66,1.76,1.86,1.97,2.08,
2.19,2.32,2.44,2.58,2.72,2.86,3.01,3.17,3.34,3.51,3.69,3.88,4.07,4.27,4.48,4.71
```

```
11320 DATA .69,.74,.78,.83,.89,.94,1,1.07,1.13,1.2,1.28,1.35,1.43,1.52,1.61,1.7,1.8,1.91,2.02, 2.13,2.25,
2.37,2.5,2.64,2.78,2.93,3.09,3.25,3.42,3.6,3.78,3.98,4.18,4.38,4.59,4.83
11330 DATA .71,.75,.8,.86,.91,.97,1.03,1.09,1.16,1.23,1.31,1.39,1.47,1.55,1.64,1.74,1.85,1.95, 2.06,2.18,
2.3,2.43,2.56,2.71,2.85,3,3.16,3.33,3.5,3.68,3.87,4.07,4.28,4.48,4.7,4.95
11340DATA.72,.77,.82,.88,.93,.99,1.05,1.12,1.19,1.26,1.34,1.42,1.5,1.59,1.68,1.78,1.89,2,2.11,2.23,2.36,
2.49,2.63,2.77,2.92,3.08,3.24,3.41,3.59,3.77,3.97,4.17,4.38,4.59,4.82,5.06
11350 DATA .74,.79,.84,.9,.96,1.01,1.08,1.15,1.22,1.29,1.37,1.45,1.54,1.63,1.72,1.82,1.94,2.05,2.17,2.29,
2.42,2.55,2.69,2.84,2.99,3.15,3.32,3.49,3.67,3.86,4.06,4.27,4.49,4.7,4.93,4.93
11360 DATA .76,.81,.86,.92,.98,1.04,1.1,1.17,1.25,1.32,1.41,1.49,1.57,1.67,1.77,1.87,1.98,2.1,2.22,2.34,
2.47,2.61,2.75,2.9,3.06,3.22,3.4,3.57,3.76,3.95,4.16,4.37,4.59,4.81,4.81,4.81
11370 '----------------------------------------------------------------------


2110 '******************************************************************
2112 'Subroutine MODIS:
2114 'computes soil moisture distribution in a 7-layers soil profile
2116 '------------------------------------------------------------------
2120 '
2130  FOR T = 1 TO 96' 24 hours runing every 15 minutes
2140  RSM(LAYER%) = 0
2145     EVAP = (em / DELTAT) * (smpsi(1) - .33 * SMPWP) / (SMO(SOIL1) - .33 * SMPWP)
2146     EVAPSUM = EVAPSUM + EVAP
2150 '
2160   FOR LAYER% = 1 TO COMNUM
2170 '
2180     IF LAYER% > 1 AND LAYER% < 5 THEN SOIL = SOIL2: GOTO 2210
2190     IF LAYER% >= 5 AND LAYER% <= 7 THEN SOIL = SOIL3: GOTO 2210
2200     IF LAYER% = 1 THEN SOIL = SOIL1
2210     SMO = SMO(SOIL): GAM = GAM(SOIL): ALFA = ALFA(SOIL)
2220     AK = AK(SOIL): KO = KO(SOIL): PSIMAX = PSIMAX(SOIL)
2230     SMPWP = SMO * EXP(-GAM * LOG(16000) * LOG(16000))
2240     SMA = SMO - .02: SMB = SMO - .06
2250     SMCR = ((1 - DEPLF) * (SMO - .02 - SMPWP)) + SMPWP
2260     TRMCOM = TRMCOM(LAYER%) / DELTAT
2270 '
2280 '......actual transpiration
2290     IF smpsi(LAYER%) >= SMA THEN TRCOM = 0
2300     IF smpsi(LAYER%) < SMA AND smpsi(LAYER%) > SMB THEN TRCOM = TRMCOM * (SMA - smpsi(LAYER%)) / .04
2310     IF smpsi(LAYER%) <= SMB AND smpsi(LAYER%) >= SMCR THEN TRCOM = TRMCOM
2320     IF smpsi(LAYER%) < SMCR AND smpsi(LAYER%) > SMPWP THEN TRCOM = TRMCOM * (smpsi(LAYER%) - SMPWP) / (SMCR - SMPWP)
2330     IF smpsi(LAYER%) <= SMPWP THEN TRCOM = 0
2340     TRCOMSUM(LAYER%) = TRCOMSUM(LAYER%) + TRCOM
2350 '
2360 '......conductivities and fluxes per compartment
2370 '
2380     KAV1# = .5 * (KPSI(LAYER% - 1) + KPSI(LAYER%)) / DELTAT
2390     IF LAYER% = 1 THEN KAV1# = KPSI(LAYER%) / DELTAT
2400     KAV2# = .5 * (KPSI(LAYER% + 1) + KPSI(LAYER%)) / DELTAT
2410     V1 = KAV1# * (HEAD(LAYER% - 1) - HEAD(LAYER%)) / TCOM
2420     IF LAYER% = 1 THEN IF T < INT(durirr * DELTAT) + 1 THEN V1 = vo / DELTAT - EVAP: realirr = inpirr(day%) - roff ELSE
V1 = -EVAP
2430     V2 = KAV2# * (HEAD(LAYER%) - HEAD(LAYER% + 1)) / TCOM
2440     IF COMNUM < 7 AND LAYER% = COMNUM THEN V2 = KAV2# * (HEAD(LAYER%) - HEAD(LAYER% + 1)) / Z(LAYER%)
2450 IF LAYER% = 7 THEN IF PSI(LAYER%) = Z(LAYER%) THEN V2 = 0 ELSE IF PSI(LAYER%) < Z(LAYER%) THEN V2 = KPSI(LAYER%) / DELTAT
ELSE PSI = PSI(LAYER%): Z = Z(LAYER%): GOSUB 9970: V2 = -CRISE / DELTAT
```

```
2460      RSM(LAYER%) = V1 - V2 - TRCOM
2470      IF RSM(LAYER%) > VOLW(LAYER%) / 2 THEN PRINT "no correct input of initial suction or ground water table": GOTO 530
2480      VOLW(LAYER%) = VOLW(LAYER%) + RSM(LAYER%)
2490      smpsi(LAYER%) = VOLW(LAYER%) / TCOM: IF smpsi(LAYER%) > SMO THEN smpsi(LAYER%) = SMO
2500      PSI(LAYER%) = EXP(SQR(LOG(SMO / smpsi(LAYER%)) / GAM))
2510      IF PSI(LAYER%) > PSIMAX THEN KPSI(LAYER%) = AK * PSI(LAYER%) ^ (-1.4)
2520      IF PSI(LAYER%) <= PSIMAX THEN KPSI(LAYER%) = KO * EXP(-ALFA * PSI(LAYER%))
2530      HEAD(LAYER%) = Z(LAYER%) - PSI(LAYER%)
2540      VOLW(LAYER% - 1) = VOLW(LAYER% - 1) - V1
2550      VOLW(LAYER% + 1) = VOLW(LAYER% + 1) + V2
2560 '
2570    NEXT LAYER%
2580 '
2590 '......adjust ground water depth
2600      IF COMNUM >= 4 THEN DZ = -2 * V2 / ((SMO(SOIL3) - smpsi(COMNUM)) + .01)
2610      IF COMNUM < 4 THEN DZ = -2 * V2 / (SMO(SOIL2) - smpsi(COMNUM))
2620      TOTDEP = TOTDEP + DZ
2630 IF TOTDEP < 20 THEN PRINT "water at the surface-end of calculations": END
2640      COMNUM = TOTDEP \ TCOM: IF COMNUM > 7 THEN COMNUM = 7
2650      Z(1) = TOTDEP - .5 * TCOM
2660      FOR LAYER% = 2 TO 7: Z(LAYER%) = Z(LAYER% - 1) - TCOM: NEXT
2670     IF COMNUM < 7 THEN FOR LAYER% = COMNUM + 1 TO 7: PSI(LAYER%) = Z(LAYER%): HEAD(LAYER%) = Z(LAYER%) - PSI(LAYER%): NEXT
2680 '
2690    NEXT T
2700    RETURN
2702 '====================================================================
2704 CLS : FOR P% = 1 TO 7: PRINT USING "##"; P%; : FOR PP = 1 TO CINT(smpsi(P%) * 100): PRINT "*"; : NEXT: PRINT USING "#.##";
smpsi(P%): PRINT : NEXT: RETURN
```

```
12000 '*****************************************************************
'       Subroutine OTHONI, performs graphical output
'      -----------------------------------------------------------------
SCREEN 3, , 1, 1
LOCATE 1, 20: PRINT "---->SO.CR.AT.E.S. report for DAY="; day%; : PRINT "<----"
LINE (170, 0)-(570, 13), , B
CIRCLE (700, 20), 20: PAINT (700, 20) ' the sun
DRAW "nD50 nf50 nr50 nu50 ng50 nd50 nl50 nh50" 'sun rays
LINE (0, 150)-(750, 150) ' the uper border of the soil
LINE (0, 255)-(750, 255)' the lower border of the soil
tile1$ = CHR$(1) + CHR$(16)
tile2$ = CHR$(1) + CHR$(0) + CHR$(0) + CHR$(0) + CHR$(0)
PAINT (1, 155), tile2$
'here is the stick figure
PSET (20, 20)
DRAW "d2 ne2 nh2" 'the small grass stick figure
DIM image%(50), image1%(390)
GET (4, 4)-(22, 32), image%
' the crop:
PSET (60, 149)
DRAW "u20 ne20 nh20 u15 ne13 nh13 u10 ne10 nh10 u15"
CIRCLE (60, 84), 6: CIRCLE (48, 91), 3: CIRCLE (72, 91), 3
CIRCLE (44, 98), 4: CIRCLE (76, 98), 4
'number of soil layers
LOCATE 12, 1: FOR dumyl = 1 TO 7: PRINT dumyl; : PRINT USING " #.### "; smpsi(dumyl); : FOR dumystar = 1
```

```
TO smpsi(dumyl) * 100: PRINT "*"; : NEXT: PRINT : NEXT
CIRCLE (38, 105), 5: CIRCLE (82, 105), 5
GET (25, 75)-(90, 149), image1%
FOR dumyx = 80 TO 150 STEP 55: PUT (dumyx, 75), image1%: NEXT dumyx' your crop
FOR dumyx = 1 TO 700 STEP 10: PUT (dumyx, 130), image%: NEXT dumyx' penman grass
LINE (140, 100)-(140, 57): DRAW "ng4 nf4": LOCATE 4, 14: PRINT USING "TR=#.## cm"; TR'transpiration
LINE (180, 150)-(180, 140): DRAW "ng2 nf2": LOCATE 10, 21: PRINT USING "Ea=#.## cm"; EA'evaporation
'
'the cloud
CIRCLE (565, 45), 110, , , , .05:
PAINT (580, 49), tile1$ ' painting the cloud
'
'irrigation & rain
CIRCLE (500, 145), 3
PSET (499, 140): DRAW "ne8 nu12 h8": LINE -(480, 140), , , &HE724
LINE (509, 132)-(520, 143), , , &HE724: PSET (499, 127): LINE -(490, 140), , , &HE727
LINE (480, 110)-(480, 135): DRAW "nh5 ne5"
LOCATE 9, 55: PRINT USING "I=#.# cm"; inpirr(day%)
LINE (600, 50)-(600, 80): DRAW "nh5 ne5"
LOCATE 6, 60: PRINT USING "P=#.#cm"; prec
'evaporation and transpiration
LINE (300, 150)-(300, 112), , , &HF0F0: DRAW "ng5 nf5" 'line of Em
LINE (370, 150)-(370, 98), , , &HF0F0: DRAW "ng5 nf5 " 'line of TRm
LINE (440, 150)-(440, 85), , , &HF0F0: DRAW "ng5 nf5" ' line of ETo
LOCATE 8, 32: PRINT USING "Em=#.##cm"; em
LOCATE 7, 38: PRINT USING "TRm=#.##cm"; TRM
LOCATE 6, 44: PRINT USING "ETo=##.##cm"; eto
LOCATE 3, 60: PRINT USING "SDR=#.##"; sd
LOCATE 4, 1: PRINT USING "Tcan=##.#oC"; TCAN
LOCATE 3, 1: PRINT USING "Ta  =##.#oC"; TA
LOCATE 1, 1: PRINT USING "Tmax=##.#oC"; tmax
LOCATE 2, 1: PRINT USING "Tmin=##.#oC"; tmin
LINE (0, 0)-(100, 55), , B
'capil. rise and drainage
LINE (100, 255)-(100, 275): DRAW "nh5 ne5": LOCATE 21, 5: PRINT USING "D=#.##cm"; d
LINE (130, 275)-(130, 255): DRAW "ng5 nf5": LOCATE 21, 15: PRINT USING "CR=#.##"; CRISE
'energy -DSO,AVRAD,PAR
FOR dumy% = 1 TO 7
  dumy1% = 720 - dumy% * 10
  PSET (dumy1%, 90): FOR energ% = 1 TO 12: DRAW "g2 f2": NEXT: DRAW "d5 nh5 ne5"
NEXT dumy%
LOCATE 8, 72: PRINT USING "#### W/m2"; avrad / 86400
12010 dumyd$ = INKEY$: IF dumyd$ = "" THEN 12010
CLS 1
SCREEN 3, , 0, 0
RETURN
```

C.3 An example of calculations

```
*************************************************************************************************************************
---------------------------------->> SO.CR.AT.E.S. / N.G. DANALATOS / 25-08-89 <<-----------------------------------------

CALCULATION OF POTENTIAL PRODUCTION UNDER GREEK CONDITIONS.                                                  DATE:05-20-1992
RADIATION, TEMPERATURE, WATER AVAILABILITY AND OXYGEN                                                        TIME:14:41:01
AVAILABILITY THE ONLY CONSIDERED LAND QUALITIES

DATA FILE: lar88.rnd                   CROP: MAIZE cv. ARIS-GR                  SOIL: 13/13/13
LATITUDE : 40.0 N                      INIT.WEIGHT: 10.0 Kg/ha                  INIT. SUCTION:   1000 cm
ALTITUDE :   40 m                      MAX.ROOTING DEPTH: 90 cm                 INIT. WATERTABLE:5000 cm

DAY  TA   TCAN  DVS   LAI AMAX  FGC  MRR  RD  ETo   TRM   EM   TR   EA   CFW   NET   SL    SS   S.O.  TLDW  TDW
-----------------------------------------------------------------------------------------------------------------------
130 17.6 17.6 0.01  0.0  42     2    0  12  0.43  0.00  0.53 0.00 0.44 0.96    1     3     2    0     9     9
131 18.9 24.5 0.01  0.0  50     3    0  14  0.56  0.00  0.70 0.00 0.53 1.00    1     4     2    0    10    10
132 19.5 23.0 0.02  0.0  49     3    0  16  0.49  0.00  0.58 0.00 0.42 1.00    1     4     2    0    11    11
133 19.3 23.6 0.03  0.0  47     3    0  18  0.37  0.00  0.41 0.00 0.29 1.00    1     4     2    0    13    13
134 17.4 21.3 0.03  0.0  39     4    0  20  0.28  0.00  0.33 0.00 0.23 1.00    2     5     2    0    14    14
135 18.6 22.9 0.04  0.0  46     6    0  22  0.39  0.00  0.49 0.00 0.34 1.00    3     6     3    0    17    17
136 18.8 26.5 0.04  0.0  50     8    0  24  0.50  0.00  0.62 0.00 0.41 1.00    4     7     3    0    20    20
137 20.0 27.2 0.05  0.0  54    11    0  26  0.58  0.01  0.72 0.01 0.45 1.00    5     8     4    0    25    25
138 21.0 28.3 0.06  0.0  58    14    0  28  0.65  0.01  0.79 0.01 0.48 1.00    6    10     5    0    31    31
139 20.5 27.1 0.07  0.0  57    18    0  30  0.67  0.01  0.82 0.01 0.48 1.00    8    13     6    0    38    38
140 21.4 28.4 0.07  0.0  60    19    0  32  0.53  0.01  0.64 0.01 0.51 0.98    8    16     8    0    46    46
141 20.1 25.2 0.08  0.0  55    24    0  34  0.66  0.02  0.78 0.02 0.60 1.00   11    19    10    0    57    57
142 19.1 28.9 0.09  0.1  52    29    1  36  0.51  0.01  0.64 0.01 0.47 1.00   13    24    13    0    71    71
143 19.7 27.1 0.09  0.1  52    32    1  38  0.51  0.02  0.61 0.02 0.42 1.00   15    29    16    0    85    85
144 18.6 24.4 0.10  0.1  47    36    1  40  0.52  0.02  0.62 0.02 0.42 1.00   17    35    20    0   102   102
145 16.6 26.2 0.11  0.1  34    21    1  42  0.19  0.01  0.23 0.01 0.15 1.00    9    38    22    0   111   111
146 19.3 24.4 0.11  0.1  51    43    1  44  0.37  0.02  0.45 0.02 0.29 1.00   20    45    26    0   131   131
147 19.2 26.2 0.12  0.1  52    58    1  46  0.49  0.03  0.59 0.03 0.37 1.00   27    55    32    0   158   158
148 20.1 29.0 0.13  0.1  55    75    2  48  0.50  0.03  0.60 0.03 0.37 1.00   34    67    41    0   192   192
149 21.3 27.8 0.13  0.2  60    93    2  50  0.63  0.05  0.72 0.05 0.43 1.00   43    81    51    0   235   235
150 20.9 26.5 0.14  0.2  59   114    2  52  0.78  0.08  0.87 0.08 0.49 1.00   53   100    65    0   288   288
151 21.1 26.8 0.15  0.2  61   143    3  54  0.75  0.09  0.84 0.09 0.45 1.00   66   122    82    0   354   354
152 21.3 34.6 0.16  0.3  59    86    5  56  0.27  0.04  0.29 0.04 0.16 0.99   35   134    91    0   389   389
153 20.6 23.0 0.17  0.3  55   158    3  58  0.59  0.09  0.63 0.09 0.33 0.97   71   159   111    0   460   460
154 19.7 25.0 0.17  0.4  53   191    4  60  0.76  0.13  0.78 0.12 0.40 0.87   76   185   132    0   536   536
155 20.0 25.7 0.18  0.4  57   231    4  62  0.74  0.15  0.77 0.11 0.38 0.76   80   212   155    0   616   616
156 21.3 29.8 0.19  0.5  61   224    7  64  0.52  0.12  0.52 0.08 0.25 0.72   70   236   175    0   686   686
157 23.3 27.7 0.20  0.5  67   264    6  66  0.69  0.17  0.66 0.12 0.31 0.70   82   263   200    0   768   768
158 23.3 26.7 0.21  0.6  68   329    7  68  0.84  0.22  0.79 0.16 0.36 0.71  104   299   232    0   872   872
159 22.6 30.1 0.22  0.7  67   304   10  70  0.59  0.17  0.54 0.12 0.24 0.71   94   330   262    0   966   966
160 24.0 29.3 0.23  0.7  67   203   10  72  0.34  0.10  0.30 0.07 0.13 0.71   58   349   282    0  1024  1024
161 24.0 27.3 0.24  0.8  70   392    9  74  0.72  0.23  0.64 0.23 0.47 0.98  175   408   340    0  1199  1199
162 25.8 30.6 0.25  0.9  78   471   14  76  0.77  0.28  0.66 0.28 0.47 1.00  211   478   412    0  1410  1410
163 26.1 30.0 0.26  1.0  79   481   15  78  0.73  0.29  0.58 0.29 0.38 1.00  214   549   488    0  1624  1624
164 27.5 29.0 0.27  1.2  83   562   16  80  1.01  0.45  0.74 0.44 0.45 0.97  244   630   576    0  1868  1868
165 26.2 26.7 0.29  1.3  79   644   16  82  1.05  0.50  0.73 0.37 0.41 0.73  208   699   654    0  2076  2076
166 27.3 29.0 0.30  1.4  83   660   21  84  1.05  0.54  0.68 0.34 0.36 0.63  176   756   723    0  2252  2252
167 25.9 27.2 0.31  1.5  75   696   20  86  0.91  0.48  0.58 0.36 0.31 0.76  231   831   815    0  2483  2483
168 24.6 26.3 0.32  1.7  73   667   21  88  0.88  0.49  0.53 0.42 0.33 0.84  247   911   915    0  2730  2730
169 26.3 26.3 0.33  1.8  78   764   23  90  0.94  0.55  0.54 0.32 0.31 0.59  189   972   994    0  2918  2918
170 24.9 26.7 0.34  1.9  73   629   25  90  0.76  0.46  0.40 0.31 0.22 0.68  177  1028  1071    0  3095  3095
171 22.5 23.9 0.35  2.0  63   726   22  90  0.50  0.31  0.29 0.30 0.19 0.99  322  1132  1209    0  3417  3417
172 22.4 27.0 0.36  2.2  63   728   30  90  0.50  0.32  0.26 0.32 0.16 1.00  315  1233  1348    0  3732  3732
173 21.0 23.9 0.37  2.4  59   791   26  90  0.61  0.40  0.29 0.34 0.21 0.86  295  1327  1480    0  4027  4027
174 22.9 25.0 0.38  2.5  66   851   30  90  0.84  0.58  0.36 0.41 0.24 0.72  258  1408  1598    0  4285  4285
175 22.8 23.6 0.39  2.7  66   711   29  90  0.69  0.49  0.27 0.41 0.17 0.84  253  1486  1716    0  4537  4537
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176	23.8	23.3	0.40	2.8	69	736	30	90	0.77	0.55	0.29	0.32	0.17	0.58	170	1537	1800	0	4708	4708
177	19.4	19.8	0.40	2.9	50	756	25	90	0.70	0.51	0.26	0.27	0.15	0.53	163	1585	1880	0	4870	4870
178	25.4	28.2	0.42	2.9	76	957	46	90	0.84	0.61	0.31	0.26	0.17	0.42	142	1623	1957	0	5013	5013
179	26.0	28.6	0.43	3.0	76	971	48	90	0.93	0.68	0.33	0.46	0.25	0.67	258	1694	2091	0	5270	5270
180	27.8	29.1	0.44	3.1	85	1035	52	90	0.92	0.68	0.32	0.60	0.26	0.87	372	1795	2285	0	5642	5642
181	27.5	27.1	0.45	3.2	83	1045	48	90	1.17	0.88	0.37	0.78	0.28	0.88	385	1899	2487	2	6027	6027
182	28.0	24.5	0.47	3.4	85	1070	43	90	1.05	0.80	0.32	0.73	0.26	0.91	415	2008	2703	10	6442	6442
183	29.9	27.2	0.48	3.5	85	978	55	90	1.01	0.79	0.28	0.77	0.21	0.97	390	2104	2908	25	6832	6832
184	27.8	24.3	0.49	3.7	85	1094	48	90	1.09	0.86	0.29	0.75	0.21	0.87	401	2201	3116	45	7233	7233
185	28.8	25.0	0.51	3.8	85	1097	53	90	0.85	0.67	0.22	0.66	0.18	0.98	465	2315	3347	89	7698	7698
186	29.9	28.4	0.52	4.0	85	1113	71	90	0.98	0.78	0.24	0.76	0.18	0.97	452	2411	3568	164	8149	8149
187	31.1	27.6	0.53	4.1	85	1074	72	90	0.85	0.68	0.19	0.67	0.14	0.98	441	2492	3778	267	8590	8590
188	33.7	31.2	0.54	4.2	85	1018	98	90	0.91	0.74	0.20	0.65	0.14	0.87	330	2533	3935	381	8920	8920
189	32.3	30.3	0.56	4.2	85	1001	95	90	1.04	0.85	0.22	0.70	0.17	0.83	303	2561	4075	512	9223	9223
190	33.0	30.0	0.57	4.3	85	1054	97	90	1.08	0.88	0.23	0.68	0.16	0.77	295	2577	4206	665	9518	9518
191	30.5	29.4	0.58	4.3	85	1131	96	90	1.44	1.18	0.30	0.73	0.20	0.62	201	2537	4312	815	9719	9719
192	27.0	22.9	0.59	4.2	79	1103	63	90	0.94	0.76	0.21	0.65	0.17	0.86	381	2536	4473	1046	10100	10100
193	26.2	23.6	0.60	4.1	75	1076	69	90	0.97	0.79	0.22	0.77	0.17	0.98	434	2535	4648	1324	10534	10534
194	24.9	18.9	0.61	4.1	74	1051	52	90	0.82	0.66	0.19	0.60	0.16	0.92	402	2526	4801	1594	10936	10936
195	27.8	26.5	0.62	4.1	85	1089	92	90	0.88	0.71	0.21	0.71	0.16	1.00	424	2502	4951	1913	11360	11360
196	29.1	26.2	0.63	4.0	85	1079	95	90	0.86	0.69	0.21	0.56	0.18	0.80	304	2464	5051	2175	11664	11664
197	29.9	29.5	0.64	3.9	85	1088	123	90	0.83	0.66	0.21	0.66	0.17	1.00	375	2413	5160	2517	12039	12039
198	28.7	26.9	0.65	3.8	85	1085	107	90	0.89	0.71	0.23	0.71	0.18	1.00	393	2368	5260	2876	12432	12432
199	27.7	26.0	0.66	3.7	80	917	104	90	0.82	0.65	0.21	0.50	0.19	0.76	199	2312	5305	3105	12630	12630
200	26.5	25.0	0.67	3.6	76	818	99	90	0.54	0.42	0.15	0.41	0.13	0.99	270	2272	5354	3384	12900	12900
201	25.7	25.5	0.68	3.5	75	972	106	90	0.68	0.53	0.20	0.51	0.17	0.96	325	2230	5404	3719	13225	13225
202	27.3	27.1	0.69	3.5	80	1007	122	90	0.98	0.76	0.29	0.73	0.24	0.96	326	2185	5441	4073	13551	13551
203	25.3	21.2	0.70	3.4	73	986	84	90	0.79	0.60	0.25	0.34	0.22	0.57	139	2119	5453	4280	13690	13690
204	26.1	29.1	0.71	3.2	76	987	146	90	0.81	0.61	0.27	0.57	0.22	0.92	273	2070	5460	4618	13963	13963
205	26.8	26.0	0.72	3.2	79	982	121	90	0.81	0.60	0.28	0.60	0.22	1.00	338	2031	5466	5007	14301	14301
206	27.3	25.7	0.73	3.1	81	975	122	90	0.83	0.62	0.29	0.58	0.25	0.94	301	1990	5458	5374	14602	14602
207	29.0	28.0	0.74	3.0	85	890	148	90	0.78	0.58	0.28	0.57	0.23	0.99	262	1948	5432	5725	14864	14864
208	27.4	23.6	0.75	2.9	79	663	112	90	0.40	0.29	0.15	0.29	0.12	1.00	193	1914	5404	5995	15057	15057
209	28.0	28.5	0.76	2.9	83	940	159	90	0.90	0.65	0.34	0.65	0.26	1.00	279	1873	5365	6376	15336	15336
210	29.1	26.8	0.77	2.8	85	921	146	90	0.78	0.56	0.31	0.56	0.23	1.00	284	1834	5331	6751	15621	15621
211	28.6	27.4	0.78	2.7	85	914	155	90	0.82	0.58	0.33	0.58	0.24	1.00	271	1796	5295	7115	15892	15892
212	28.6	27.9	0.79	2.6	84	859	165	90	0.75	0.52	0.31	0.52	0.22	1.00	235	1757	5259	7445	16127	16127
213	27.0	26.4	0.80	2.6	78	799	152	90	0.65	0.45	0.28	0.45	0.19	1.00	219	1721	5226	7750	16346	16346
214	27.4	27.2	0.81	2.5	79	862	163	90	0.64	0.43	0.29	0.43	0.19	1.00	238	1684	5192	8077	16585	16585
215	27.1	28.5	0.82	2.4	80	856	182	90	0.78	0.53	0.35	0.51	0.23	0.96	199	1644	5154	8373	16784	16784
216	27.1	26.6	0.83	2.4	80	855	162	90	0.83	0.55	0.38	0.51	0.24	0.93	201	1606	5121	8662	16985	16985
217	26.5	26.0	0.84	2.3	78	828	158	90	0.86	0.57	0.41	0.50	0.24	0.88	172	1566	5090	8921	17157	17157
218	26.8	26.4	0.85	2.2	79	803	166	90	0.82	0.53	0.40	0.44	0.23	0.83	130	1523	5059	9142	17287	17287
219	24.8	25.1	0.86	2.2	70	587	153	90	0.72	0.46	0.34	0.46	0.27	0.99	113	1491	5030	9331	17400	17400
220	25.2	22.5	0.87	2.1	70	526	129	90	0.40	0.25	0.21	0.25	0.16	1.00	110	1462	5006	9506	17510	17510
221	19.8	20.7	0.88	2.1	50	606	115	90	0.47	0.29	0.26	0.29	0.19	1.00	164	1435	4985	9728	17673	17673
222	23.7	25.1	0.88	2.0	67	706	157	90	0.76	0.47	0.40	0.47	0.28	1.00	169	1404	4956	9971	17843	17843
223	24.6	24.1	0.89	2.0	71	709	148	90	0.65	0.40	0.36	0.40	0.24	1.00	180	1375	4930	10220	18023	18023
224	25.7	26.2	0.90	1.9	74	708	174	90	0.73	0.44	0.41	0.44	0.26	1.00	153	1343	4900	10450	18176	18176
225	26.5	26.3	0.91	1.9	76	708	177	90	0.86	0.51	0.48	0.47	0.29	0.92	116	1308	4869	10646	18291	18291
226	26.2	25.3	0.92	1.8	76	699	167	90	0.78	0.46	0.46	0.43	0.27	0.94	133	1276	4841	10854	18424	18424
227	27.0	26.6	0.93	1.8	78	697	185	90	0.80	0.46	0.48	0.41	0.27	0.89	93	1240	4811	11029	18518	18518
228	26.9	27.2	0.94	1.7	78	615	193	90	0.74	0.42	0.44	0.35	0.24	0.84	30	1201	4779	11145	18547	18547
229	27.7	27.6	0.95	1.6	80	555	199	90	0.64	0.35	0.39	0.31	0.20	0.89	16	1164	4747	11245	18563	18563
230	26.0	26.6	0.96	1.6	74	603	186	90	0.59	0.31	0.38	0.31	0.29	1.00	88	1135	4717	11407	18651	18651
231	27.1	28.5	0.97	1.5	76	551	214	90	0.61	0.32	0.39	0.30	0.34	0.92	10	1101	4683	11503	18662	18662
232	26.2	27.6	0.98	1.5	73	564	201	90	0.52	0.27	0.36	0.27	0.29	1.00	55	1071	4651	11634	18717	18717
233	28.1	30.8	0.99	1.4	80	596	254	90	0.56	0.28	0.40	0.28	0.30	1.00	17	1038	4612	11741	18733	18733
234	28.4	32.6	1.00	1.4	82	587	287	90	0.63	0.31	0.44	0.31	0.33	1.00	-22	1004	4568	11819	18712	18712
235	27.6	29.5	1.01	1.3	80	541	232	90	0.83	0.40	0.56	0.40	0.40	1.00	13	974	4532	11914	18724	18724

D. SUMMARY OF SOIL PHYSICAL DATA

Soil physical data for the calculations at PS-2 level

Soil				<---- Section A: 0 - 20 cm ---->							<---- Section B: 20 - 80 cm ---->							<---- Section C: 80 - 140 cm ---->						
Unit	RDM	SO	A	KO	SMO	GRV	GAMA	PSIm	AK	ALF	KO	SMO	GRV	GAMA	PSIm	AK	ALF	KO	SMO	GRV	GAMA	PSIm	AK	ALF
F1AP1w	80	0.40	0.0006	0.0014	0.302	3	0.01435	300	14.4	0.0231	0.0028	0.427	6	0.01019	300	55.6	0.0174	0.0028	0.427	10	0.01019	300	55.6	0.0174
F1Ah1w	70	0.50	0.0003	0.0009	0.369	6	0.01190	170	36.0	0.0237	0.0028	0.427	6	0.01019	300	55.6	0.0174	0.0028	0.427	10	0.01019	300	55.6	0.0174
F1Ap1M	80	0.30	0.0001	0.0002	0.276	4	0.01558	300	14.4	0.0231	0.0095	0.409	4	0.01068	300	55.6	0.0174	0.0095	0.409	4	0.01068	300	55.6	0.0174
F1Ap2w	80	0.40	0.0006	0.0014	0.327	3	0.01337	300	14.4	0.0231	0.0028	0.494	4	0.00847	300	55.6	0.0174	0.0028	0.445	7	0.00970	300	55.6	0.0174
F1Ah2w	70	0.50	0.0005	0.0016	0.361	3	0.01215	300	55.6	0.0174	0.0028	0.548	4	0.00725	300	55.6	0.0174	0.0028	0.455	7	0.00945	300	55.6	0.0174
F1Ah2m	70	0.50	0.0006	0.0020	0.361	3	0.01215	300	55.6	0.0174	0.0028	0.548	4	0.00725	300	55.6	0.0174	0.0028	0.455	7	0.00945	300	55.6	0.0174
F1Vpw	80	0.83	0.0020	0.0095	0.427	3	0.01019	300	55.6	0.0174	0.0028	0.515	3	0.00798	300	55.6	0.0174	0.0028	0.515	3	0.00798	300	55.6	0.0174
F1Vpm	80	0.83	0.0020	0.0095	0.427	3	0.01019	300	55.6	0.0174	0.0028	0.515	3	0.00798	300	55.6	0.0174	0.0028	0.515	3	0.00798	300	55.6	0.0174
F1Ic	55	0.40	0.0006	0.0028	0.455	3	0.00945	300	55.6	0.0174	0.0028	0.455	3	0.00945	300	55.6	0.0174	0.0028	0.455	3	0.00945	300	55.6	0.0174
F2Ah	80	0.60	0.0022	0.0070	0.354	0	0.01239	300	14.4	0.0231	0.0070	0.393	0	0.01117	300	55.6	0.0174	0.0069	0.393	0	0.01117	300	55.6	0.0174
F2If	80	0.60	0.0022	0.0052	0.360	0	0.01313	300	14.4	0.0231	0.0052	0.414	0	0.01068	300	55.6	0.0174	0.0400	0.335	0	0.01435	290	26.5	0.0248
HAhf	90	0.60	0.0043	0.0136	0.361	0	0.01215	300	33.6	0.0353	0.0136	0.361	0	0.01215	200	33.6	0.0353	0.0136	0.361	0	0.01215	200	33.6	0.0353
HIc	80	0.60	0.0840	0.2658	0.390	0	0.01617	300	14.4	0.0231	0.2658	0.390	0	0.01617	300	14.4	0.0231	0.2658	0.390	0	0.01617	300	14.4	0.0231
AE1	110	1.01	0.0520	0.1234	0.292	3	0.02886	290	26.5	0.0248	0.1234	0.282	3	0.03023	290	26.5	0.0248	0.1234	0.271	3	0.03160	200	16.4	0.0398
AE2	110	0.80	0.0300	0.0712	0.308	10	0.02680	290	26.5	0.0248	0.0712	0.308	10	0.02680	290	26.5	0.0248	0.0712	0.308	10	0.02680	300	14.4	0.0231
AE3	80	0.60	0.0084	0.0266	0.387	0	0.01651	300	14.4	0.0231	0.0266	0.414	0	0.01308	300	14.4	0.0231	0.0266	0.414	0	0.01308	300	14.4	0.0231
1Ic3	55	0.85	0.0130	0.0411	0.445	30	0.01451	290	26.5	0.0248	0.0411	0.445	50	0.00892	290	26.5	0.0248	0.0411	0.445	60	0.01414	290	26.5	0.0248
1Ip	40	0.85	0.0130	0.0411	0.454	3	0.01358	200	33.6	0.0353	0.0411	0.454	3	0.01358	200	33.6	0.0353	------	-----	--	-------	---	----	------
1El	80	0.85	0.0130	0.0411	0.445	30	0.01451	290	26.5	0.0248	0.0411	0.445	80	0.01451	290	26.5	0.0248	------	-----	--	-------	---	----	------
1Ic4	55	0.80	0.0060	0.0285	0.503	3	0.00817	300	55.6	0.0174	0.0285	0.503	3	0.00817	300	55.6	0.0174	0.0285	0.503	3	0.00817	300	55.6	0.0174
2El	80	1.06	0.0150	0.0356	0.449	50	0.01414	290	26.5	0.0248	0.0411	0.445	80	0.01451	290	26.5	0.0248	------	-----	--	-------	---	----	------
2Ic3	45	1.06	0.0150	0.0356	0.449	12	0.01414	290	26.5	0.0248	0.0411	0.445	12	0.01451	290	26.5	0.0248	0.0356	0.449	60	0.01414	290	26.5	0.0248
2Ic4	50	0.80	0.0060	0.0285	0.497	0	0.00892	300	55.6	0.0174	0.0285	0.497	0	0.00892	300	55.6	0.0174	0.0285	0.497	0	0.00892	300	55.6	0.0174
2Id3	60	1.06	0.0150	0.0475	0.469	3	0.01190	300	55.6	0.0174	0.0475	0.476	3	0.01115	300	55.6	0.0174	0.0475	0.480	3	0.01078	300	55.6	0.0174
2Id4	85	0.80	0.0060	0.0189	0.471	3	0.01171	300	55.6	0.0174	0.0142	0.493	5	0.00929	300	55.6	0.0174	0.0142	0.493	8	0.00929	300	55.6	0.0174
2Iv	85	0.80	0.0030	0.0095	0.481	0	0.01059	300	55.6	0.0174	0.0095	0.481	0	0.01059	300	55.6	0.0174	0.0095	0.481	0	0.01059	300	55.6	0.0174
2Mt	75	1.43	0.0150	0.0475	0.490	7	0.00966	300	55.6	0.0174	0.0475	0.493	7	0.00929	300	55.6	0.0174	0.0475	0.500	7	0.00854	300	55.6	0.0174
2fIp	40	1.43	0.0150	0.0475	0.480	0	0.01078	300	55.6	0.0174	0.0475	0.480	0	0.01078	300	55.6	0.0174	------	-----	--	-------	---	----	------
3Vt	90	1.10	0.0035	0.0166	0.495	0	0.00910	300	55.6	0.0174	0.0712	0.502	0	0.00836	300	55.6	0.0174	0.0712	0.502	0	0.00836	300	55.6	0.0174
3Mv	80	1.43	0.0150	0.0712	0.497	0	0.00892	300	55.6	0.0174	0.0475	0.488	0	0.00985	300	55.6	0.0174	0.0117	0.471	0	0.01171	300	55.6	0.0174
3Mv/c	100	0.43	0.0150	0.0712	0.500	2	0.00854	300	55.6	0.0174	0.0712	0.497	2	0.00892	300	55.6	0.0174	0.0712	0.497	2	0.00892	300	55.6	0.0174
3Iv	60	0.80	0.0030	0.0142	0.495	0	0.00910	300	55.6	0.0174	0.0142	0.485	0	0.00910	300	55.6	0.0174	0.0142	0.485	0	0.00910	300	55.6	0.0174
AcEx1	90	0.80	0.0500	0.1187	0.460	0	0.02156	290	26.5	0.0248	0.3472	0.480	0	0.02396	290	26.5	0.0248	0.3472	0.480	0	0.02540	290	26.5	0.0248
AcEx2	75	0.01	0.0500	0.0119	0.500	0	0.02059	300	14.4	0.0231	0.0119	0.460	0	0.02011	290	26.5	0.0248	0.0119	0.500	0	0.02300	290	26.5	0.0248
AmEx1	140	0.03	0.0004	0.0009	0.460	0	0.01867	300	14.4	0.0231	0.0009	0.490	0	0.02107	290	26.5	0.0248	0.0009	0.460	0	0.02107	290	26.5	0.0248
AmEx2	110	0.16	0.0010	0.0024	0.460	0	0.01867	300	14.4	0.0231	0.0024	0.520	0	0.01626	300	47.3	0.0200	0.0024	0.470	0	0.02492	290	26.5	0.0248
AmEx3	90	0.16	0.0010	0.0032	0.510	0	0.01434	300	1.69	0.0248	0.0032	0.510	0	0.01578	170	36.0	0.0237	0.0032	0.510	0	0.01578	170	36.0	0.0237
AmExa	75	0.03	0.0004	0.0010	0.500	0	0.02059	300	14.4	0.0231	0.0119	0.460	0	0.02156	290	26.5	0.0248	0.0119	0.460	0	0.02444	290	26.5	0.0248
AmEae	100	0.47	0.0050	0.0158	0.510	0	0.01434	300	1.69	0.0248	0.0237	0.460	0	0.01915	300	14.4	0.0231	0.0237	0.460	0	0.02156	300	14.4	0.0231
AbIxv	100	1.95	0.0620	0.1962	0.520	0	0.00761	300	55.6	0.0174	0.1962	0.520	0	0.00472	300	55.6	0.0174	0.1962	0.520	0	0.01723	300	47.3	0.0200
AbIav	100	1.95	0.0400	0.1899	0.520	0	0.00568	300	55.6	0.0174	0.1899	0.520	0	0.00328	300	55.6	0.0174	0.1899	0.520	0	0.00809	300	55.6	0.0174
AbIxa	100	0.54	0.0270	0.0854	0.470	0	0.01626	200	33.6	0.0353	0.1000	0.510	0	0.00953	200	55.6	0.0174	0.1000	0.510	0	0.00857	200	1.69	0.0248
AbExa	80	0.03	0.0004	0.0010	0.500	0	0.02059	300	47.3	0.0200	0.0010	0.460	0	0.02156	300	14.4	0.0231	0.0010	0.490	0	0.01530	300	14.4	0.0231
AbEae	80	0.47	0.0050	0.0119	0.460	0	0.01963	300	14.4	0.0231	0.0119	0.530	0	0.01915	300	47.3	0.0200	0.0119	0.520	0	0.01723	300	47.3	0.0200
AbEa	80	0.47	0.0050	0.0119	0.540	0	0.00713	50	28.2	0.0480	0.0119	0.540	0	0.00713	50	28.2	0.0480	0.0119	0.540	0	0.00664	50	28.2	0.0480
FEx1	80	0.80	0.0500	0.1187	0.460	20	0.02011	300	14.4	0.0231	0.1187	0.460	20	0.02204	300	26.5	0.0248	0.1187	0.460	50	0.02204	290	26.5	0.0248
FEx2	60	0.80	0.0500	0.1187	0.460	20	0.01771	300	14.4	0.0231	0.1187	0.460	50	0.01482	300	14.4	0.0231	0.1187	0.510	60	0.01194	300	1.69	0.0248
FIx	80	0.54	0.0270	0.0854	0.510	0	0.01194	300	1.69	0.0248	0.0854	0.510	0	0.01194	300	1.69	0.0248	0.0854	0.510	0	0.01194	300	1.69	0.0248
EI/Exa	80	0.54	0.0270	0.0854	0.510	0	0.01194	170	36.0	0.0237	0.0854	0.490	0	0.01194	170	36.0	0.0237	0.0854	0.510	0	0.01194	170	36.0	0.0237
EEae	80	0.47	0.0050	0.0119	0.520	0	0.01434	300	47.3	0.0200	0.0119	0.520	0	0.01434	300	47.3	0.0200	0.0119	0.470	0	0.02396	300	16.4	0.0398
Thes.	140	0.51	0.0124	0.0184	0.439	0	0.03300	200	16.4	0.0398	0.0184	0.439	0	0.03300	200	16.4	0.0398	0.0184	0.439	0	0.03300	200	16.4	0.0398
TEI/L	100	0.28	0.0020	0.0024	0.500	0	0.00589	300	55.6	0.0174	0.0024	0.500	0	0.00589	300	55.6	0.0174	0.0024	0.500	0	0.00589	300	55.6	0.0174

Note: RDM (cm), SO (cm min$^{-1/2}$), A (cm/min), KO (cm/min), SMO (cm^3/cm^3), GRV (gravel in vol. %), GAMA (cm^{-1}), PSIm (cm), AK (cm^2/d), ALF (cm^{-1})

E. COSTS OF OPERATIONS

E.1 Operations other than irrigation

Ploughing	43 ECU/ha
Disking	18 ECU/ha
Harrowing	19 ECU/ha
Sowing wheat	20 ECU/ha
Sowing maize	28 ECU/ha
Sowing cotton	28 ECU/ha
Fertilization	8 ECU/ha
Pest control	8 ECU/ha
Harvest of cotton	134 ECU/ton
Harvest of Cereals	8% of gross return
Transport	6.2 ECU/ton

After Min. Env., Planning & Public Works (1987). The original figures for 1983 (in drs/stremma) have been converted to ECU/ha.

E.2 Costs of irrigation

- The 3 irrigation methods considered are:
I. drip irrigation
II. overhead irrigation with travelling guns
III. overhead irrigation with moving laterals

- The costs are split into:
1. Pumping costs
2. Labour costs
3. Capital investment (annual pay-off)

Pumping costs

Assumptions
-- parcel size (A) is 10 ha;
-- discharge (Q) is 9.72 lt/sec (35 m^3/hour);
-- operating pressure (H) is 45 m for drip irrigation (I) and for irrigation with moving laterals (III); H=35 m for irrigation with travelling guns (II).
-- days of full operation (T) is 80;
-- operating hours per day (h) is 13 (III) and 18 (I&II);
-- efficiencies 0.65 (pump) and 0.85 (motor);
-- agric. tariff for electricity (electrical motor) (P) is 0.0374 ECU/kWh

Calculation of hourly pumping cost (Ch) and total pumping cost

I. Drip irrigation

$$Ch = \frac{9.72 \times 35 \times 0.0374}{102.4 \times 0.65 \times 0.85} = 0.224 \text{ ECU/hour}$$

Total cost = 0.224*80*18=323 ECU/10 ha or 32 ECU/ha

II. Travelling guns

$$Ch = \frac{9.72 \times 45 \times 0.0374}{102.4 \times 0.65 \times 0.85} = 0.288 \text{ ECU/hour}$$

Total cost = 0.288*80*18=414.7 ECU/10 ha or 42 ECU/ha

III. Moving laterals

$$Ch = \frac{9.72 \times 35 \times 0.0374}{102.4 \times 0.65 \times 0.85} = 0.224 \text{ ECU/hour}$$

Total cost = 0.224*80*13=232.9 ECU/10 ha or about 23 ECU/ha

Labour costs

I. Drip irrigation:

-application:	approx. 7 ECU/ha
-installation/removal:	64 ECU/ha
-total:	71 ECU/ha

II. Travelling guns:
-application: approx. 25 ECU/ha (80 days, 1 hour/day, 23.8 ECU daily wage).

III. Moving laterals:
- 1.8 man-day/day (full occupation of the farmer and another helper-member of the family) for 100 days. At a daily wage of 3.8 ECU, the total cost amounts to 4,250 ECU/10 ha or 425 ECU/ha.

Annual amortization

$$\text{Annual amortization} = K * r * \frac{(1+r)^n}{(1+r)^n - 1},$$

where K=capital invested, r=annual interest rate, and n=life span (years).

Capital invested	Interest	Years	Ann.Pay-off	Ann. Pay-off/ha
I. 1,390 ECU	0.15	5	4,160 ECU	416
II. 12,800 ECU	0.15	20	2,045 ECU	205
III. 1,276 ECU	0.15	15	218 ECU	22

Approximate total irrigation cost

I. Drip irrigation: 32+71+416=519 ECU/ha
II. Travelling gun: 42+25+205=272 ECU/ha
III. Move-laterals: 23+425+22=470 ECU/ha

E.3 Cost of agricultural production of maize, cotton and wheat in the Larissa plain (ECU/ha).

ITEM	MAIZE	COTTON	WHEAT
Materials[1]			
Fertilizers	170	120	120
Seed	85	35	17
Pesticides	13	70	7
Operations[2]			
Fertilization	8	8	8
Sowing	28	28	20
Cultivation	123	123	43
Pest control	8	8	8
Harvest	8% of returns	134/ton	8% of returns
Miscellaneous	8	27	6
Annual pay-off buildings, constr.	77	192	64
Labour (-irrigation)	60	60	60
Taxes	20	90	15

Irrigation costs (see Appendix E.2)

	Pumping	Labour	Amortization	Total
I. Drip Irrigation	32	71	416	519
II. Travelling guns	42	25	205	272
III. Moving laterals	23	425	22	470

Legend: [1] average values from Section 5.2 of main text. [2] See Appendix E.1. "Miscellaneous"; includes also maintenance of buildings and constructions. This item and the items "annual amortization of buildings and constructions" and "taxes" are adopted from farm utilization studies done in the Larissa region by Pagonis (1987). Costs of land are not considered in this study.

SUMMARY

A dynamic crop-growth simulation model was developed, based on the "Wageningen modelling approach", calibrated and applied for quantified land evaluation purposes in the Larissa (east Thessaly) plain, Greece.

The soil and climatic conditions of 3 pilot areas were studied in detail. The areas studied, the Nikea area, the Platanoulia area and the Peneios delta area have a total extent of about 10,000 ha. After an introductory chapter, the physical environment is discussed in Chapter 2. Section 2.1 gives a brief introduction to the geomorphology and (agro)climate of the Larissa region in general. The pilot areas are described in Sections 2.2 through 2.4. The Karla area is discussed in Section 2.5; this area was not studied in detail, but its brief description complements the global overview of the Larissa region.

The Nikea pilot area (Section 2.2) includes soils formed on Tertiary slopes and in the valleys of the Middle Thessalic Threshold. It is located 10 km south of the city of Larissa, between 95 and 180 m ASL, and covers 1,815 ha. The Platanoulia pilot area (Section 2.3) includes soils formed on the Pleistocene terrace, on the Holocene terraces and in the meandering flood plain of the Peneios river. It is located in the western Larissa plain, 11 km west-northwest of the city of Larissa, between 74 and 110 m ASL, and covers 2,000 ha. The third pilot area (Section 2.4) comprises a large part of the Peneios delta and has a different climate from the rest of the Thessaly plain and soils with a shallow ground-water table. It is situated between 0 and 15 meters ASL, includes the channel- and meander-belt of the Peneios river, backswamps, estuarine plain, beach ridges and some alluvial fans, and covers 57 km^2.

Quantitative correlations have been established between soil conditions, notably the texture, and the physical parameters required for simulating the production environment. Besides soil conditions, the geology, geomorphology and hydrology of the pilot areas as well as the human environment were studied.

Methodology is discussed in Chapter 3. In Section 3.1, the biophysical production potential is calculated. The rate of CO_2 reduction by the green canopy is determined as a function of the available solar radiation, the temperature and the properties of the crop canopy. The partitioning of the assimilates to the various plant organs is described. A substantial deviation from the Wageningen approach is that the maintenance cost per plant organ is subtracted from the assimilates allocated to each organ. Losses incurred in the conversion of sugars to structural plant material are accounted for thereafter. The development stage is computed on the basis of the accumulated heat units above a threshold temperature. For the calculation of heat units, the temperature of the canopy was used. The calculations of each interval conclude with the adjustment of the dry weights of all plant organs and the calculation of a new value for the total leaf area.

In Section 3.2, the water-limited production potential is discussed. The actual assimilation rate is related to the calculated actual water consumption, and the reduction of production due to water stress is expressed by the ratio of the actual over the maximum transpiration rates. The maximum transpiration rate is calculated from the potential transpiration rate and the leaf

area of the crop. The actual transpiration rate is a function of the quantity of soil moisture available for uptake. The latter is described in a dynamic water balance model, which accounts for all fluxes of water in the system and their interactions. A multi-layered soil profile is considered. The upper boundary is the soil surface; the lower profile boundary is the lower boundary of the lowermost compartment. Apart from surface losses/influx and loss or gain of water through the lower boundary, loss of water takes place from the rooted interior part of the profile through uptake by the roots. Three soil layers are considered, viz. A: 0-20 cm, B: 20-80 cm and C: 80-140 cm. All compartments in the same soil layer have the same soil physical properties, which enables to use the information supplied by the National Soil Map. The number and depth of the soil layers can however be easily modified.

In Section 3.3, the time to ponding, vital to the assessment of effective irrigation and rainfall influx is discussed in relation to soil sorptivity and soil permeability. Soil sorptivity is approximated from a reference value, modified as a function of the actual and saturation soil moisture contents. The roles of permeability and conductivity (saturated and transmission zone conductivity) are discussed. Data measured on non-swelling soils in the study area could be satisfactorily reproduced with the simplified Philip model if the latter is improved to account for experimental errors. Thus sorptivity and "final" permeability values could be established for major soils in the study area. In strongly swelling Vertisols, infiltration is unpredictable, as bypass flow, prior to closure of surface cracks outweighs infiltration and greatly influences irrigation management. Although the supporting data are limited, soils with weakly swelling properties show a slow re-orientation rate and exhibit a compound behaviour with elements of both rigid and swelling soils.

Chapter 4 is concerned with the collection of crop/cultivar-specific input data and the calibration of data for maize (Section 4.1), cotton (Section 4.2) and wheat (Section 4.3). The growth of maize cv. ARIS and cotton cv. ZETA-2 was studied in Larissa in 1987 and 1988. In the same years, the growth of maize cv. PIONEER 3165-DONA was studied in Thessaloniki. Additional information for a number of other maize plantings in Larissa, Thessaloniki and Aliartos was collected as well, including the cv. PIONEER 3183. The experiments of 1987 were carried out with maximum fertilization, frequent irrigation and total pest/disease control. In the experiments of 1988, fertilization and weed control were also optimum, but the effect of water stress on potential production was studied in a number of alternative irrigation scenarios. The potential growth of wheat cv. MEXICALI 81 was recorded in a fully (drip) irrigated and fertilized planting in Larissa 1988-89 and compared with the growth of a rainfed crop. The same variety was observed in Spata (Athens) in 1991.

From the results, the crop constants, viz. the threshold temperature, the accumulated heat requirements for anthesis and from anthesis to maturity, the reference temperature for maintenance respiration, and the rate variables, viz. the specific leaf area, the assimilate partitioning and the dying rate of leaves, were established. Cotton in particular proved very sensitive to the ambient temperature; the importance of the introduced canopy temperature is discussed. The good agreement between measured growth rates and those simulated with the model demonstrates the model's flexibility and capacity to predict the yield fluctuations observed in different years, with different irrigation methods and applications, plant densities and sowing/germination dates.

Chapter 5 deals with land evaluation. A complete land evaluation of the Larissa area on the basis of the FAO-Framework was not attempted. Rather, it was demonstrated that the model developed allows to quantify reference yield levels and the impact of selected limitations on land-use system performance as a basis for Land Suitability classification.

After an introductory section, the key attributes of relevant Land Utilization Types including the 3 studied commodities are discussed (Section 5.2). In Section 5.3, the corresponding Land Qualities and their place in the crop-growth simulation model are described. The Land and Land Use characteristics considered in the calculations of the production potentials are summarized. The potential production levels are quantified in Section 5.4. Attention is given to year-to-year fluctuations and to fluctuations associated with different sowing/germination dates, cultivars, plant densities and their interactions. A methodology for quantifying the "fertilizer-nutrient requirement" is additionally discussed in Section 5.5.

The calculated reference yield levels and the impact of selected limitations on sample land use systems form the basis of Land Suitability Classification in the area. This is explained in Section 5.6, where the cost-benefit ratio of scenarios with present and future inputs are discussed on the basis of simple economic considerations and under the assumption that the water-limited production potential is within the reach of the farmers in the study areas.

CURRICULUM VITAE

Nicholas Gerassimou Danalatos was born on Kos, Greece, on October 6th, 1958. After obtaining his Gymnasium certificate at the Experimental School of the University of Athens, he started his studies at the Aristotle University of Thessaloniki, School of Agriculture, in 1976. He completed his studies at the Agricultural University of Athens in 1982, graduating as an Agricultural Engineer, specializing in Land Reclamation with a major assignment on Land Evaluation. From 1983 to 1985 he followed the M.Sc. Course in Soil Science and Water Management at the Agricultural University of Wageningen. He graduated in June 1985, specializing in Land Evaluation and Agropedology. In February 1986 he undertook research leading to the degree of Doctor in Agricultural Science at the Agricultural University of Wageningen. He worked both in The Netherlands (Wageningen) and in Greece (Larissa and Thessaloniki) on a 4-years Dutch Government scholarship. In the summer periods of 1987 through 1989, he was guest-researcher and he obtained facilities to prepare his thesis at the Institute of Soil Mapping and Classification and the Technological Education Institution (TEI), School of Agriculture, in Larissa. After completing his military duty in August 1990, he was employed by the Agricultural University of Athens, Department of Soil Science and Agricultural Chemistry, where he participated in 3 EEC Projects, viz. the "Evaluation of Soil Resources in the Prespa Region", MEDALUS (EPOCH) and WASTES (STEP) projects. In the period October 1991-June 1992 he finalized his doctoral thesis in Wageningen, supported by the "Sandwich Fellowship Program" of the Wageningen Agricultural University. He resumed his assignment at the Agricultural University of Athens in June 1992.