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Production and water use of several food and fodder crops under irrigation in the desert area of southwestern Peru

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Summarized from the extensive report in the Spanish language entitled: Factores que influyen en la producción de cultivos alimenticios y forrajeros en areas deserticas, edited by Isaac Zipori, Mark N. Versteeg and L. Huber Valdivia, Arequipa, Peru, 1982, 398 pp.

A limited number of copies of this publication is available on request at the Centre for Agrobiological Research, P.O. Box 14, 6700 AA Wageningen, the Netherlands.

The growth dynamics of alfalfa, Rhodes grass, maize and potatoes is also treated extensively in a Ph. D. thesis entitled: ' Factors influencing irrigated crop production in southern Peru in relation to prediction by simulation models', by M.N. Versteeg, together with efforts to simulate the production of these crops under the prevailing conditions. This thesis will appear in the beginning of 1985. It can also be ordered at the adress given above.

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Abstract

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This report describes the results of a research project in the desert of southwestern Peru that was carried out jointly by researchers from Peru, Israel and the Netherlands.

Because the only way to extend agriculture in this area is by irrigation, data were obtained on production and water use of the most important crops for the area; data were also obtained on the water holding capacity and fertilizer requirements of several soil types.

The results indicate considerable differences in the water use efficiency between crops and the possibility of high growth rates under the prevailing climatic conditions.

Free descriptors: growth dynamics, potential yield, transpiration coefficient, water use, dry matter production, leaching of salts, alfalfa, maize, Rhodes grass, potatoes.

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1 Introduction

At the request of the Directorate for International Technical Aid of the Dutch Ministery of Foreign Affairs, a Dutch-Israeli cooperation was initiated in 1970 to study agricultural production possibilities in arid regions, under conditions of natural rainfall and irrigation.

Both aspects were worked out in a project under supervision of experts from the Botany Department of the Hebrew University (HU) of Jerusalem (the late H.N. Tadmor), the Faculty of Agriculture of this university in Rehovot (A. Dovrat), the Department of Theoretical Production Ecology of the Agricultural University, Wageningen (C.T. de Wit) and the Institute for Biological and Chemical Research on Field Crops and Herbage (IBS), Wageningen (Th. Alberda).

The 'dry part' of the project focused mainly on the primary production possibilities of natural pastures with and without fertilization under rainfed conditions; the 'wet part' studied the production potentials of crop surfaces under near optimum conditions of water and fertilization. Not only was the productivity in both parts determined, but attention was also paid to the underlying physiological processes, such as photosynthesis, respiration and transpiration, and to the influence of soil and climatic factors on these processes.

A better understanding of these underlying processes enabled adaptation of existing simulation models to arid conditions. Furthermore, new, specific ones were developed to predict the production potentials in other arid areas, given the climatological and soil characteristics.

The project lasted four years and resulted in a number of publications (see Van Keulen & De Wit, 1975) and in the wish on the part of both participating countries to continue the cooperation and to apply the methodologies and results. To this purpose three new coordinated projects were initiated:

- Continuation of the research on productivity of natural rangelands in arid regions, with more emphasis on secondary production and production stability. Research was carried out mainly in Israel under the name APPSAG-II.
- Research on productivity of natural rangelands in the Sahelian Zone of Africa, and the possibilities of its utilization. This is mainly a continuation of the dry part; it has been executed as the PPS project in Mali (Penning de Vries & Djitèye, 1982).
- Research on production possibilities of food and fodder crops in the

desert area of southwestern Peru with ample supply of fertilizers and irrigation water; this is mainly a continuation of the wet part.

The activities of the latter project were excuted under the title: Factores que influyen en la producción de cultivos alimenticios y forrajeros en areas deserticas (FAPROCAF). The main purpose of the project was to study the factors governing crop productivity, both under optimal and stress conditions for minerals and water to provide data to be used by extension officers in the region and for extrapolation to other arid areas.

Southwestern Peru was chosen for several reasons:

- When the project was initiated Peru belonged to the target countries, countries on which Dutch development aid centres.
- There were already two projects at the chosen site, one under Dutch, the other under Israeli, supervision.
- The local people already cultivated irrigated crops in the river valleys, and thus were familiar with this technique.
- Because of the absence of precipitation the area is ideally suited for water balance experiments.
- The Peruvian government is developing a large irrigation project in the neighbourhood and data on crop production and water use are of great importance for this project.
- There was already an experimental station in the area: offices and a laboratory with some equipment were available for the project, as well as the possibility of conducting field trials in the direct vicinity.

Once basic agreement about the project was reached between the three countries involved, a more detailed plan of operations was worked out and approved. This done, the personnel were selected and appointed.

The actual research commenced at the end of 1978 and continued until August 1982. This report contains a summary of the various experiments carried out and the results obtained. Extensive information can be found in the original project report, which is published in Spanish (Zipori et al., 1982).

2 Duration of the project, and participants

The project lasted four years. It started with the appointment of the three foreign scientists, who, together with the consultant experts of the Dutch-Israeli collaboration, mentioned in the Introduction, made a scheme of the topics for research for the first half of the project. In the meantime all the necessary formalities between the three countries were fulfilled and the work in Peru started with the appointment of the Peruvian personnel. Together with them, experiments were carried out and the laboratory was extended and updated with the new instruments, so that the processing and analyses could be carried out as soon as the first samples from the trials arrived.

For the first half of the project, the plan of experiments was carried out in close cooperation between the foreign experts and the appointed Peruvian scientists. Reports of results, alterations, difficulties encountered, etc., were sent regularly to the consultants in Israel and the Netherlands; comments were sent back before the next report had to be written. This and the telex communication and the yearly visits of the consultants ensured that there was a constant contact between the project and the mother institutions in both Israel and the Netherlands.

During the second half of the project there was a gradual shift of leadership from the foreign to the Peruvian scientists, so that the latter could take over the daily leadership, the planning and execution of the experiments and reporting. The result was that at by the end of the project, in August 1982, a symposium could be held during which all scientists and the laboratory staff could actively participate, and which was attended by over 200 participants. All the papers presented at this symposium are bundled into the book on which this Agricultural Research Report is taken.

The following persons were attached to the project:

Consultants
Dr Th. Alberda (CABO), general project leader until 1 Oct. 1979
Dr Ir H. van Keulen (CABO), general project leader after 1 Oct. 1979
Prof Dr A. Dovrat (HU)
Ing^{o}. Luiz Juarez G. (INIPA)

Research workers
Ir M.N. Versteeg, crop scientist, daily project leader

Mr I. Zipori, soil scientist
Ing^{o}. J. Medina L., crop scientist
Ing^{o}. L. Valdivia P., soil scientist, acting daily project leader

Laboratory staff
Mr M. de Wijs, laboratory head
Ing^{o}. E. Soto P., acting laboratory head
Ms J. Sanz C.
Ms V. Frisancho M.
Ms E. Gonzalez Ch.*
Mr J. Gutiérrez G.
Mr L. Ramirez L.

*Not for the whole duration of the project

Administrative personnel

Mr J. Montoya N.*
Mr L. Ramos N.*
Ms Y. Rendón Z.*
Ms F. Rendón Z.*
Ms M. Llerena V.*
Ms E. Caceres A.*

Field workers
Mr M. Yajo F.
Mr A. Melgar V.
Mr F. Pari Q.
Mr D. Javier R.
Mr T. Châvez V.
Mr A. Yajo F.
Mr R. Yajo F.

Students
Ms Odile Nijssen*
Ms Gerriet Kooi*
Mr Gert-Jan Noij*
Mr Henk Haitsma*
Mr Wim van der Putten*

*Not for the whole duration of the project

3 The analytical laboratory

To obtain data on the fresh and dry weight of plant material harvested, on the chemical composition of plants, soils and irrigation water, and for additional measurements and analyses, it was necessary to have a laboratory at hand. Particularly as the experimental site was in the middle of the desert, more than one hour's driving from the nearest town. Facilities for chemical analyses of the main nutritional elements as well as the main organic plant constituents were required.

Fortunately, a laboratory was already available at the start of the project. The building was upgraded and extended somewhat. The laboratory was supplied with the necessary equipment to carry out the analyses just described. Care was taken to adopt relatively simple analytical procedures and instruments and to have a stock of spare-parts. In addition, a dust free air filtering system was installed and the electrical power supply was improved and supplemented by two extra diesel generators over the one already available.

In this way it was possible to work very efficiently as the analytical results were quickly available, which facilitated planning of successive trials. Quality control of the analytical results was carried out through analysis of control samples, sent regularly to several analytical laboratories by the Department of Soils and Fertilizers of the Agricultural University, Wageningen.

It is not considered necessary to present an extensive description of the building and its equipment in this publication; this is given in Zipori et al. (1982).

4 Results

4.1 GENERAL ASPECTS

Peru does not produce enough food for its entire population, around 17 million inhabitants. This is largely due to the fact that a relatively large area is natural grassland. For the world as a whole the ratio of the acreage of permanent grassland to arable land is 2.29; for the South American continent it is 4.47 and for Peru 8.75. For Peru to become self sufficient in food 1.64 million hectares of grassland would have to be turned into arable land, which is 6 % of the grassland area. It must be realized, however, that large parts of this area are not suited for arable agriculture because of slope or altitude. Self sufficiency may also be achieved by increasing the output per hectare, but that is a rather slow approach since it seems difficult to increase the productivity with more than 80 kilograms per hectare per annum (De Wit et al., 1979).

For Peru there is still another possibility: to increase the area of arable land by irrigating the desert. Around 7 500 ha is already under irrigation and in the coming years another 60 000 ha will be added when the Majes project is executed. As the irrigation water that reaches the pampas is expensive, due to all the technical works involved, it is of the utmost importance that data are available on productivity and water use of the most important crops in the area, in order to try to use the available water as efficiently as possible. One of the main purposes of FAPROCAF was to obtain more data on this aspect.

Among the aims of the project were an increase of insight into the processes governing crop productivity in arid regions, extrapolation of the data obtained to other arid areas, and in this way the saving of time and money. The data obtained were used to test existing simulation programs that had been developed for other arid areas, to correct and improve them if necessary and to develop additional ones.

All over the world, irrigated agriculture is better tended than rainfed agriculture, as can be derived from the fact that the irrigated acreage comprises 13 % of the total area, but that it yields 34 % of the total production. In irrigated agriculture a number of factors are important:
- The first is to avoid as much as possible a shortage of water in any period of the growth of a crop. But, as that is difficult to achieve, one should also have information about the water requirements and the effects of stress in different physiological stages.

- Second, one should avoid a shortage in the necessary chemical elements. It has been demonstrated (Van Keulen, 1975) that fertilizer shortage in a crop restricts growth also under limiting water supply.
- The third factor is salinization. Salts enter the soil with irrigation water, part of which is retained when water evaporates or transpires. This excess must be leached, otherwise sooner or later the soil will become too saline. If the groundwater table is far below the root zone this can be done by leaching with extra water, otherwise a drainage system has to be applied to sustain continuous agriculture.
- Fourth, one has to take care that the greatest possible part of the water applied can be used by the crop. This means avoiding open spaces and weeds. To ensure high efficiency, diseases and pests must be controlled.

The experimental site is situated on a large plain (pampa), about 50 km wide, that runs parallel to the coast but is separated from it by a range of low mountains and cut into sections by rivers running from the Andes to the sea. In the geological past, such rivers formed the pampa by filling a trough behind the coastal range with heterogeneous material consisting of boulders and pebbles with coarse sand. Often dense lenses were formed which contain rather high concentrations of silicium or gypsum and which are hardly penetrable by plant roots. This has resulted in very variable soil characteristics over very short distances.

These sediments can hardly be called soils in the agricultural sense as no profile development has taken place; they contain practically no organic material and have a low cation exchange capacity. It is of course possible to cultivate crops on these soils when water and plant nutrients are well administered, but this requires continuous, careful attention.

The climate is extremely dry; rainfall is practically non-existant. Occasionally, in winter, some coastal fog may reach the pampa and get as far as the project site, but usually the sky is clear. As in most deserts the irradiation is high (mean monthly values vary between 2 100 J cm^{-2} d^{-1} in winter and 2 900 J cm^{-2} d^{-1} in summer), but this does not result in extremely high day temperatures as for most deserts. This is due to a relatively cold sea breeze during daytime. The mean monthly day temperatures are remarkably constant, around 27 °C throughout the whole year, but the night temperatures vary between 6 °C in winter and 15 °C in summer (Zipori et al., 1982). The relative humidity is low during the day, with values between 25 and 50 %, but dew formation is possible during the night. The low humidity during the day combined with high irradiation leads to high evaporation, around 7.5 mm d^{-1} measured with a Class A pan.

The data obtained by the project can be divided into three categories: climatic data, soil data and crop data.

The climatic data comprise the registration and integration of irradiation intensity by a solarimeter, temperature and relative humidity by thermohygrographs and average wind velocity by a cup anemometer. The evaporative demand was determined by a Class A pan. Soil physical and chemical characteristics were determined (pF curve, cation exchange capacity, salinity); further data concern the soil water content, which was determined gravimetrically before and after drying soil samples, as well as by means of a neutron probe for which the differential weighing served as calibration and check. Furthermore, the water tension in the soil was determined with tensiometers. As is well known, these tensiometers are only reliable within a restricted range of water tensions.

The crop growth rate was followed by means of periodic harvests of plots of sufficient size; sub-samples were taken to determine fresh and dry weights of the various plant parts, as well as the leaf area. From these data the dry weights of the plant parts per hectare and the leaf area index could be deduced with reasonable accuracy. In the water stress experiments, the water potential in the plants was measured with a Scholander pressure cell, and stomatal resistance by means of a porometer and by directly measuring stomatal opening by means of stomatal prints (a qualitative measurement).

When required the sub-samples were chemically analysed to determine the concentrations of the main nutritional elements, N, P and K. Light interception by the canopy was measured by a long bar on which a number of small photo-cells was mounted. By measuring the light intensity above and below the crop, the fraction of the light that is intercepted by it could be calculated.

In addition to field trials, pot trials were carried out, mainly to determine transpiration coefficients (amount of water transpired per unit of dry matter produced), but also to determine root development more accurately than was possible in the field. In a few cases 'simulated' alfalfa swards of 0.8 m^2 were grown in the Netherlands to determine crop photosynthesis and transpiration (for apparatus and methodology see Louwerse & Eikhoudt, 1974; Louwerse, 1980).

For each crop the data on crop growth rate and related features will be presented first, followed by data on water use.

4.2 GROWTH DYNAMICS OF ALFALFA (MEDICAGO SP)

There are two species of alfalfa, one, *Medicago falcata* L., originating from Southern Siberia, which is fairly cold-tolerant, and the other, *Medicago sativa* L., originating from the plains of Iran and Turkmeniya, which is far less cold resistant. As these species can be crossed without much difficulty, many strains and varieties are available.

Of the countries of the American continent, Peru is the fifth in area of cultivated alfalfa and the second in South America (after Argentina). Alfalfa grows on the coastal plains as well as in the lower mountains up to 2000-2500 m above sea level.

The literature about alfalfa is vast, but most research has been carried out in temperate regions and with temperate varieties. It was, therefore, thought necessary to carry out a detailed study with subtropical varieties, i.e. mainly the local lowland variety Tambo and, for comparison, a variety common in another warm and dry climate, the Californian Moapa.

The following emphasises the results of the various experiments, not the methodological details (see Zipori et al., 1982).

As the climatic conditions in the coastal pampas of Peru permit the cultivation of crops throughout the year, it was important to study crop performance of both varieties over the whole period. Variations in fertilization with N, P and K, in age of the crop and in cutting frequency were also studied. In the trials optimum supply with water was maintained by sprinkler irrigation.

The growth curve of an established sward of alfalfa was determined over growing periods of about 8 weeks throughout the year, adjusting treatments to optimize the conditions as data became available. The experiment was carried out on different fields, for Tambo for a total period of 2½ years and for Moapa for a period of 1 year. In the Tambo trial, differences between the years were small. Therefore the mean of the data is presented in Figure 1, together with the data for Moapa. Each curve gives the crop dry weight at weekly intervals during each growing period of 8 weeks. After each growing period the whole field was harvested (general cut) and the experiment was repeated at another site. Only after three general cuts elsewhere was it thought permissible to return to the same site. Weekly yields were obtained by cutting an area of about 10 m^2 for weight determination and a subsample of about 0.1 m^2 for the determination of leaf area and specific leaf weight (or specific leaf area).

The results show that during the six summer months, September until March, the ceiling yield for Tambo was above 4 tonnes of dry matter per hectare; in October and December no ceiling was reached but extrapolation of the curves indicate ceiling values around 5 tonnes dry herbage. For Moapa a ceiling was reached within each growing period and all final yields were distinctly lower than those of Tambo. Average values centered arround 3 tonnes of dry herbage per hectare, somewhat lower in April and higher in December, indicating a smaller difference between the seasons than for Tambo. However, during the first two to three weeks after cutting Moapa showed a higher growth rate. This was also clearly visible in the field since Moapa reached the closed crop situation earlier than Tambo. This is demonstrated in Figure 2, where the increase in leaf area index (LAI) and in light interception by both varieties is plotted against time. For both varieties the relation between LAI and light interception is identical, so that the one may be derived from the other.

A ceiling yield has also been found by other authors and with other

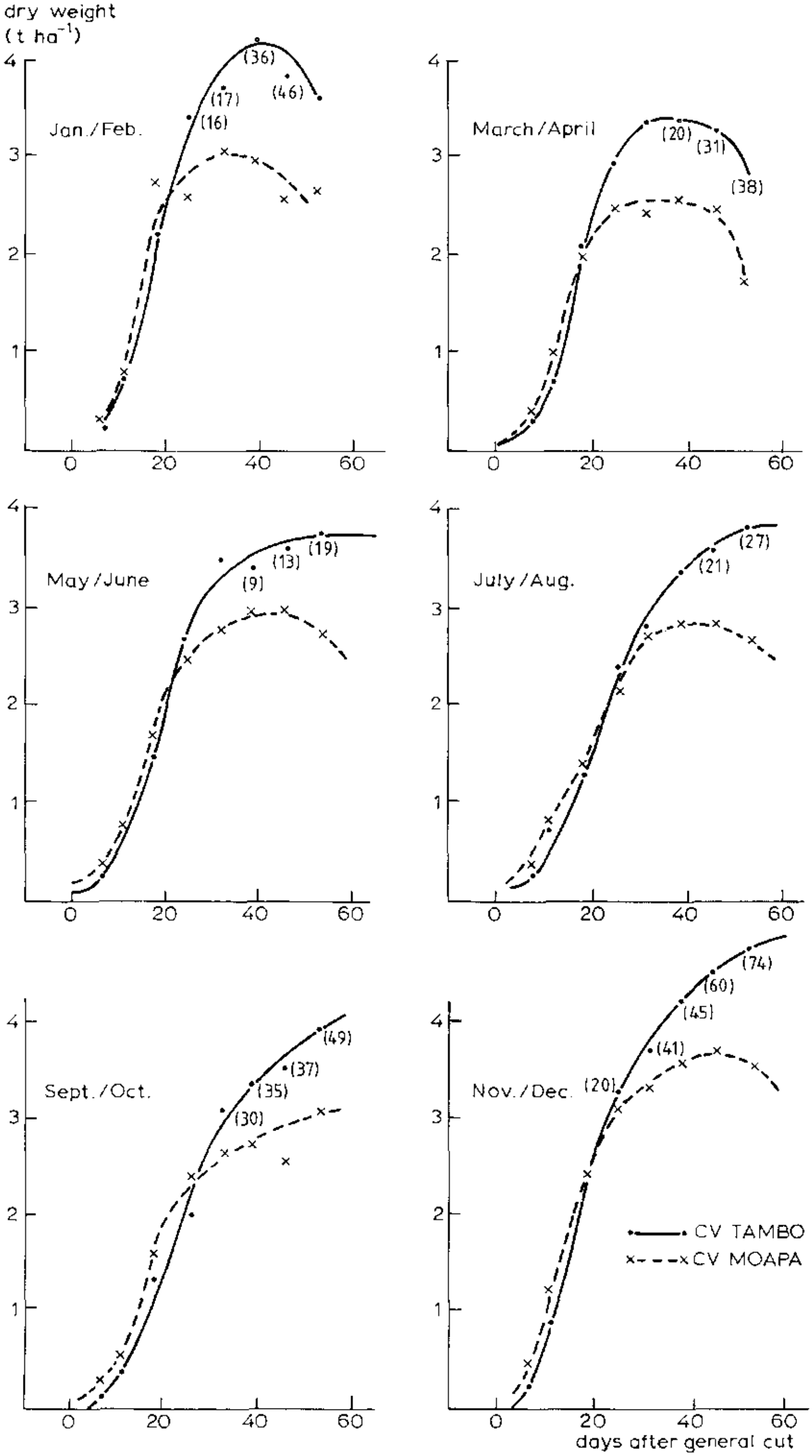

Fig. 1. Growth curves of dry herbage production of irrigated alfalfa during different periods of the year. Numbers in parenthesis indicate percentage flowering stems.

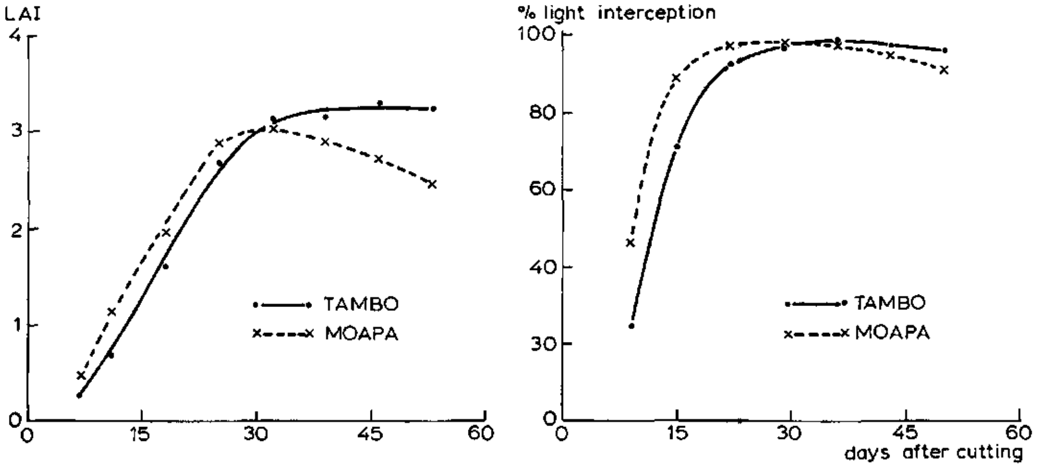

Fig. 2. Leaf area index (LAI) and percentage light interception of two alfalfa varieties during a growing period (mean of 5 periods between 5 May and 25 Jan. 1982).

forage crops, for instance grasses (see also Section 4.3). Simulation models have clearly demonstrated that this phenomenon cannot be solely attributed to an increase in respiratory losses due to increasing dry matter such that the rate eventually equals the rate of gross photosynthesis. Curves like those of Figure 1 could only be reproduced in simulation models if it was supposed that the photosynthetic capacity of the leaves decreases with age and/or that the percentage assimilates that is transported below the cutting level increases. However, neither in the Netherlands nor in California could such a decline in the rate of crop photosynthesis with age be demonstrated. If this also holds for the Sam Camilo situation it must be assumed that at the end of the growing period large quantities of photosynthates were transported below the cutting level either for growth or for respiration (see also Section 4.5).

Cutting frequency trials showed that the growth rate of a sward at a certain time after cutting (e.g. 35 days) depends both on the frequency of cutting and the time of the year. When a distinct ceiling is reached relatively soon after cutting, as with Moapa from January till May, a higher cutting frequency is advantageous for yield; when the ceiling is reached later, and thus reaches a higher level, it is the other way around.

In the literature regrowth rates are often related to the level of reserve substances in the plant parts left after cutting. Also in alfalfa a rapid depletion of the reserves after cutting, and a subsequent build-up, is often reported. However, in our trials no distinct fluctuations in the concentration of non-structural carbohydrates (water soluble sugars + starch) could be found. But the amount of plant parts below the cutting level varied from 2.5 tonnes dry material per hectare at a cutting interval of 3 weeks to 20 tonnes at an interval of 7 weeks. Especially at the lower cutting frequencies the high residual dry weight may mask the drop in reserve concentration. Trials in which fluctuations in concentrations of non-structural carbohydrates were found were all carried out with young plants with a relatively low amount of dry matter below the cutting level. The plants with a high cutting frequency also had a low rate of regrowth, therefore no clear drop in reserve concentration could be expected here. A relation between the rate of regrowth and the weight of the tissue below the cutting level could be demonstrated by measuring the regrowth in the dark (Table 1). In a pot trial with young plants arranged in such a way that a closed sward was formed, a distinct drop in dry weight and in carbohydrate reserves was demonstrated.

To examine the mineral requirements of an alfalfa crop, plant analysis is easier and more reliable than soil analysis because of the latter's heterogeneity. Several trials to determine the necessary level of nitrogen, phosphorus and potassium were carried out.

The trials showed that the percentages of N, P and K in a growing alfalfa crop, even with ample nutrient supply, have the tendency to diminish gradually with age. This is most pronounced for P and least for K. Superimposed upon this is a seasonal variation: for all three elements the concentration is higher in winter than in summer. Apparently this is related to the growth rate: the higher the growth rate the lower the concentration and visa versa. Fertilizer rate trials have never shown a yield response in the dry herbage to P and K application, although some effects on fresh weight were observed occasionaly. Abundant fertilization with a combination of N, P, and K led consistently to somewhat higher yields than without any fertilization. As no influence of P and K fertilization could be demonstrated it is most likely that this is due to a slight but distinct effect of N availability on yield. Uptake of inorganic N seems thus slightly advantageous over the nitrogen fixation process. This advantage could be explained by the fact that energy is supplied by the plant to the *Rhizobia* bacteria, but insufficient data are available on the energy cost

Table 1. Mean of the dry weight (g m^{-2}) of stubble grown in the dark under wooden boxes of 0.1 m^2 area, estimated for the different cutting intervals directly after cutting and 2 weeks later.

Treatment	Directly after cutting	Two weeks after	Significance[1]
every 3 weeks	16.9	14.0	*
every 4 weeks	19.3	18.3	N.S.
every 5 weeks	21.8	21.8	N.S.
every 6 weeks	39.6	25.8	***
every 7 weeks	41.3	29.8	N.S.

1. N.S.: not significant; * : $P \leq 0.10$; *** : $P \leq 0.005$

of N fixation and the reduction of absorbed nitrate to permit calculation of an exact energy balance. Anyhow, the yield differences between fertilized and non-fertilized fields are so small that the use of nitrogenous fertilizer is never profitable. On the basis of experimental results it is estimated that an alfalfa crop can fix around 700 kg of pure nitrogen per hectare per year. The trials indicate that the percentage of the elements N, P and K in alfalfa herbage at zero application did not drop below 3, 0,2 and 2 per cent of the dry weight, respectively; values that are considered in the literature to be sufficient. For the conditions in the La Joya pampa no effect of minor elements could be demonstrated.

It has been suggested that the obligate rest period in temperate regions is the main cause of the growth rate of an alfalfa crop being high in spring, directly after the rest period, and dropping gradually towards autumn. To see whether this also holds for areas where crop growth is possible throughout the year, an artificial rest period was induced by temporarily restricting the water supply (1/3 of normal supply) or by omitting a cut and thus more or less keeping the crop at the ceiling level for some time. In no case could a positive influence of that rest period be observed, neither in winter nor in summer. However, there are indications that the general practice of cutting more frequently in summer than in winter gives the highest yearly production and the best management of the sward.

Although the number of plants per unit area always decreased most rapidly during the first year after sowing, a persistent slow decrease remained. The rate of the decline depended more on the variety than on the cutting frequency. Open spaces are easily filled by weeds. In general this was not detrimental to the yield nor to the feeding value; only Bermuda grass (*Cynodon dactylon* L.) and kikuyu grass (*Pennisetum clandestinum* Hochst.) were distincly disadvantageous because of their relative agressiveness compared to alfalfa and their persistence.

4.3 GROWTH DYNAMICS OF MAIZE AND RHODES GRASS

Maize As maize is the second most important forage crop in the desert of southwestern Peru, much attention was paid to this crop.

In first instance efforts were made to establish the production potential in a factorial experiment with different amounts of nitrogen and potassium (both in rates of 0, 200 and 500 kg ha^{-1}); phosphorus was applied at a fixed rate of 125 kg ha^{-1}. The crop was supplied with optimal amounts of water by sprinkler irrigation.

Due to the small storage capacity of the coarse sandy soil (Zipori et al., 1982), it was necessary to irrigate frequently. In the beginning the crop was sprinkler irrigated every other day. After crop establishment this was gradually diminished to once every week in amounts equal to those lost by free evaporation from a Class A pan (k = 1.0).

Cumulative above ground dry matter was determined by periodic harvesting. There appeared to be no differences for the fertilizer levels of N and P, except for N_0; even border rows that did not receive P did not show any sign of shortage in that element. The observed growth curve obtained under optimal conditions was compared to similar data obtained elsewhere (Figure 3).

In the linear phase of growth, the rate of dry matter production was higher than that in the Netherlands, comparable to that in California but somewhat lower than that in Israel. However, the main cause of differences in final yield was the length of the growing period. Figure 3 shows large differences in the time to reach a dry weight of 4000 kg ha^{-1}, the value

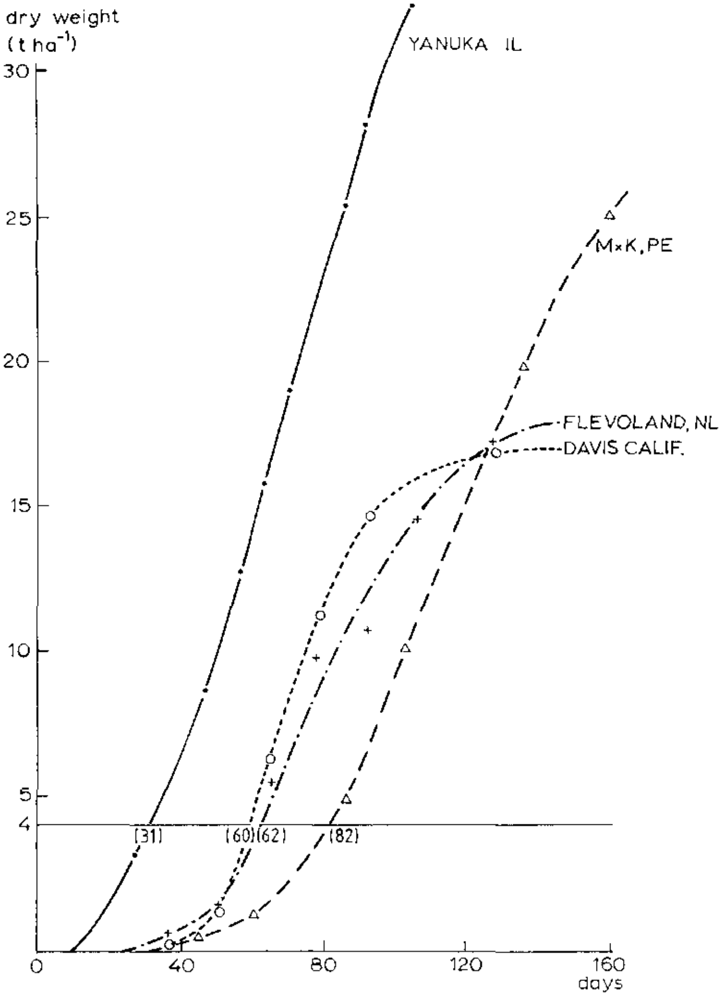

Fig. 3. Growth curves of maize varieties from different parts of the world. Numbers between brackets indicate the number of days to reach a dry weight of 4 t ha^{-1}.

above which the growth rate becomes linear, this ranging from 31 days in an experiment in Israel to 82 days in Peru. In the trials in the Netherlands and in California, the growth rate diminished rather suddenly to practically zero at a yield around 17-18 tonnes dry matter per hectare, whereas in the trials in Israel and Peru there was only a relatively small reduction in the rate of dry matter accumulation up to yields of around 33 and 25 tonnes per hectare, respectively.

The causes of these differences are not well understood. In Peru the rate of dry matter production differed distinctly between seasons, as is clearly illustrated in Figure 4. Sowing in September resulted in the slow start already described: it took 82 days to reach 4000 kg ha^{-1} of dry matter. In all probability this was caused by the relatively low night temperatures, which caused a slower increase in temperature after sunrise and a more rapid decline in the afternoon. Then the grand period of growth coincicided with the summer months, December and January, when the night temperature reached the highest values. On the other hand, for sowing in summer (January) the early growth period had high night temperatures. This shortened the time to reach 4000 kg ha^{-1} to 62 days. However in that case the main growing period fell in the colder months, so that ultimately only 12 tonnes per hectare was reached, less than half the value of the other two trials presented in Figure 4.

Fig. 4. Growth curves of maize obtained in San Camilo after different sowing dates (I: 18-09; II: 18-11; III: 12-01). Horizontal lines indicate the time necessary to reach a dry weight of 4 t ha^{-1}.

To investigate these phenomena somewhat further, an experiment was carried out in which three varieties, a local, a Dutch and an Israeli one, were tested both in San Camilo at 1300 m a.m.s.l., and at Tambo, at 30 m a.m.s.l.. At the latter site the average temperatures are higher and the amplitude far smaller. Indeed, all three varieties showed a higher initial growth rate at Tambo, but the differences were not as large as expected. For both the Israeli and the Peruvian varieties, the period between sowing and the 4000 kg ha^{-1} level was shortened by only 4 or 5 days, whereas the high temperatures at Tambo already unfavourably affected the growth rate of the Dutch variety. The further development of above-ground dry matter accumulation clearly showed that the Peruvian variety was by far superior, with the Israeli variety as second-best.

The temperate Dutch variety lagged far behind. The two latter varieties even showed an appreciable decrease in weight at the end of the growing period. The weights at final harvest and at the penultimate one are presented in Table 2.

All ultimate yields were higher at San Camilo than at Tambo, indicating that none of the three varieties was especially adapted to a climate with rather elevated day and night temperatures.

To check whether the observed differences were indeed the result of differences in climate, a number of trenches were dug (0.25 m x 0.25 m) in the San Camilo field and were filled with the soil of the Tambo field and the Peruvian variety was grown on both soils under otherwise identical conditions. The results were astonishing. The Peruvian variety growing on Tambo soil reached the 4000 kg ha^{-1} level in 59 days compared to 66 for the one growing in San Camilo soil. Their ultimate above ground dry matter yield was 36 t ha^{-1} and 26 t ha^{-1}, respectively. This was achieved in 150 days from sowing to harvest, hence overall growth rates of 241 and 174 kg ha^{-1} d^{-1}, respectively. The root system was far better developed in the Tambo soil, with much more profuse fine branches. Apparently a rather specific soil factor exists that has a dominant influence on above ground dry matter production. Time did not permit a detailed analysis, but it was established that there were no differences in the daily

Table 2. Dry matter yields in kg ha^{-1} of three maize varieties at the last two harvest dates at San Camilo (1300 m a.m.s.l.) and Tambo (30 m a.m.s.l.).

	Dry matter yield by variety			
Location of trial	Peruvian	Israeli	Dutch	Harvest date
San Camilo	15 680	13 937	7 981	82-03-01
Tambo	20 686	9 174	3 567	82-03-02
San Camilo	26 340	7 620	4 230	82-04-16
Tambo	19 981	5 080	3 683	82-03-30

course of temperature or water potential in both soils, nor was there evidence of a shortage of minerals in the San Camilo soil. The percentage N, P and K in the Tambo-soil plants was slightly lower than that in the San-Camilo-soil plants, possibly because of a dilution effect due to the higher dry matter production. The distinct influence of soil condition on dry matter production of maize also appears from the fact that subsoiling, i.e. breaking compact soil layers at depth, had a pronounced positive influence. Dry matter production on subsoiled plots without nitrogen fertilization was much higher than on undisturbed plots with ample nitrogen. The difference was mainly due to differences in growth rate during the early phase, i.e. before the 4000 kg ha^{-1} level was reached. Large differences in root system were also found; that in the subsoiled plots reaching down to about 70 cm and that in undisturbed plots to about 30 cm.

Although the three varieties differed in initial growth rate, maximum growth rate and final yield, and also reacted differently to different temperature regimes, the relation between the mean length of the plants and the weight of the crop in the first phase of growth was remarkably constant (Figure 5). In this stage it seems possible to determine crop yield non-destructibly with a reasonable accuracy by measuring the length of a number of individual plants.

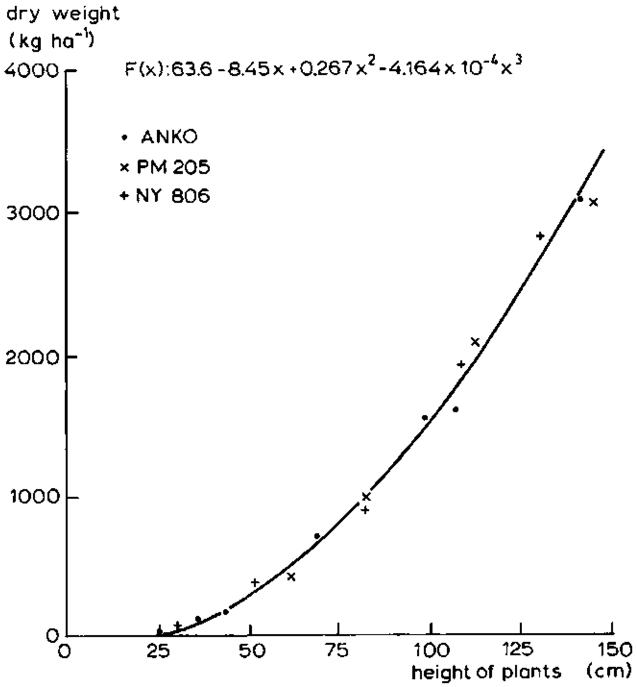

Fig. 5. Relation between the dry yield of maize (up to 4 t ha^{-1}) and plant height for three varieties.

A higher initial growth rate could also be induced by increased sowing density, leading to an earlier closure of the crop. Densities of 50 000 and 200 000 plants per hectare were compared for two local varieties. In both varieties, the number of days to reach the 4000 kg ha^{-1} level was distinctly shorter at the higher planting density. This higher growth rate persisted, also in the closed crop situation, possibly caused by a more efficient light absorption. After 80-90 days of growth the LAI dropped strongly in both varieties at both densities. The onset of this phenomenon was correlated with the attainment of the ceiling yield. In some cases, total above-ground dry matter decreased at the end of the growing period so that the ultimate yields were not correlated with initial plant density.

The uptake of N, P and K is presented in Figure 6, both as a percentage of the dry weight and in absolute amounts. The results of the fertilizer experiment are presented as well as those of the trial with Tambo soil in San Camilo and those of the trial in Israel. For all three elements the percentage was high when the plants were young. For P and K an initial increase was observed in most experiments, but after 60 to 80 days the percentage gradually declined in all experiments and levelled off towards the end of the experiments. There was no correlation between the percentage of an element in the dry weight and the rate of dry matter production, so that chemical plant analysis does not seem to be a reliable method to establish the nutritional status of a maize crop.

Rhodes grass (*Chloris gayana* Kunth) A Rhodes grass field was established and growth curves were determined, as described before, for two levels of nitrogen fertilization: 1560 and 520 kg $ha^{-1}yr^{-1}$ of nitrogen. Half of the plots with the higher N application also received P at a rate of 300 kg ha^{-1} yr^{-1}. Potassium fertilizer was not thought to be necessary. It was demonstrated that the production of Rhodes grass is negligible during winter, but during summer, August to May, growth rates of 170-190 kg $ha^{-1}d^{-1}$ in the middle of this period were established. This held for the high-N plots; at the lower N level the growth rates were lower. Fertilization with P had no influence on dry matter production.

Comparing these yields to those obtained in Israel, it appeared that there higher daily growth rates were obtained (peak values around 330 kg $ha^{-1}d^{-1}$) but that ceiling yields hardly exceeded 12 t ha^{-1}, compared to 20 t ha^{-1} in San Camilo (if a ceiling yield was obtained at all). As the growing season in Israel is shorter, the total dry herbage yield was lower.

Higher N fertilization not only increased the percentage nitrogen in the tissue but also that of phosphorus and potassium substantially. For the latter element an extraction of 330 kg ha^{-1} yr^{-1} was cal-

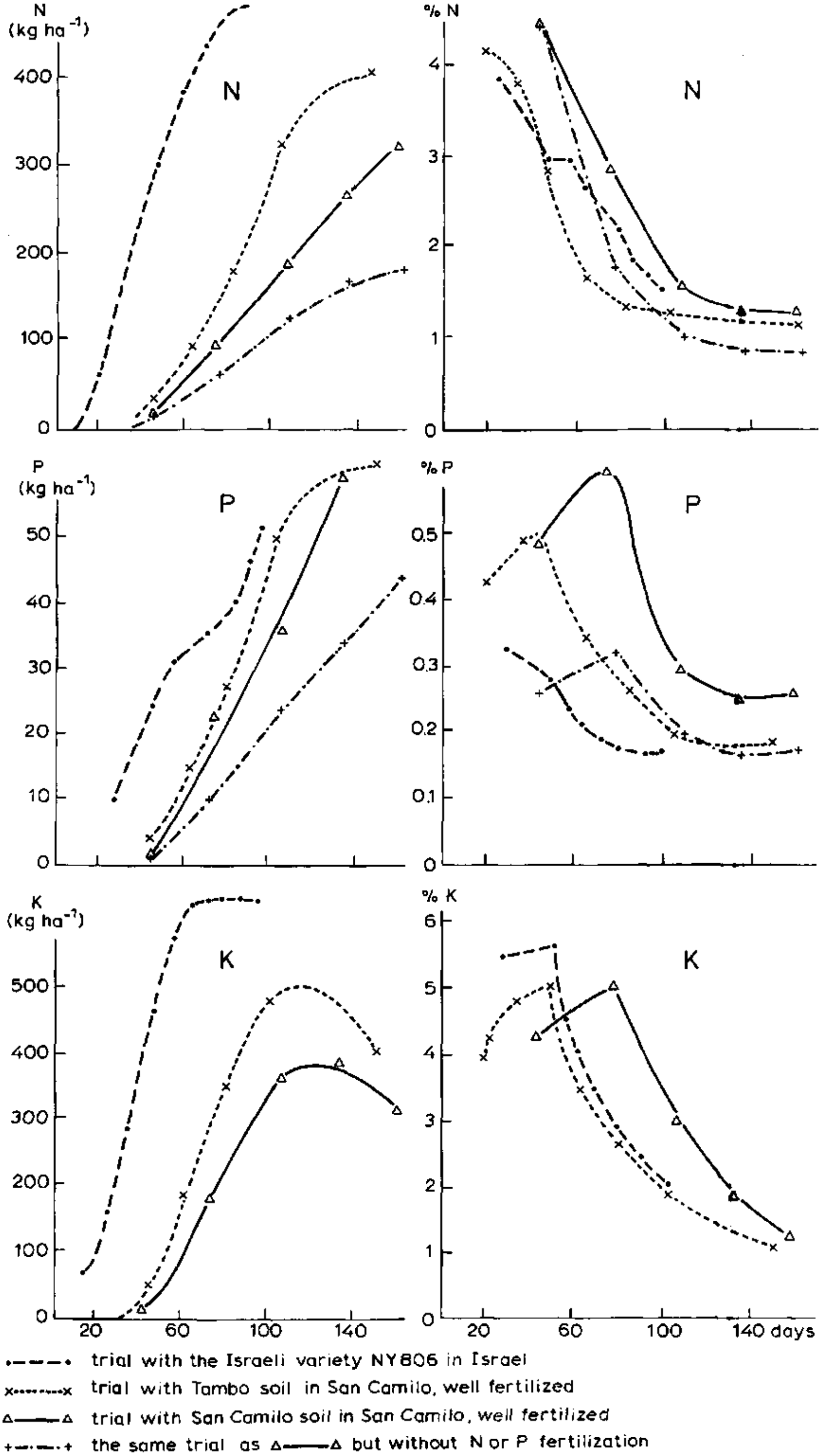

Fig. 6. Amounts (kg ha^{-1}) and percentage (of dry weight) of N, P and K in the above ground parts of maize in 3 trials with good growth.

culated. Fertilization with P resulted in a P percentage in the tissue two to three times higher than that in the high N plants without P fertilization. In general, the percentage of the three elements in the tissue did not show large variations throughout the year; only the percentage P was distinctly lower in summer than in winter. During one growing period, between two general cuts, the percentages of N and P dropped continuously, whereas the percentage K remained fairly constant.

Although yields of Rhodes grass during the summer season were higher than those of alfalfa over the same period, large-scale use of Rhodes grass is not advisable because of the large nitrogenous fertilizer requirements. However, advantages of Rhodes grass are: 1) a dense sward can easily be maintained for a number of years, thus completely preventing the penetration of weeds; 2) the herbage is more suitable for haymaking and silage; 3) it needs, in comparison to alfalfa, only half the amount of water for the same amount of dry matter. As also a high recovery of applied nitrogen is possible under good management cultivation of Rhodes grass for storage fodder seems to be a practical possibility.

4.4 YIELD POTENTIAL OF POTATOES

Only one experiment was carried out with potatoes, at the end of the project. The set-up was rather complex in order to obtain as much data as possible, but because of this generalizations should be drawn with caution.

As usual, the design of the experiment was such that it permitted periodic harvests to obtain a curve of cumulative dry matter production, leaf area index and light interception. All samples obtained were split into tubers, roots, stems and leaves. These were separately analyzed for N, P and K, P and K were applied in quantities of 90 and 231 kg ha^{-1} respectively; P was disked in before the experiment started and K was applied weekly with the sprinkler irrigation system in equal quantities of 10.5 kg ha^{-1}. The latter method was also used for administering nitrogen. The weekly quantities of nitrogen were adapted to the assumed growth rate of the crop; they totalled 388 kg ha^{-1}. The experiment was carried out between two irrigation lines with sprinkler spacing of 12 m within and between the lines, and 16 hills between the lines. Outside one line, but parallel to it, another 8 hills were planted. Consequently, these hills received less water, as the distance from the line increased; this layout was set up to obtain data about the relation between water dosage and dry matter production. Two varieties were used in this experiment: the Peruvian variety Revolucion and a the Dutch variety Desiree.

Cumulative dry matter data for both varieties are presented in Figure 7. The highest rate of total dry matter production was found for Revolucion, i.e. 300 kg ha^{-1} d^{-1}, which gave a maximum dry matter production of 19.90 t ha^{-1}. Subsequently, the total weight dropped to 15.20 t ha^{-1} at the last harvest. For Desiree the maximum rate of dry matter production was lower (220 kg ha^{-1} d^{-1}), but the weight loss in the last phase of the experiment was less, resulting in only negligible differences in dry weight at the ultimate harvest.

The maximum rate of dry matter accumulation of the tubers showed the same pattern: 215 kg ha^{-1} d^{-1} for Revolucion and 170 kg ha^{-1} d^{-1} for Desiree. Here, too, final tuber yields were identical but this was not so much caused by differences at the end of the growing period (there was no drop in tuber weight), but at the beginning: tuber formation with Desiree started earlier than with Revolucion.

The final tuber fresh weight of Revolucion was about 10 % higher than that of Desiree, but tuber size distribution was more regular for Desiree, so that there was no difference in the weight of marketable potatoes.

Figure 7 also shows that Revolucion had a much higher percentage of roots and shoots than Desiree. This led to large differences in leaf area index (LAI): Revolucion reached a maximum of about 8 at 110 days after planting; for Desiree the maximum was about 3.5 at Day 65.

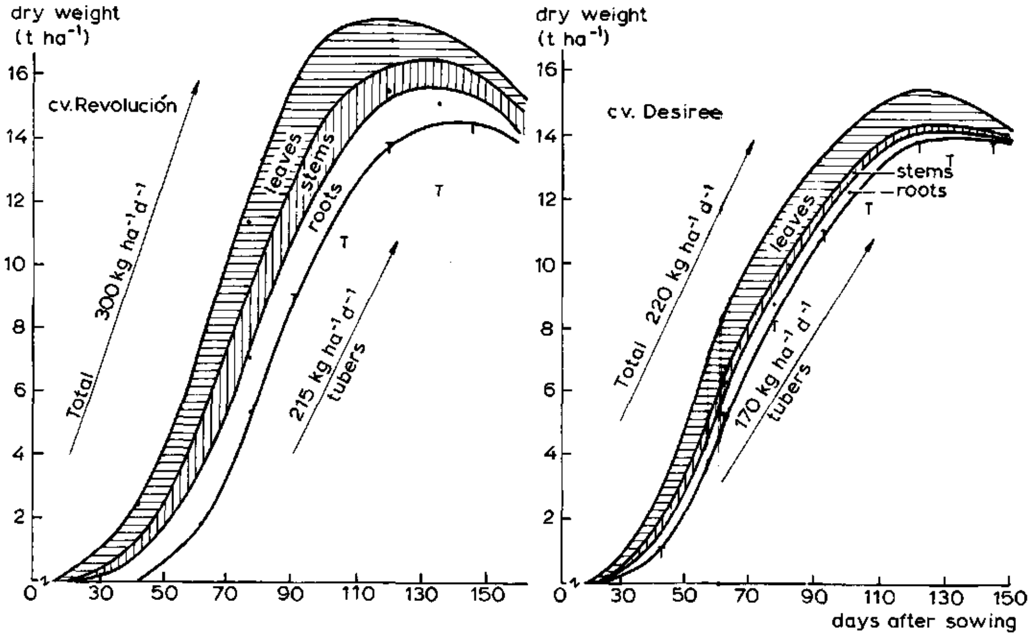

Fig 7. Accumulated dry weights of leaves, stems, roots and tubers of the potato varieties Revolucion and Desiree at San Camilo.

Despite these large differences in LAI, for example at Day 60 R is 5.5 and D 3.3, differences in light interception were negligible, indicating a more efficient leaf angle distribution for Desiree. The maximum light interception by the crop was around 85 %, indicating still some open space between the rows.

The amounts of nitrogen, phosphorus and potassium accumulated by the crop were 240, 50 and 520 kg ha^{-1}, respectively, of which the tubers contained 145, 45 and 400 kg ha^{-1}, respectively. Compared to the amounts of N, P and K applied, 388 kg ha^{-1}, 90 kg ha^{-1} and 231 kg ha^{-1}, respectively more potassium was extracted than was applied. However, it was demonstrated in experiments with maize and alfalfa that the potassium-supplying capacity of the soil was so high that fertilization with this element was not necessary. Consequently, it is not very likely that potassium deficiency played a role, even though the potassium percentage in the plant was not very high, though above the level considered critical.The same can be said for nitrogen. Both the total nitrogen content and the nitrate content in the plant tissue were fairly low, but an extra nitrogen fertilization of border rows had no effect on the total tuber production nor on the colour of the leaves. Only the weight of the above-ground tissue was slightly higher.

Water supply had a very pronounced effect on dry matter production. Within a growing period of 120 days, in which the maximum values were reached when sufficient water was given, total dry matter production decreased progressively with decreasing irrigation (Table 3).

The reduction was far greater for Desiree than for Revolucion, which is mainly related to a difference in dry matter distribution. As

Table 3. The influence of a reduction in irrigation on total dry matter yield and tuber fresh weight (t ha^{-1}); in parentheses percentage values.

	Percentage water applied			
	100	87	78	69
Total dry matter yield				
Revolucion	14.9 (100)	15.2 (102)	12.2 (82)	6.7 (45)
Desiree	12.8 (100)	10.8 (84)	5.6 (43)	3.1 (24)
Tuber fresh weight				
Revolucion	56.1 (100)	50.8 (91)	41.5 (74)	20.3 (36)
Desiree	55.8 (100)	52.0 (93)	29.2 (52)	15.9 (28)

has already been stated, the onset of tuber formation was much earlier in Desiree than in Revolucion. This difference was distinctly enlarged by progressive water shortage. Thus less dry matter was used for the formation of leaves, which consequently led to a lower yield. In Revolucion tuber formation was progressively postponed with less water. At the final harvest both varieties did not differ much in tuber fresh weight. It should be mentioned in this respect that the leaves of Desiree were badly damaged by the application of extra nitrogen, which was necessary to compensate for the lower amount of N with less irrigation water. Revolucion appeared to be far less sensitive to this application.

In Figure 8, total dry weight and tuber fresh weight are plotted against the amount of water applied. Two important facts can be deduced from this figure. The first is the large amount of water that is not used by the plants. Extrapolation of the curves to the *x* axis shows that this amounted to about 550 mm (5500 m^3 ha^{-1}) of water. This amount is probably so large because of the relatively large distance between the hills and because these hills also cause some runoff to sites where the least amount of roots can be expected. Moreover, soil

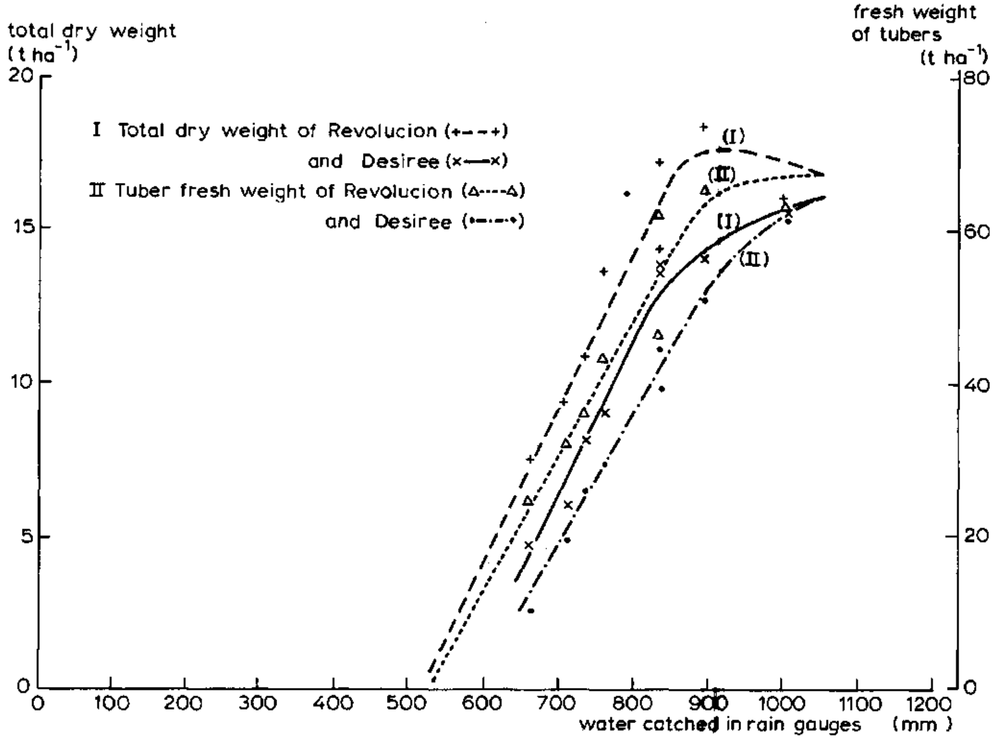

Fig. 8. Response of both total dry weight and tuber fresh weight to the amount of irrigation water that the crop received.

evaporation increases through enlargement of the exposed surface of the hills.

The second factor is the transpiration coefficient (TRC), which can be derived from the slope of the lines. For Desiree, a coefficient of 213 kg of water transpired per kilogram of total dry matter produced was calculated, for Revolucion 205. Although the absolute value of these numbers is influenced by the prevailing weather conditions, they are nevertheless very low for a C3 species as potato under the conditions at San Camilo. For both alfalfa and ryegrass, the TRC values were more than double that of potatoes. On fresh tuber basis, the water requirements are for Revolucion 50 kg of water per kilogram of dry matter and for Desiree 58 kg.

Thus, if the large non-productive water loss could be reduced by closer spacing of hills, more efficient irrigation methods or using soils with a higher water-holding capacity, then the high yields and low transpiration coefficients are quite promising.

4.5 DETERMINATION OF THE TRANSPIRATION COEFFICIENT (TRC) OF SEVERAL CROPS

The transpiration coefficient is defined as the amount of water transpired per unit of dry matter produced and is therefore a measure of the efficiency of water use. In areas where water is a scarce commodity, as in San Camilo and in many other regions in Peru, it is of great importance to know the transpiration coefficient of the most important crops. In combination with the energy-determined maximum production possibilities of a crop this parameter yields the water requirements.

It should be recognized, however, that the TRC is not a universal constant, but may vary with climate conditions and with crop species, even with variety. The data in Table 4 already show this variation for three alfalfa varieties. Therefore, it is preferred to derive the TRC value from local measurements on different varieties. For this a pot trial is easier, simpler and more precise to handle than a field

Table 4. Production and water use of three alfalfa varieties during the summer and winter season (averaged over the growing period) together with the calculated TRC and M values and the mean E_o values; M values were calculated with the formula $P=M \times W/E_o$. For symbols see text

		Tambo		Moapa		Baker	
		summer	winter	summer	winter	summer	winter
P	(g pot^{-1})	170.5	97.2	140.6	85.9	93.0	77.9
W	(g pot^{-1})	99 357	67 496	105 930	74 404	65 349	74 184
E_o	(mm d^{-1})	7.9	6.4	7.9	6.4	7.8	6.6
TRC	(kg kg^{-1})	582	694	753	866	703	952
M	(kg ha^{-1} d^{-1})	136	93	105	74	111	69

trial. First, the amount of water applied to the crop must be measured, including natural rainfall. Second, part of this water is not transpired by the crop but evaporates directly from the soil or plant surface, or percolates past the root zone.

These factors can be better controlled in a pot trial. The soil in the pot can then be brought daily to the predetermined pot capacity by adding measured amounts of demineralized water to prevent salinization. Nutrient levels are properly maintained by adding fertilizers after each harvest and by regularly following the N-P-K contents in the plants. Direct soil evaporation in the pots is reduced as much as possible by covering the soil with mulch. By using control pots with the same treatment, but without plants, the direct evaporation from the soil can be measured too. After some time the pots are harvested; from the dry matter yield and the amount of water transpired, the TRC can be calculated. In the San Camilo trials all pots were placed in an outer pot; the space between the pots was filled with plastic (polystyrene) insulation material to minimize temperature differences between the soil within and outside the pots. The pots were placed at random in an alfalfa field surrounded by hedges, to prevent an oasis effect by advection from the surrounding desert. All pots were harvested monthly and TRC values were calculated on the basis of dry matter production above the cutting level. For further details and sketches of the experimental layout see Zipori et al., 1982.

In addition to the optimal water supply experiment, a pot trial was carried out in which the amount of water administered to the pots was reduced to 80, 60, 40 and 20 % of the optimal supply to study the relation between transpiraton and dry matter production. The hydraulic properties of the sandy soil at San Camilo are not well suited for this purpose and it was therefore replaced by a heavy textured soil from a developed profile in the Tambo valley that contained 24 % water (w/w) at field capacity instead of 17 %, and that shows a more or less linear increase in pF with decreasing water content. Trials were carried out with alfalfa, maize, Rhodes grass and ryegrass.

Three varieties of alfalfa were used in the TRC experiment: the Peruvian variety Tambo, the Californian variety Moapa, both well-known varieties in South-Western Peru, and another North American variety, Baker, which presented a winter-hardy type. The first two varieties were studied for a period of more than a year; Baker was studied for a somewhat shorter time, but within the same period. The data presented in Table 4 are mean values for all harvests, but separated for the summer period (October-March) and the winter period (April-September). The table shows distinct differences in TRC, among varieties and between the two seasons. the variety Tambo had the highest yield in both seasons. This corroborates the results from the field trials in which this variety also gave the highest production (Section 4.2). Total water use did not increase proportionally, so that of the three varieties tested, Tambo had the lowest TRC value.

For all three varieties, the winter yields were distinctly lower than those in summer. For Tambo, the reduction amounted to 33.6 %, for Moapa to 28.9 % and for Baker to 44.2 %. Total water use was also reduced in winter, but to a lesser extent than dry matter production, resulting in a better economy (lower TRC) in summer than in winter. De Wit (1958) has suggested that for arid zones with high radiation the effect of climatic conditions on water use could be accounted for by dividing total transpiration by the daily evaporation of a free water surface (E_o). He thus arrived at the formula $P = M \times W/E_o$, in which P is the total dry matter production in kg ha^{-1}, W is total transpiration in mm (= 10^4 kg ha^{-1}) and E_o is the average free water evaporation during the growing period in mm d^{-1}. The factor M then has the dimension of a rate, kg ha^{-1} d^{-1}, which, according to De Wit, eliminates the effect of climatic conditions on the plant's water use efficiency. For this reason the M value is also presented in Table 4. As has been found earlier by Van Keulen (1975), the M value did not remove the influence of different seasonal conditions on water use, so that only TRC values will be used to characterize the water economy of a plant or a crop.

Figure 9 shows the daily transpiration rate (mean values of Tambo

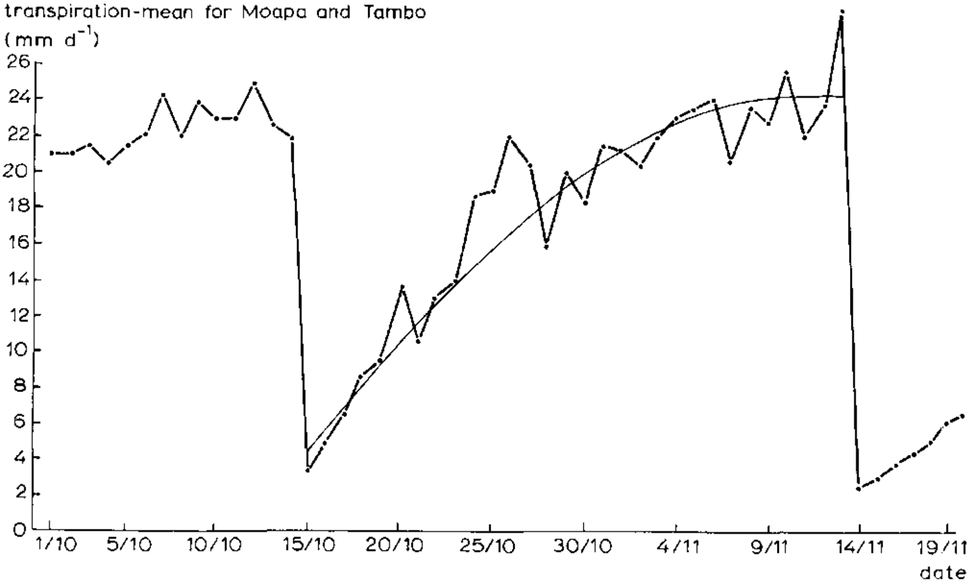

Fig. 9. Water consumption of two alfalfa varieties in pots during a growing period between two cuts.

and Moapa) over a period of about two months, comprising two cuts. Directly after cutting the transpiration rate was reduced from about 22 mm d^{-1} to about 4 mm d^{-1}, but immediately thereafter it increased again, rapidly at first, but at a declining rate so that again values of 20-25 mm d^{-1} were reached just before the next cut. These data clearly indicate that administering water in relation to the need of the crop can save water in comparison to applying constant quantities estimated on the basis of a closed crop, which is the usual practice.

When the daily supply of water to the pots was reduced to 80, 60, 40 and 20 % of the amount that replaced the measured evaportranspiration losses, dry matter production was more or less proportionally reduced, although there was a tendency for the TRC to rise at lower water dosages. This may be explained by the fact that only the tissue above the cutting level has been measured and that the proportion of roots has the tendency to rise at lower water supply. Besides, transpiration could be more affected than photosynthesis.

Some pots were sown with 12 maize seeds. After germination, 6 plants were left in each pot. Cumulative aerial dry weight was determined by harvesting pots at 35, 49, 63 and 77 days after sowing. Half of the pots were covered with artificial mulch - a layer of gravel to reduce evaporation from the soil surface - and in the other half the soil was left bare. Control pots without plants but with and without mulch were used to determine evaporation from the soil. Water loss was compensated daily by refilling to the original weight, corrected for the increase in plant weight. The data are presented in Table 5.

The transpiration coefficient of maize turned out to be much lower than that of alfalfa. This is because maize is a C4 species that

Table 5. Calculation of TRC (transpiration coefficient) and ETRC (evapotranspiration coefficient) of maize in pots with and without mulch over different growing periods.

Growing period (d)	Mulch	Evapo-trans-piration (g pot^{-1})	Evapo-ration (g pot^{-1})	Trans-piration (g pot^{-1})	Dry weight (g pot^{-1})	TRC	ETRC	Direct evapo-ration
35	with	6 447	2 245	4 202	18.1	232	356	
	without	7 600	5 773	1 827	13.4	136	567	76
49	with	14 251	3 252	10 199	42.6	259	334	23
	without	14 954	10 973	3 981	23.5	169	636	73
63	with	21 646	4 180	17 538	61.8	284	350	19
	without	27 294	14 673	12 621	59.4	212	459	54
77	with	34 905	5 117	29 788	107.5	277	325	15
	without	33 071	18 433	14 638	65.6	223	504	56

has a different photosynthetic pathway, one that leads to a better water use efficiency. At each harvest the TRC of the plants growing in the pots with mulch was higher than that of plants growing without, which means that the latter had a better water economy. This was most probably caused by the fact that partial closure of the stomata, due to water stress, had a relatively greater influence on transpiration than on photosynthesis. This stress apparently had been rather severe, as it reduced the yield at the last harvest by nearly 40 %. Although the application of mulch is not easily possible in practice, its large effect on the water economy warrants further research.

Pot trials with Rhodes grass and ryegrass were carried out in the same manner as with alfalfa. After establishment, Rhodes grass was cut every 3 or 4 weeks and ryegrass every 2 or 4 weeks and the dry weight of the material determined. Ample fertilizer was added in soluble form after each cut. The trials lasted for about a year.

The data for Rhodes grass show that cutting frequency had virtually no influence on transpiration and on yield and, consequently, not on TRC (Table 6). However there was some seasonal difference. The amount of dry matter produced and the amount of water transpired were higher in the summer months (October-March) than in the winter months (April-September). Since production was more affected than transpiration, the TRC values turned out lower in summer than in winter.

With ryegrass, both cutting frequency and season had an influence. When cut every 4 weeks, the yields were always higher than when cut every 2 weeks. The latter is a very high cutting frequency and a direct comparison with Rhodes grass is not possible, because the higher frequencies were not the same. The seasonal effect on ryegrass was

Table 6. Transpiration, yield and TRC for Rhodes grass and ryegrass for summer and winter and for different cutting frequencies. For ryegrass, cut every 4 weeks, mean data are also presented as the number of cuts was different in both seasons.

Plant species	Season	Cutting frequency (weeks)	Total transp. (g pot^{-1})	Total yield (g pot^{-1})	TRC (kg kg^{-1})	Mean transp. per cut (g pot^{-1})	Mean yield per cut (g pot^{-1})
Rhodes grass	summer	3	81 453	253.0	322		
		4	81 281	235.3	345		
	winter	3	64 726	169.8	381		
		4	65 195	170.5	382		
ryegrass	summer	2	67 979	139.4	488		
		4	90 467	179.7	503	12 924	25.7
	winter	2	71 436	142.6	501		
		4	81 376	177.6	458	13 563	29.6

opposite to that on Rhodes grass. Both production and transpiration were higher in winter than in summer. The effect on dry matter production was not very pronounced, but it was apparently large enough to affect the transpiration so much that it also had higher values during the winter months so that it counteracted the lower evaporation during this period. The detrimental effect of summer conditions on the productivity of ryegrass could be due to the fact that it is a species from a temperate climate. The TRC values did not show distinct differences as a mean over the season for each cutting regime.

Finally, Table 7 shows that there are considerable differences in TRC between the species. Alfalfa, especially, had a very high transpiration coefficient. This may be partly due to the fact that it is calculated from harvested matter only, whereas the weight of the plant parts below the cutting level is very high. It is, however, virtually impossible to determine total dry matter production (above and below ground) during individual trial periods. Where a comparison was possible, it appeared that the TRC values determined in the field and in pots were quite similar. So it seems possible to use the experimentally determined TRC and yield values to calculate crop water requirements; see last column, Table 7. Because of a low TRC and a moderate yield level the water requirement of potatoes is by far the lowest of the three main crops grown in the area. It should be realised however that water is not only lost through the plant but also via evaporation and deep percolation and that in practice these losses can be considerable.

4.6. THE RELATION BETWEEN WATER USE AND DRY MATTER PRODUCTION OF ALFALFA

To study the effect of water stress on the above ground dry matter production of alfalfa, two trials were laid out.

In the first trial, small plots of 2 x 5 m were laid out in a

Table 7. Water requirements of several crops for conditions in southern Peru calculated from measured transpiration coefficients and estimated optimum yields.

Crop	Mean TRC value	Yield (t ha^{-2})	Growing period (months)	Water use (mm month^{-1})
alfalfa	660	30	12	165
maize	270	25	5	135
Rhodes grass	350*	40	8	156
potatoes	300	18	6	90

*Calculated for total dry weight (other three tops only) and derived from field data only.

field of cv. Tambo on both sides of a sprinkler irrigation line in a manner already described for the potato trials. To ensure a more regular water distribution the distance between the sprinklers was reduced to 6 m . A rain gauge was placed on each plot to measure the actual amount of water applied. The plots were replicated eight times. Seven distances were distinguished. For layout and water distribution pattern see Zipori et al. (1982). In half of the plots, neutron access tubes were installed to measure soil water content by means of the neutron moderation technique, and in some plots the soil was covered with artificial mulch.

In the second trial a larger field was sown with alfalfa and divided into experimental plots. These plots received different amounts of water according to the following scheme:

1. water according to $k = 1.3$, administered once a week
2. water according to $k = 1.0$, administered twice a week
3. irrigation to field capacity as soon as the soil water content dropped below 40 % of available water.
4. timing determined by 3, but 85 % of the amount of water applied there
5. timing determined by 3, but 70 % of the amount of water applied there
6. timing determined by 3, but 55 % of the amount of water applied there
7. water according to $k = 1.0$, administered once a week.

Not all treatments were applied at the same time. Plots were laid out at random with four replicates per treatment, both with and without mulch and with the two varieties Moapa and Tambo.

In the first trial a wider range of water applicatons was obtained than in the second, but the statistical evaluation was more difficult, since each level of application was determined by the distance to the irrigation line.

The 'line source' trial produced very clear results (Figure 10). At high rates of water application ($k > 0.8$), production did not show a response, but below this level a linear relation was found between water dosage and production, indicating a constant TRC, down to very low rates of application. Whether the relation deviates from straight line when approaching the x axis could not be ascertained, but this is not very important since it concerns only very low values of production (less than 300 kilograms of dry matter per hectare per harvest). Application of mulch had no influence in this trial, probably because hardly any roots were present in the upper 10 cm of the soil. This could have been due to the fact that the sward was already 18 months old when the trial began. During that time watering was rather infrequent so that the upper layer of the soil was mostly too dry to allow the development of roots.

The results of the second trial were less conclusive (Figures 11 and 12). The data show that there were differences between the two

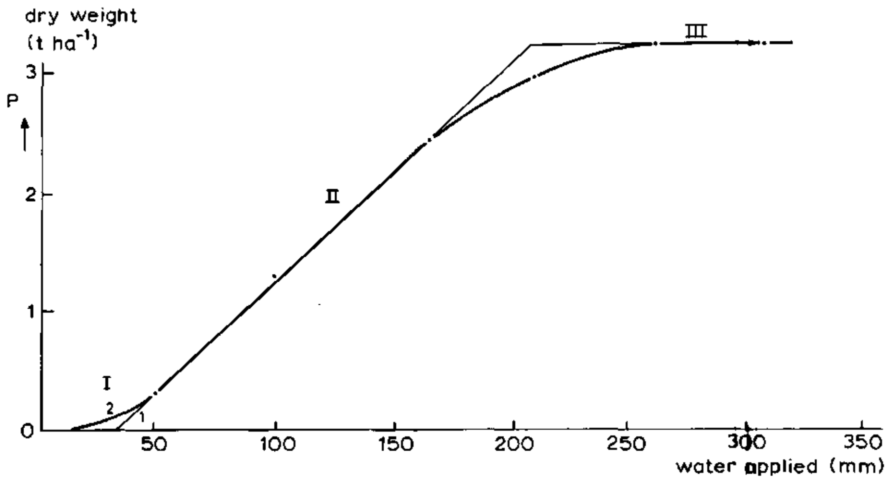

Fig. 10. Relation between the dry weight of an alfalfa crop and the amount of water applied (mean of 4 successive growing periods). Phase I: relation uncertain (1 and 2 see text); Phase 2: relation linear; Phase III: no influence of irrigation on dry matter production.

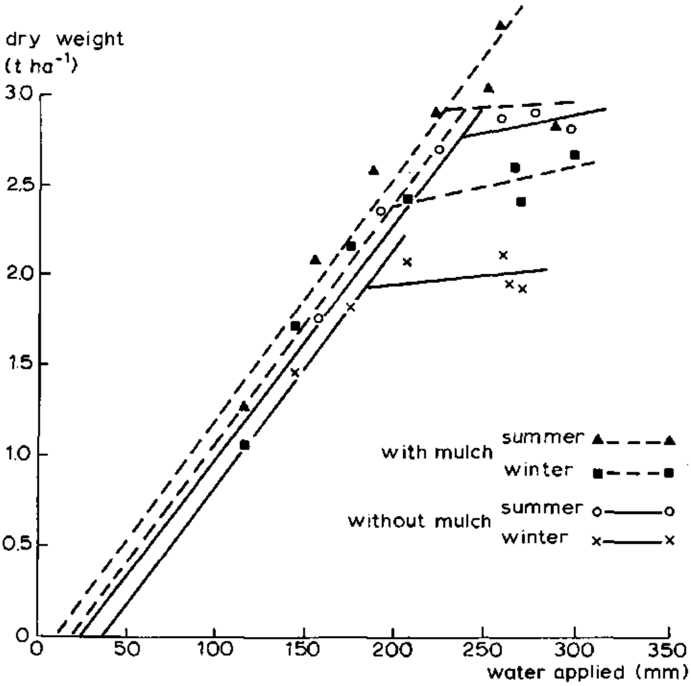

Fig. 11. Response of the alfalfa variety Moapa to the amount of water applied.

varieties, between the growing seasons and between the plots with and without mulch. For any given amount of water applied the dry matter production was:

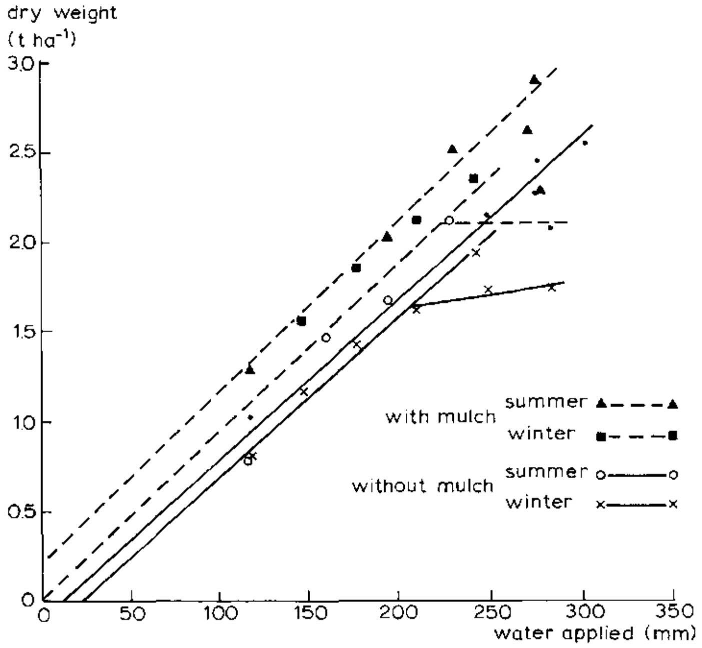

Fig. 12. Response of the alfalfa variety Tambo to the amount of water applied.

- higher for Tambo than for Moapa (thus, consequently a lower TRC value for Tambo;
- higher in summer than in winter, under otherwise equal conditions;
- higher with mulch than without;

There is some indication that the shape of the curve is identical to that in the first trial: dry matter production increases proportionally with an increase in the amount of water applied, until a ceiling dry weight is reached. Extrapolation of the linear part of the curves towards the origin shows that they do not always intersect with the x axis, as one would expect. This points to more irregularities than in the preceding trial. The intersects all centre around the origin, indicating a relatively small soil surface evaporation.

If one calculates the water use coefficient (1/WUE), defined as the amount of water applied per unit of dry matter production, the data invariably show that the highest efficiency was obtained around the highest production rate. This is reasonable because very high dosages hardly influence dry matter production, whereas low dosages induce a relatively high direct soil evaporation.

Water lost by deep percolation could be calculated from measurements of the water content of the soil before and after watering. Correcting the application for these losses yields total evapotranspiration. Figures 13 and 14 show the relation between total evapo-

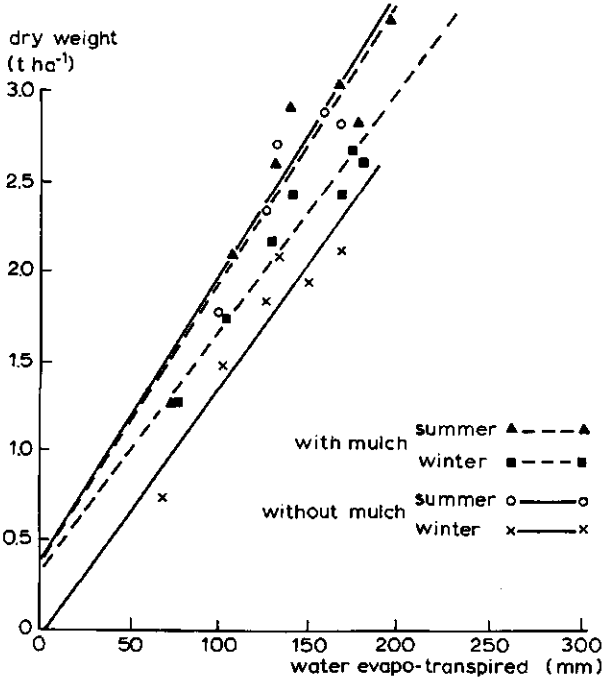

Fig. 13. Response of the alfalfa variety Tambo to the amount of water evapo-transpired.

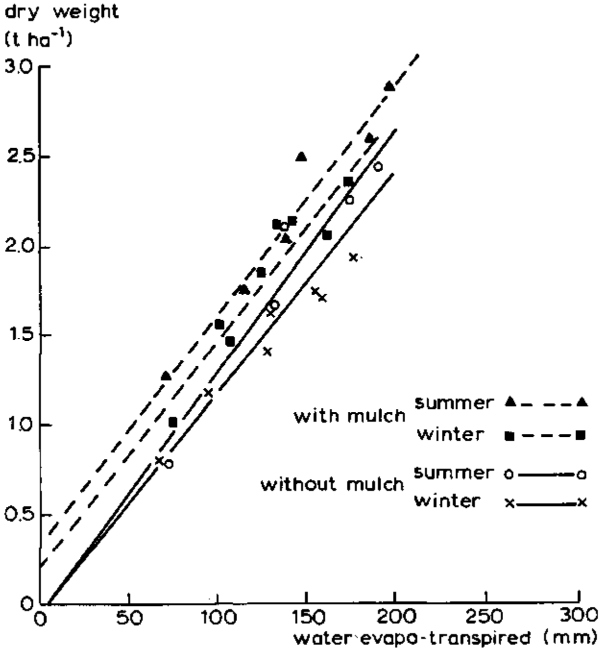

Fig. 14. Response of the alfalfa variety Moapa to the amount of water evapo-transpired.

transpiration and dry matter production. The variability remains too large to distinguish the evaporation component from the transpiration, as again the lines do not all intersect with the *x* axis when extrapolated. Since the lines relating to the plots with mulch consistently intersect with the *y* axis, it can reasonably be supposed that mulch reduced evaporation considerably.

For dry matter yields, the local variety Tambo had again a higher production than the Californian variety Moapa and for both varieties the production was higher in summer than in winter. The application of mulch had a positive effect on dry matter production at all levels of water applied. The response to the water supply was somewhat complicated. Taking the mean data averaged over varieties, seasons and mulch treatments, the difference between Treatments 1, 3 and 7 was negligible, i.e. k = 1.3, k = 1.0, and the treatment in which water was applied to field capacity as soon as the soil moisture content had dropped to 40 % of available water, respectively. When the amount was reduced to 85, 70 and 55 % of the available water (Treatments 4, 5, 6, respectively,) a progressive reduction in dry matter production was observed, as was already expressed in Figures 11 and 12. In all these cases water was applied once per week. When, however, water was applied twice per week at k = 1.0, dry matter production increased in the variety Moapa. This indicates that in the sandy soils of San Camilo, which have a low water retention capacity, an irrigation frequency of once per week is insufficient. The amount of water may be sufficient for a short time (there is no difference in production between k = 1.0 and k = 1.3), but insufficient for a whole week because of too much deep percolation and the rapid increase in soil water tension.

In contrast the first trial, application of mulch had a distinctly positive effect on dry matter production. In this trial the mulch was applied directly after emergence of the sown alfalfa. As all plots were frequently supplied with water from the beginning, roots could also develop in the upper soil layer and remained in the plots to which the mulch was added. In the plots without mulch, the roots in the upper layer were bound to die because of intermittent drying, as in the first trial.

The high transpiration coefficient of alfalfa as compared to other C3 crops, such as ryegrass and potatoes, was apparently not caused by insufficient stomatal regulation, as these were found completely closed in situations of water shortage. The cuticle on the epidermis was observed to be very thin or virtually absent, so the obvious conclusion is that the alfalfa crop loses a considerable amount of water via cuticular transpiration.

In the second trial the different levels of water application had no detectable effect on plant density; in the first trial, in which the range of water application was far wider, a severe reduction in the number of plants per square metre could only be observed at the lowest application level, $k = 0.05$. In practice this means that not much harm is done to the crop when it is irrigated at a low level for some time.

Finally, plant analysis showed that none of the treatments resulted in a shortage of the main nutritional elements, N, P and K.

4.7 THE RELATION BETWEEN WATER USE AND DRY MATTER PRODUCTION OF MAIZE

Maize was sown in rows at two plant densities, 50 000 and 200 000 plants per hectare. Part of the field was divided into 12 x 12 m plots with sprinklers at the corners of each plot. The experimental plots were separated from each other by border plots of the same size. Half of each plot had the high plant density, the other half the low density.

After an initial period of three weeks of frequent watering, five irrigation treatments were begun. One of the treatments consisted of a weekly irrigation with a constant k of 0.8; in the other four treatments the amount of water applied was adapted to the expected growing stage of the plant. For this purpose, the growing cycle was divided into four periods. The dry weight was assumed to increase in the first three periods and to decrease somewhat in the last period. For each period, three different k values were used to determine the minimum amount of irrigation water necessary for optimum growth in each growth phase. The fourth treatment was equal to one of the other three in k value but water was applied twice a week instead of once. The k values, for each treatment and each growing period are presented in Table 8.

Within each treatment, the growth rates were determined by periodic harvests at 44, 65, 86, 107 and 142 days after sowing. An amount of 80 kg P was added as triple super phosphate before field preparation and N was added as urea with the irrigation water at a rate of 400 kg ha^{-1}. Fertilization with K was considered unnecessary.

Table 8. Irrigation scheme in a trial with maize with different values of k (constant $k_c = 0.8$; variable k: $k_v = 0.45$; $k_v = 0.72$; $k_v = 0.86$; $k_{vv} = 0.72$, the latter with a frequency of twice per week).

Age (d)	Once per week				Twice per week
	k_c (0.8)	k_v (0.45)	k_v (0.72)	k_v (0.86)	k_{vv} (0.72)
21- 50	0.8	0.2	0.4	0.5	0.4
51- 75	0.8	0.4	0.7	0.8	0.7
71-125	0.8	0.6	0.9	1.1	0.9
126-142	0.8	0.5	0.8	0.9	0.8

At the same time a parallel trial was carried out using the same two plant densities, but applying water by trickle irrigation instead of sprinklers. The irrigation lines were 1 m apart; either close to each row of plants (low density) or midway between two rows of plants (high density). The drippers on each line were 40 cm apart and supplied water at a rate of 4 l h^{-1}. Water was administered every 2 or 4 days in quantities adapted to the age of the crop and at three different levels as presented in Table 9. The elements P and N were given in the same way as in the first trial.

The results of the first trial are presented in Figure 15. Since the first trial of this experiment was heavily disease infested, it had to be reseeded, with the result that the period of maximum growth fell in April and May, months when the growth rate is normally always lower than in the summer months. This must have influenced yields, which were very low at the final harvest, as has been stated before (see Figure 4).

In the first half of the growing period the growth rates were generally higher in the high density plots than at low density, but for some unknown reason the growth at high density virtually stopped during the last phase of the trial, so that the ultimate yields did not vary much between treatments. Application of water at a constant k and at low plant density gave the highest yield. At high plant density, the constant k treatment also performed best during the first 80 days, but after that growth ceased completely because of lodging so that the ultimate yield was the one but highest.

The fact that all 'constant k' plots had the highest growth rate at the beginning suggests that in the other moisture treatments applications were so low at the start (during the first growing period not above k = 0.5) that they caused temporary water shortages, although the choice of the k values was based on results obtained in a previous trial. For this reason and due to the generally low growth rates, this trial did not give a good insight into the possibilities of economizing on water use by adapting the quantities of irrigation water to the growth stage of the crop. It can only be concluded that with this system, one has to be carefull not to give too small

Table 9. Irrigation program for the drip irrigation trial with maize.

Age (d)	k_v (0.43) (low)	k_v (0.51) (medium)	k_v (0.62) (high)
21- 50	0.20	0.30	0.40
50- 75	0.35	0.46	0.56
71-125	0.60	0.66	0.80
126-142	0.46	0.53	0.60

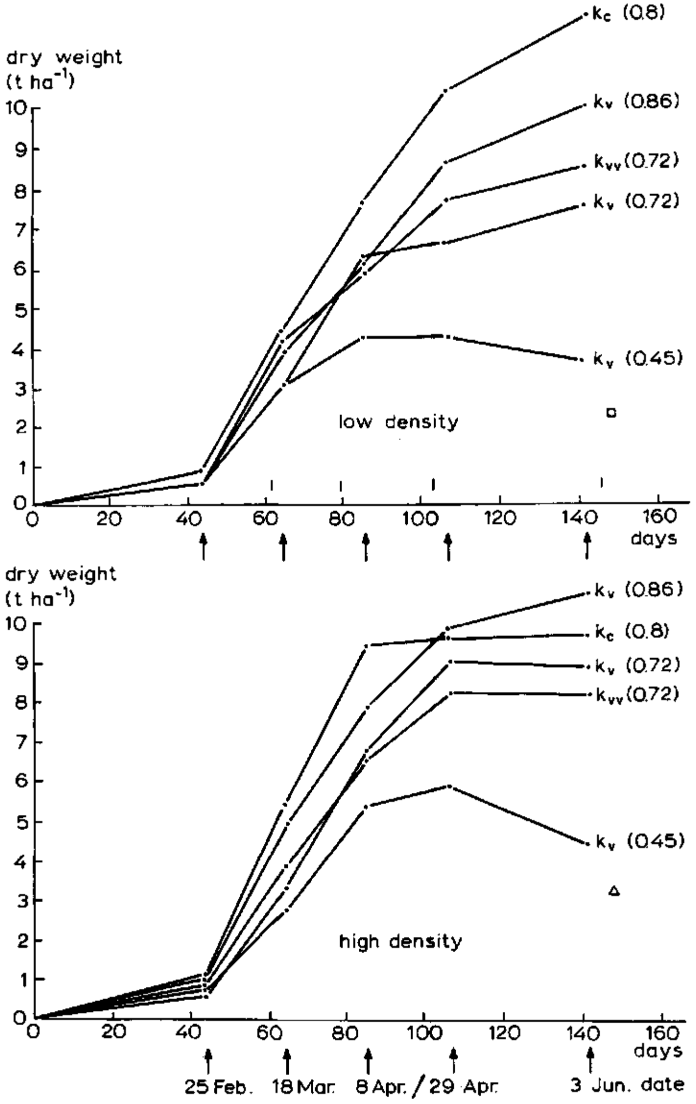

Fig. 15. Growth curves of maize with high and low plant density.

amounts, otherwise more is lost in yield than is gained by saving water.

Due to the low production values the calculated water use coefficients were higher (lower efficiency) than those found in other trials.

By determining the water content of the soil before and after the weekly waterings, the amounts of water lost by deep drainage could be calculated. These calculations show the tendency of these losses to increase in a linear way with the amount of dry matter produced.

The trickle irrigation trial showed that a reduction in the amount of water applied (the highest was 6080 m^3 ha^{-1} in total) resulted here, too, in a severe reduction in dry matter yield, but also that the water use coefficient at each comparable level of water application was distinctly lower (higher efficiency) than for sprinkler irrigation.

Whether trickle irrigation in maize can be used in practice depends much on the situation. When there is already a trickle irrigation set available it might be profitable to use it also in maize.

4.8 COMPARATIVE STUDIES ON THE PROCESS OF LEACHING OF SALTS FROM DIFFERENT SOIL TYPES AND ON THE PRODUCTIVITY OF THESE SOILS

Although the vast plains in the area under consideration look very homogeneous at first sight, there are considerable differences in composition, especially in the percentage of larger stones in the profile, but also in the occurrence of layers with higher concentrations of soluble and insoluble salts as calcium carbonate and calcium sulphate. On the basis of these criteria the virgin soils were classed as a number of different types. All these types are commonly lightly textured, have virtually no organic matter and, consequently, are low in natural fertility and water holding capacity.

As these characteristics do not sound very promising for bringing the land under cultivation, more basic data on these soil types are required, for example:

- the amount of water needed to leach the salts below the root zone;
- the amount of water and fertilizers needed to grow the crops planned for the area.

For this purpose a lysimeter experiment was installed, close to the main research centre for the development of the area. Each lysimeter contained approximately 2000 kg of soil. The 12 main types of virgin soil were compared to eight soils from neighbouring river valleys with a relatively well developed profile and from irrigation projects that had been under cultivation for at least several years. Each of the 20 soil types was tested in triplicate so that the experiment comprised 60 free drainage lysimeters. For the construction and layout see Zipori et al. (1982).

For each soil type a characteristic site was chosen and the soil was removed in layers of 1.5 x 1.5 x 0.05 m and the three replicate lysimeters were filled with these layers in a sequence identical to that occurring in situ. After filling, the lysimeters were flushed with water and the electrical conductivity (EC_e) of the applied and drained water (via a drain at the bottom) was measured.

The results for two typical soil types are presented in Figures 16 and 17. For the other soil types, comparable graphs are presented in Zipori et al. (1982). In these figures, the EC_e of the drain water

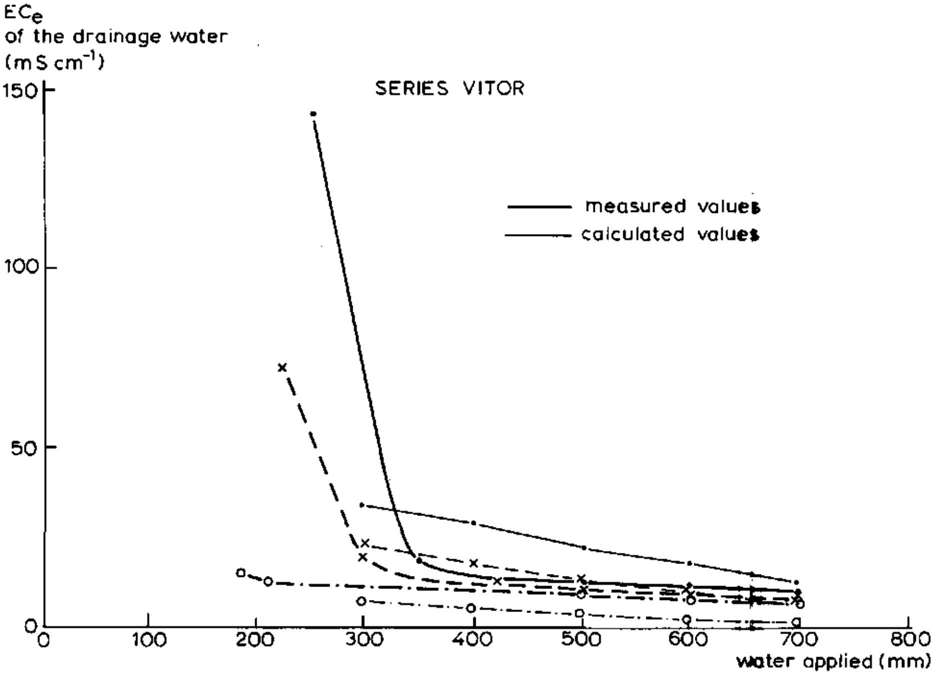

Fig. 16. Pattern 1 of the relation between the electrical conductivity (EC_e, measured and calculated) and the amount of water applied (series Vitor). I, II and III refer to three seperate lysimeters filled with the same soil.

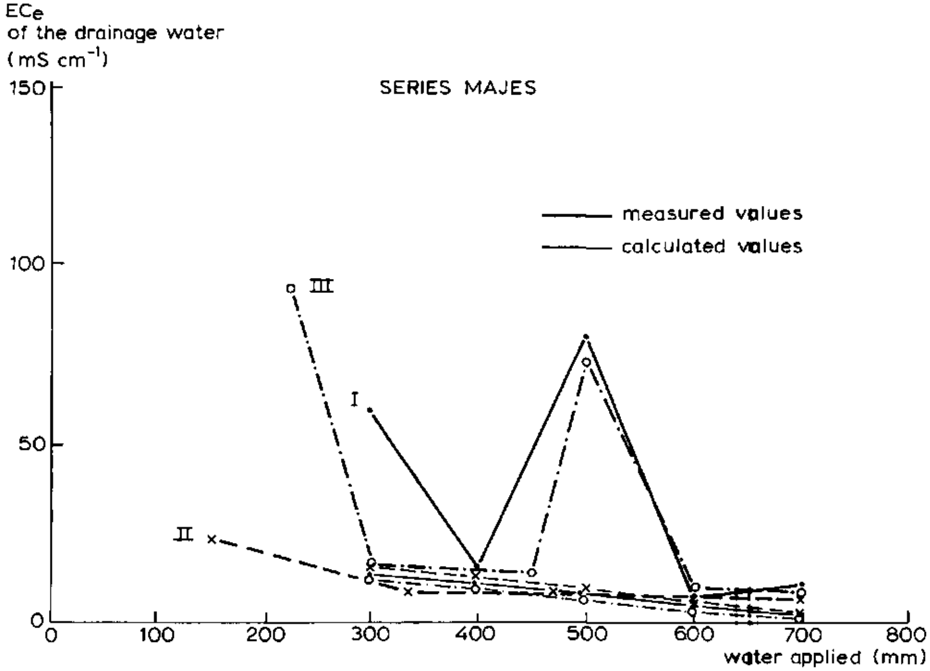

Fig. 17. Pattern 2 of the relation between the electrical conductivity (EC_e, measured and calculated) and the amount of water applied (series Majes). I, II and III refer to three seperate lysimeters filled with the same soil.

is plotted against the amount of water applied. A conspicuous feature is the enormous variability among the replicates, despite the fact that the samples were taken from almost the same site. In most cases around 200 of water (about 133 mm) had to be applied before drainage began. Where the EC_e of the first leachate was high, it dropped rapidly with increasing application of water. This indicates that leaching, at least partially, takes place according to the so-called piston displacement, i.e. the concentrated solution is replaced by more dilute solutions without complete mixing between the two. The concentrations that would have resulted from complete mixing were calculated and are also presented in the figures.

The theoretical considerations underlying the phenomena of piston displacement versus complete mixing were developed by Van der Molen (1973). In a few cases the concentration dropped at first but showed a temporary increase as the leaching proceeded (Figure 17, replicates I and III). Perhaps this is due to delayed appearance of salts, trapped within agglomerates of gypsum, calcium carbonate and other salts, which desintegrate only after absorbing large amounts of water.

After leaching, all lysimeters were fertilized with K and P and sown with inoculated seed of the alfalfa variety Tambo. Plant development was much faster on the developed soils than on the virgin ones. Therefore comparison of productivity started after the lysimeters with the developed soils had been cut twice and the others once. After each cut, all lysimeters were fertilized with 60 g of K_2SO_4 and 30 g of super phosphate (later increased to 90 g). Water was applied every three days at k = 1.2. This high k value was chosen to compensate for advective energy, because a large number of the lysimeters was situated on the edge of the plot, where

Table 10. Relative productivity of the different pampa soils (see text).

Series	Cutting dates							
	28/5	15/7	25/8	1/10	4/11	8/12	7/1	8/2
Vitor	77	78	84	74	84	91	98	99
Majes	83	75	93	84	82	90	96	95
Hospicio	107	71	64	65	66	70	82	87
Vitor Guij	80	90	104	88	86	101	102	106
Pampas Alt.	70	67	95	97	95	103	015	109
Vitor Yesos.	94	63	85	89	70	85	94	97
Molles	88	78	88	79	76	79	88	88
Pumicita	81	76	96	89	91	103	93	110
Pacarquinta	108	92	86	79	86	92	90	95
Terraza	87	104	109	78	103	108	88	99
S.C. Virg.	66	83	93	85	91	91	100	100
Siguas	83	81	105	98	92	92	96	104
F[1]	2.73^{*}	4.06^{*}	4.17^{*}	3.21^{*}	3.41^{*}	3.89^{*}	1.31^{NS}	1.58^{NS}

[1] NS: not significant; * $P \leq 0.10$.

they are exposed to advective energy fluxes of desert winds.

The yield of a number of subsequent cuts on the 12 virgin soils is presented in Table 10 in values relative to the mean of the yields of the developed soils. The table shows that there were fairly large differences in relative yield in the beginning, varying between 66 and 108, but that these differences decreased with time, so that the variation was only between 87 and 110 at the last harvest, a variation no bigger than that within the series of developed soils.

The trial shows that on all soils, irrespective of their structure and organic matter content, the same amount of alfalfa dry matter can be produced provided that water and minerals are supplied in sufficient quantities. It should be realized, however, that in some soils more than 25 % of the water applied was lost by leaching below the root zone and that an analysis showed that more than 10 % of the applied potassium could be lost in this way. Moreover, it turned out during the experiment that some soils had to be irrigated every other day to prevent serious temporary wilting of the crop, whereas sprinkling once every three days is already difficult to realize in practice. Therefore, it has to be concluded that on several soil types in the area farmers will meet serious difficulties when cultivating alfalfa. More research in this

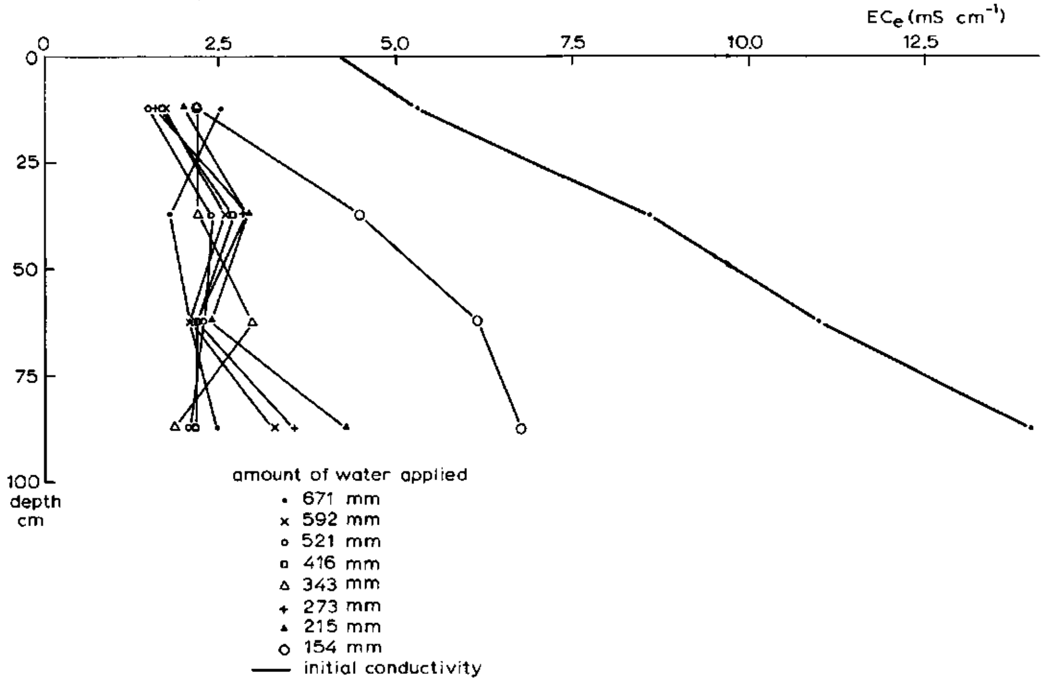

Fig. 18. Distribution of salts (measured as electrical conductivity, EC_e) in the soil profile before and after application of different quantities of water.

set-up is necessary to obtain more data about critical values for irrigation and fertilization requirements of different crops.

To increase the understanding of these phenomena, a trial was carried out on a virgin soil at San Camilo with one single line of sprinklers (the line source method mentioned before). Water was applied during the 16 hours of the day when there was virtually no wind. During the remaining 8 hour period the soil was harrowed lightly to prevent a crust forming. After some time, soil samples were taken at different distances from the irrigation line in layers of 25 cm to a depth of 1 m. The amount of water received at each site was measured by rain gauges. Each soil sample was mixed with distilled water in a 1 : 1 (w/w) ratio and the electrical conductivity determined.

The results are presented in Figure 18. Before leaching the soil the EC_e increased rapidly with depth up to 1 m. With the lowest amount of water applied (154 mm), the EC_e was already reduced to about half of the original value at each depth and with an application of about 200 mm the minimum was already obtained, down to a depth of 75 cm. This means that in the San Camilo soils an application of 200 mm is sufficient to leach the soil. This is far less than the 700-1200 mm that is usually applied on virgin soils in the area.

Although the EC_e value of the irrigation water was around 0.9 mS cm^{-1}, it was not possible to obtain these values in the soil; these remained around 2.5 mS cm^{-1}. This is probably due to the presence of gypsum, which, due to its low solubility, adds some electrolytes to the soil solution for a prolonged period of time.

5 Financial survey

The project budget as well as the money actually spent are presented in Table 11, subdivided into different articles. The total amount spent was within the budget, mainly due to the budgetting for contingencies, which was eight per cent of the rest. Some expenses, such as transport of all necessary items to Peru and the necessary field equipment, were much higher than budgeted, others were lower, but in general there was a reasonable agreement.

As for salaries, it was agreed that each member of the project should be paid according to the salary regulations in his own country. In the last column of Table 11, in which the expenditures of each heading are expressed as a percentage of the total, it is shown that salaries of the three foreign experts, including costs of displacement, amount to more than 50 % of the total budget. It also shows that the salaries of all Peruvian project personnel, including three scholarships in Europe, are of the same magnitude as the personal costs of one foreign expert.

Although it is true that around half of the money is not directly spent on development aid in the strict sense of the word, it must be realized that the work continues in the same way after the project was finished. About 18 months after finishing, the project has been

Table 11. The amount of money (Dutch guilders) budgeted and spent.

Description	Budgeted (Dfl.)	Spent (Dfl.)	Percentage of total spent
Dutch crop scientist	675 500	817 460	22.5
Dutch head of laboratory	525 500	526 420	14.5
Israel soil scientist	554 000	513 900	14.2
Peruvian personnell + scholarship	590 000	524 910	14.5
travel expenses project leaders	64 000	27 300	0.8
transport costs in Peru	133 000	127 750	3.5
laboratory costs	517 000	481 950	13.3
weather station	20 000	10 120	0.3
telex communication	30 000	9 920	0.3
field equipment and instruments	160 000	279 180	7.7
office costs	60 000	46 030	1.3
transport of materials to Peru	85 000	170 830	4.7
unforeseen	270 000	86 230	2.4
total	3 684 000	3 622 000	

visited by two of the foreign experts and despite all kind of difficulties, for example temporary strikes, the research continues in much the same way as during the project and the Peruvian scientific staff has even been extended. Thus, although the actual project costs were roughly one million Dutch guilders per year, the work is now continued for an extra 2½ years as a 'post Faoprocaf project' with budgeted Dutch aid of around Dfl. 60 000 per year for travel costs of foreign experts and some scholarships. All the runnning costs of the project have been taken over by the Peruvian government. If the research can be continued in this way until 1986, it is hoped that this very small amount of foreign money can be spent for a longer time to continue the cooperation between the three countries. In that light the relatively large expenditure in sending foreign experts for a period of four years seems well spent, as it has stimulated and upgraded local research for a much longer period.

6 Conclusions

The FAPROCAF project presented here was both planned and financed as a research project. This was done in the conviction that more fundamental knowledge about the effect of environmental factors on basic plant physiological processes, such as photosynthesis and transpiration, stomatal behaviour and water potentials, that determine crop productivity would lead to a better understanding of agricultural possibilities in the region itself and to better extrapolations to other arid zones. Especially as the existence of simulation models opened the possibility of developing or improving these with the information obtained, thus helping to make calculations of production possibilities more reliable.

Such a concept of development aid is by its nature not in the first instance directed towards solving specific agricultural problems in the target country. It may evoke, therefore, some suspicion amongst local authorities that such a project is not primarily meant to assist the target country, but to extend the research possibilities and solve scientific problems of the donor country. This could also be said of the attitude in Peru concerning the usefulness of the project in solving pratical problems. This attitude changed as the project advanced, especially among the Peruvian agriculturists working in the same or in neighbouring experimental stations. This resulted in increasing cooperation with people and institutes outside the project.

Through the Peruvian National Agricultural Research Organization (INIPA, Instituto Nacional de Investigación y Promoción Agropecuaria) contacts were established with DEPEMA, the organisation concerned with the development of the Majes-Siguas project, a planned irrigation project of 52 000 ha (see Zipori et al., 1982).

It appears from the data obtained so far on water use that the amount of available water is insufficient to fully irrigate the planned area. The development scheme would thus have to be revised to avoid a catastrophic situation in the future whereby more land would be issued to farmers than can be irrigated. Especially when rainfall in the mountains is deficient for several years in succession, which will in any case cause food shortages, such miscalculations can easily result in serious food shortages.

It is also important in this context to suggest that farmers should pay for their irrigation water, although payment should be commensurate with their economic possibilities. Nevertheless payment may encourage farmers to economize on water use and to adopt results from the FAPROCAF project, such as leaching the soil with no more than 250 mm water and irrigating a crop according to its development stage. At present water is obtained free of charge and the only restriction is the period in which it is made available to certain areas. Especially during dry spells, everybody tries to get as much water as possible, with the result that it is not used in the most profitable way.

Another important result that deserves practical application is the better assessment of production possibilities. A good example of this results from the research on potatoes. With adequate nitrogen fertilization and irrigation, yields of around 80 tonnes of fresh tubers per hectare are possible. These yields are around seven times higher than the mean yield obtained in the area, but appear to need little more irrigation water. As there is most of the time a ready market for more potatoes the extra nitrogen and some more care will be easily paid back. In a similar way, other data obtained by FAPROCAF can be easily translated into practical application, and additional experiments can easily give more background information and more practical applications.

As both the skills and the infrastructure are present after termination of the project, all three participating countries agreed in a continued cooperation in which regular contacts are to be maintained between INIPA (Peru), the Faculty of Agriculture of the Hebrew University (Israel) and the Centre for Agrobiological Research CABO (the Netherlands). To make such a continuation possible there is some continued Dutch financial aid for short visits to the project, as well as for a limited number of scholarships for promising Peruvian scientists. In addition, a financial buffer-fund has been created which permits immediate purchase of necessary implements, like instrument and machinery spare-parts, chemicals, glassware and fertilizers, under the proviso that the money is refunded later by the Peruvian government.

In this way it is hoped to maintain prolonged and efficient contacts and to continue the research for the benefit of the irrigated desert areas in southwestern Peru and in arid zones elsewhere.

Summary

This research project was carried out in the coastal desert of southwestern Peru.

It was financed by the Directorate General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs. The project, which lasted four years, was supervised by the Centre for Agrobiological Research (Netherlands), the Faculty of Agriculture of the Hebrew University (Israel) and the Instituto Nacional de Investigación y Promoción Agropecuaria (Peru).

The main purpose of the project was to investigate dry matter production and water use of the most important crops in the region under irrigated conditions and fertilizer application. To facilitate the necessary measurements and analyses, an existing laboratory was improved and measuring instruments were purchased.

The research was carried out by a team comprising a Dutch crop scientist, an Israeli soil scientist and irrigation expert, a Dutch laboratory head, their Peruvian counterparts and Peruvian laboratory personnel and field workers.

In addition to field trials, pot trials were carried out, mainly to determine the transpiration coefficient (TRC), i.e. the amount of water transpired per unit of dry matter produced.

The crops mainly studied were alfalfa, maize and potatoes, which are the most important crops in the region, and Rhodes grass for comparison. All crops were sprinkler irrigated, but in a few cases trickle irrigation was used for comparison. By periodic harvesting - usually at weekly intervals - data for growth curves, the time course of the leaf area index, light interception and dry matter partitioning were compiled. In addition, the water supply to the crop was measured as well as the soil water content before and after watering. The results obtained were compared with those obtained elsewhere, sometimes also with simulation programs.

DIFFERENT CROPS

The rate of growth of an alfalfa sward varied with the season; it was higher in summer than in winter. A ceiling yield was reached earlier in the year and was more pronounced than at the end of the year. The local variety Tambo gave higher yields than the Californian variety Moapa, mainly due to higher ceiling values (Figure 1). Under the prevailing conditions fertilization with P and K was not necessary; N fertilization resulted in slightly higher yields, but without fertilization an amount of N of about 700 kg per ha per year was fixed by *Rhizobia* bacteria. No clear relation could be demonstrated between the rate of regrowth and the amount of reserve carbohydrates left in the remaining plant parts after cutting. However, there was a relation between regrowth in the light and that in the dark, indicating that, in some way, carbohydrate reserves are important.

Maize in the project area had a slower initial growth under optimal conditions than elsewhere in the world, but in the linear phase growth rates were comparable to those in other arid zones, leading to yields of around 25 tonnes of harvestable dry matter per ha (Figure 3).

The local variety performed better than those from elsewhere (Table 2). Both the initial growth rate and the final yield were sensitive to temperature. In the winter period, growth rates were slower than in summer (Figure 4). Nevertheless yields were higher at the experimental site (about 1000 m a.m.s.l.) than in a warmer river valley at sea level, mainly due to the longer growing period. Contrary to expectations, rooting was much better and yields higher on old valley soil than the well-watered and well-fertilized sandy desert soil.

Rhodes grass formed such a very dense sward that weeds were not able to penetrate. During the summer months, yields were high enough to be able to compete with other fodder crops, but during winter, growth virtually stopped, mainly due to the low night temperatures. For this reason large scale use of Rhodes grass is not recommended on the desert plains of Peru.

Potatoes, well supplied with water and nutrients, yielded around 70 tonnes of fresh tubers per hectare - comparable to yield levels elsewhere in the world. Again the Peruvian variety yielded more than a Dutch variety, but as the latter had a more homogeneous tuber size, the marketable yield was about the same.

DRY MATTER PRODUCTION AND WATER USE

The relationship between the amount of dry matter produced and water recieved at increasing distances from a single sprinkler irrigation line was established by measurement.

For potatoes this relation was linear, almost up to the highest amount of water applied (Figure 8). From the slope of this line a transpiration coeficient (TRC) of around 210 kg water per kg of dry matter was calculated, which is very low for a C3 species under the conditions prevailing at San Camilo. Extrapolation of the line to the x axis indicates that a large proportion of the water applied (around 550 mm) was not used by the crop.

For alfalfa a comparable relation was found (Figure 10). When more than 250 mm water was applied, the crop did not show a response; below this value the relation was linear, down to about 50 mm water. Compared to potatoes, the TRC was much higher (55 kg water per kilogram dry matter produced), but evaporation and percolation were very much lower.

Both with alfalfa and with maize, experiments were carried out in which the amount of water applied to different plots was varied in relation to the evaporation of a Class A pan. For alfalfa, this resulted again in a rectilinear relation between dry matter production and water application up to about 250 mm water applied for both varieties and in all seasons. Application of an artificial mulch gave a better utilization of the irrigation water (Figures 11 and 12).

The relation between dry matter production and the amount of water evapo-transpired could be calculated from the soil water measurements (Figures 13 and 14).

For maize the results were less conclusive, partly because the trial was carried out in the unfavourable season. To economize on water it was administered according to the expected transpiration rate, but the results indicate that especially at the beginning all application rates were too low (Figure 15). The highest yield was attained when water was applied at a high and constant rate for the lower plant density. Trickle irrigation instead of using sprinklers saved a considerable amount of water. However, due to the higher costs, a trickle irrigation can only be profitable if it can also be used for other crops.

To obtain a better insight into the water economy, a series of pot trials was carried out, mainly with alfalfa and maize. With pot trials percolation is zero and evaporation can be almost completely reduced by covering the pots with gravel. The pots were placed in an alfalfa field to reduce advection of dry air from the desert; distilled water was added regularly and the pots were weighed before and after. Control pots were used to measure evaporation. For alfalfa the data are presented in Table 4, for maize in Table 5. In addition, the daily transpiration of alfalfa between two cuts is presented in Figure 9.

The TRC of maize (a C4 plant) was much lower (better water economy) than that of alfalfa (a C3 plant). Furthermore it could be established that for alfalfa the TRC was lower in summer than in winter and that a temporary water shortage reduced the transpiration more than photosynthesis, which causes a lower TRC.

Some different soil types of the pampa were tested on their water holding capacity in a lysimeter experiment with alfalfa as the test crop. When well watered and fertilized, all soils were able to give good yields. However, some soils needed to be irrigated every other day, which would require too much labour in normal practice to use them economically.

The value of the results for farming in the regions is discussed.

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