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PERFORMANCE OF YEAR-ROUND CROPPING SYSTEMS ON THREE TROPICAL SOIL FAMILIES

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By

NARAINA P. S. VARDE

Dissertation Committee:

Goro Uehara, Chairman
Bernandino Cagauan Jr.
Chauncey T.K. Ching
Haruyoshi Ikawa
Yoshinori Kanehiro
James A. Silva

We certify that we have read this dissertation and that in our opinion it is satisfactory in scope and quality as a dissertation for the degree of Doctor of Philosophy in Agronomy and Soil Science.

Dissertation Committee

Goro Uehara
Chairman

Yoshinori Kanehiro

James A. Silva

B. G. Cagauan, Jr.

H. Ikawa

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ABSTRACT

A favorable climate throughout the year as well as the prevailing socio-economic conditions in the tropics are ideal for multiple cropping in time and space. Despite of its relevance, year-round cropping systems have seldom been used to evaluate the productivity of well-characterized tropical agroenvironments. The major objectives of this study were to monitor the effects of agroclimatic parameters on the performance of various crops and sequences of crops, and to investigate the possibility of stratifying crop production potential, on the basis of the soil family category of Soil Taxonomy, in the tropics.

Year-round cropping patterns were tested on a weather-monitored network of ten sites located in Indonesia, The Philippines and Hawaii representing the tropical soil families of thixotropic, isothermic Hydric Dystrandepts; clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox and clayey, kaolinitic, isohyperthermic Typic Paleudults. The cropping patterns used were specifically designed for each of the three agroenvironments and similar management practices were followed on all sites.

The sequential cropping pattern of Irish potato followed by soybean and then by field corn, designed specifically for the Tropeptic Eutrustox agroenvironment, gave the highest calorie and protein yield (46581 k cal/ha and 2101 kg/ha, respectively) at the Eutrustox site of Waipio, Hawaii. The above cropping pattern also resulted in higher calorie and protein production at the Dystrandept site in Kukaiau, Hawaii compared to the specifically-designed pattern of Irish potato and vegetables followed by vegetables and then followed by soybean and peanut. The Dystrandept sites in Indonesia and The Philippines had lower yield potential compared to the site of Kukaiau, mainly because of higher temperatures of the former, that resulted in low yields of vegetables and Irish potato.

Head cabbage, mustard cabbage, Irish potato, carrot and bushbean were found to be susceptible to high temperature and excess moisture. The yields of the above crops were highly correlated ($r = -0.70^{**}$) with soil temperature at 10 cm, and their best yields were obtained within a soil temperature range of 18 to 23°C. In contrast, soybean and peanut were adapted to a wide range (21 - 28°C) of air temperature and soil moisture. Soybean planted during April-May (long days) gave significantly higher yields compared to August-September (short days) plantings. Multiple regression equations with agroclimatic parameters as independent variables, were derived to predict yields of crops. Except for green corn, only crops that were sensitive to temperature and excess moisture (mustard cabbage, head cabbage, carrot, bushbean and Irish potato) had prediction equations with coefficients of determination close to 0.80. However, for soybean and peanut the best models incorporating as many as six environmental parameters explained less than 50 percent of the yield variability.

In the Hydric Dystrandepts and Typic Paleudults (udic moisture regime), most crops grown year-round did well without irrigation. Crop performance in Tropeptic Eutrustox confirmed the absolute necessity of supplemental irrigation for year-round crop production under an ustic moisture regime.

Response to Rhizobium inoculation as reflected by soybean yields, was variable. However, the number of significant responses to inoculation was greater in the Tropeptic Eutrustox than in Hydric Dystrandept sites. Bushbean yields were significantly higher in the "bushbean + mustard cabbage" intercrop combination then in the "bushbean + green corn" combination. Air temperature was negatively correlated ($r = -0.96^{**}$) with the number of days required for maturity of Irish potato.

In this study, segregation of a soil family based on crop performance was possible only in case of Typic Paleudults. High average air and soil temperatures (> 26°C) prevalent in the Paleudults resulted in poor performance of temperature-sensitive crops such as head cabbage, mustard cabbage, Irish potato and carrot.

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Cropping Pattern	Crop Sequence
TE	Irish potato - soybean - corn
HD-A	Bushbean + carrot + cabbage - bushbean + Green corn - soybean
HD-B	Bushbean + carrot + cabbage - bushbean + green corn - peanut
HD-C	Bushbean + carrot + cabbage - mustard cabbage + bushbean - soybean
HD-D	Bushbean + carrot + cabbage - mustard cabbage + bushbean - peanut
HD-E	Irish potato - bushbean + green corn - soybean
HD-F	Irish potato - bushbean + green corn - peanut
HD-G	Irish potato - mustard cabbage + bushbean - soybean
HD-H	Irish potato - mustard cabbage + bushbean - peanut
TP-A	Rice + green corn - soybean - cowpea
TP-B	Rice + green corn - soybean - mungbean
TP-C	Rice + green corn - peanut - cowpea
TP-D	Rice + green corn - peanut - mungbean

For Appendix 1

BSB	Bushbean
CAB	Cabbage
CRT	Carrot
CWP	Cowpea
FCN	Field corn
GCN	Green corn
IPO	Irish potato
MCB	Mustard cabbage
MGB	Mungbean
PNT	Peanut
RIC	Rice
SOY	Soybean
PAT	Cropping pattern
SEASN	Season
REGN	Region
YIELDI	Irrigated crop yield
YIELDNI	Non-irrigated crop yield
DUR	Crop duration
DYS	Number of days
WINDV	Wind velocity
TPPT	Total rainfall for the crop period

SLRD	Solar radiation
STMX	Maximum soil temperature
STMN	Minimum soil temperature
ATMX	Maximum air temperature
ATMN	Minimum air temperature
RHMX	Maximum relative humidity
RHMN	Minimum relative humidity
HD	Cropping pattern for Hydric Dystrandepts
TP	Cropping pattern for Typic Paleudults
TE	Cropping pattern for Tropeptic Eutrustox
AND	Hydric Dystrandept soil
OXI	Tropeptic Eutrustox soil
ULT	Typic Paleudult soil
H	Hawaii
I	Indonesia
P	The Philippines
IOL	IOLE
ITK	ITKA

CHAPTER I

INTRODUCTION

The cropping systems research approach

Multiple cropping systems are both natural and essential for tropical agriculture. Tropical regions are characterized by adequate solar radiation and favorable temperature for crop growth throughout the year. Millions of farmers in this part of the world have been utilizing the long growing season to produce more than one harvest a year and to grow more than one crop at a time. Besides the favorable physical agroenvironment which makes multiple cropping naturally feasible, there are other socio-economic factors that make such a system essential for the food security of the region. Some of such factors are population pressure, scarcity of additional cultivable areas, risk reduction, provision of the multiple needs of the small farm family, and small land holdings.

As early as 1934, it was recognized (Wood, 1934) that multiple cropping systems are predominant in small farming systems. It has been shown, that in Columbia and Central America, 70 percent of the food consumed is produced on small farms (CATIE, 1974; Pinchinat *et al.*, 1976). In Tropical Asia 75 percent of all farms are smaller than 2 ha (Harwood and Price, 1976). Inspite of the forgoing facts and some early studies emphasizing the importance of multiple cropping (Aiyer, 1949; Anderson, 1950) agricultural researchers did not attach due importance to cropping systems until the work of Bradfield (1969, 1970, 1972) at the International Rice Research Institute in The Philippines. Since then considerable emphasis has been given to cropping systems research throughout the world, but mainly in the Tropics. Today the cropping systems research in developing countries is spearheaded by the international agricultural research centers such as International Crops Research Institute for Semi-Arid Tropics (ICRISAT) in India, International Rice Research Institute (IRRI) in The Philippines and International Institute for Tropical Agriculture (IITA) in Nigeria. A major problem of research on cropping systems is the limited transferability of its results, due to the poor characterization of the agroenvironments involved. In the majority of cases the descriptions of the agroclimate are highly subjective and not widely recognized. The experimental work described here was conducted as a result of the realization of the importance of cropping systems and the major flaw of current research in this area.

Background and objectives of the present study

The cropping systems experiments were conducted in the experimental sites of the University of Hawaii Benchmark Soils Project (BSP) network of soil families fully characterized using Soil Taxonomy (Soil Survey Staff, 1975). The principal objective of BSP was to test the hypothesis that agroproduction technology can be transferred from its site of origin to other locations having similar agroenvironments, in widely separated parts of the tropics based on Soil Taxonomy. Soil classification at the family level in the Soil Taxonomy (Soil Survey Staff, 1975) was proposed as the basis for transfer. For testing the hypothesis a network of experimental sites on three selected tropical soil families was established. After extensive trials it was demonstrated that maize response to applied P can be transferred among sites of the same soil family if appropiate site variables are considered (BSP, 1979; 1982). It was therefore conceivable to believe that cropping systems performance as a whole or of its component crops should be similar in two locations classified under the same soil family. Also, year-round cropping integrates agroenvironmental effects on crops for the entire growing season and thus can give a better assessment of the yearly productivity of different agroenvironments. These benefits were the prime motivators for a cropping systems approach to management experiments, that evolved at a University of Hawaii workshop entitled "A Multidisciplinary Approach to Agrotechnology Transfer" (BSP, 1982). Following up on this idea, cropping patterns for each soil family were designed in October, 1980.

The design of cropping patterns was accomplished by matching crop requirements to the agroenvironmental characteristics. Crops were broadly chosen based on the temperature and moisture regimes identified through the soil family designation. Further, the additional data on mean seasonal variations of rainfall and temperature were utilized to fit crops in a particular sequence. Guidelines for the establishment of cropping patterns on BSP sites were developed in December, 1980.

The experiments were conducted on ten sites representing three soil families, listed below:

(1) Thixotropic, isothermic Hydric Dystrandepts: Sites Iole (Hawaii),

Kukaiau (Hawaii), Palestina (The Philippines), ITKA (Indonesia), and LPH (Indonesia).

(2) Clayey, kaolinitic, isohyperthermic, Tropeptic Eutrustox: Sites Molokai (Hawaii) and Waipio (Hawaii).

(3) Clayey, kaolinitic, isohyperthermic, Typic Paleudults: Sites Davao (The Philippines), Sorsogon (The Philippines), and Nakau (Indonesia).

The soil family characteristics and the agroclimatic data collected daily, provided the basis for quantifying the agroenvironment. Traditionally, cropping systems research seeks to increase the benefits derived by crop production with available physical, biological and socio-economic resources (Zandstra et al., 1981). The aim in this study was to use promising cropping patterns for taxonomically identified agroenvironments so as to assess their relative crop production potentials. The designed patterns had three crops grown during the year in sequence. The first season crop was planted at the onset of the rainy season. The specific objectives of this study were the following:

(1) To assess the relative year-round production potential of each soil family of the BSP network.

(2) To evaluate the performance of a particular cropping pattern under different agroenvironments.

(3) To assess the comparative potential of the three agroenvironments to sustain year-round cropping without irrigation and validate the moisture regime stratification accomplished by Soil Taxonomy.

(4) To verify the response of soybean to Rhizobium inoculation as influenced by the three agroenvironments.

(5) To relate the crop performance to edaphic as well as agroclimatic parameters.

(6) To see the possibility of gathering transferable information on crop performance.

(7) To determine the stratification efficacy of Soil Taxonomy for the purpose of matching land characteristics with crop requirements.

CHAPTER II

LITERATURE REVIEW

2.1 Cropping systems research-general

Perhaps the most important aspect of multiple cropping research for tropical agriculture is that it provides a means to increase food production without increasing the cultivated area but by increasing yields by harvesting more than one crop from the same piece of land each year. Multiple cropping exploits crop intensification as one of the major ways of preventing food shortages. This is not a new concept, but an ancient practice that has persisted in many parts of our globe to maximize land productivity. The practice is common in areas of the tropics where temperature and moisture are favorable for year round crop production (Papendick et al., 1976). The systems in use today have evolved largely from experience and in response to high food demand in densely populated areas.

Technically, multiple cropping can be defined as the intensification of cropping in time and space dimensions (Andrew and Kassam, 1976). The various types of multiple cropping systems, reflect essentially two underlying principles, that of growing crops simultaneously in mixtures i.e. intercropping; or of growing individual crops in sequence i.e. sequential cropping. Mixed, row, strip and relay intercropping work on the former principle, while double (and triple etc.) and rattoon cropping use the latter. All the other derived forms of multiple cropping originate through the synthesis of simultaneous and sequential cropping practices. Conventional agricultural research concentrated upon enhancing crop production in two dimensions:

(i) Increasing cultivated area.

(ii) Increasing yields per unit area per crop.

Multiple cropping as explained above, allows intensification in two additional dimensions: time and space.

Before reviewing the structure of cropping systems research practiced today, it would be worthwhile to probe the reasons why this research field remained obscure till recent times and how it gained the appropriate attention it deserves.

Systematic agricultural research and development mostly started in industrialized nations and then were introduced in less developed countries. According to Whyte (1981) two general agricultural research and development models have been transferred. The European Colonial model was introduced before World War II in the African and Asian colonies. The other type of model was developed after 1945 through U.S. aid in Asia, Middle-East and Latin America.

The basis for European Colonial model was large scale plantation research devoted for improvement of export crops, e.g. Tea, Coffee, Cocoa and Cotton. Such research provided little or no assistance to the small farmers who were raising crops for self-sustainance and local marketing, until shortly before the end of colonial period. The plantation research system was found ineffective to deal with small farmers. The European model was distinctly "Vertical" (Whyte, 1981). Research was carried out in laboratories and sent "down" to plantations, where production is essentially controlled and supervised as in traditional industrial setup. "Feed-back" was "upwards" to the researcher directing the operation. Evidently this procedure could not be adopted for the small farmers.

The U.S. model of agricultural research came into existence after the colonial era. It was assumed that transfer of this model to developing countries could result in the same degree of success as had occurred in the United States. The model of American land grant universities linked to an extension service for dissemination of university research to the farmers, was carried to the developing nations through technological and financial assistance. Ideally the system intended to bring farmer's experience and problems "back" to the researchers. Thus a horizontal flow model was intended though practically it tended to resemble the European model essentially involving a one way flow of initiatives and information.

Towards the end of 1960s the United States Agency for International Development (U.S.A.I.D.) commissioned an evaluation (Rice, 1971) to determine the effects of millions of dollars of U.S. aid spent to extend the U.S. model in Asia, Middle East and Latin America. It was found that the impact of U.S. aid was very poor specially in Andean nations. Until the failure of this partial transplant "agri-extension" was evident, the planners did not undertake to build in developing countries the other components particularly the university and experiment station based research programmes, which were also vital to the U.S. model. The failure of the agri-extension system however cannot be attributed to any single cause. The description of some of the main factors involved is in order.

It was wrongly assumed that research results achieved in the U.S. and other developed countries could be extrapolated to the developing nations. Due to enormous variability of soil type, climate and water, within and among developing countries, general recommendations for a region are rarely valid for all farmers. Yield increases in a country depend as much upon information and genetic materials developed or adapted within that country, as they do upon information and materials from international sources.

Agricultural extension methods were employing a now discredited assumption that small farmers have such inadequate knowledge about agriculture that they must depend upon professionals to provide them with the information and ideas to improve production. The extension agents in most developing countries have little or no farming experience, are bookish in knowledge and hence their relationship with farmers is not constructive. Also the extension agent is overly loaded with unproductive work of writing innumerable "reports" and too many farmers are assigned to him, thus making him ineffective in followup work.

Small farmers face major problems in the number of uncoordinated agencies with which they have to deal if they are to get help from the State. Therefore more effective organizational models will have to provide better coordination among these agriculture related agencies. In addition there are the major problems of communication and cooperation between small farmers and agri-professionals, influenced by the cultural and social traits of the country in which they live and work.

Due to the growing recognition of the inability of the existing agricultural development programme to deal effectively with the problem of small farmers and the rural poor, some agricultural research and development projects were initiated from the late 1950s into 1970s in developing countries. Four important projects were Comilla (Bangla Desh) CADU (Ethiopia), PUEBLA (Mexico) and CAQUEZA (Columbia). Such projects gave insight to various problems of the small farmers (CIMMYT, 1974; Blair, 1974, 1978, 1982; Zandstra, 1979). The Puebla project pointed to the increasing appreciation of the small farmer or peasant rationality, as the key in the new approach to agricultural research and development. A number of recent experiences have also shown that even the poorest farmers take up certain technologies while rejecting others (Winkelmann and Moscardi, 1982). Thus as originally proposed by Schultz (1964), and is widely, though not universally accepted, small farmers are efficient in utilization and allocation of available resources among known technologies if they have been farming under stable conditions for some time. Hence the consensus is that the small farmers will and do accept changes when the available resource base changes or new appropriate technology becomes known (Hildebrand, 1982), otherwise they could not be efficiently adjusted to alternatives they now have. But it is important to realize that this efficient adjustment is in terms of the farmer's own understanding and interpretation of their situation and it is not necessarily efficient according to the perceptions of well meaning but incompletely informed scientists. Also, it was not until the 1930s that scientists had acquired the knowledge, experience and genetic materials necessary to help already efficient farmers to increase their yields per unit of land. It was no mean feat to hold yields steady over decades in the face of crop pests, soil erosion, weeds and other problems and the new science contributed to this achievement (Whyte, 1981).

The high yielding varieties created in 1960s and their phenomenal success, known universally as the green revolution, raised hopes that such technology would usher in a generally higher standard of living for all farm population. By 1970s observers were coming to recognize that the benefits of green revolution had been very unevenly distributed and that the majority of small farmers cultivating rainfed areas, had received relatively little benefit. Ponnamperuma (1979) reported that 75 percent of the world's rice farmers concentrated mostly in South and South East Asia were not affected by the new rice technology. He also observed that small farmers could not provide the management input required to extract the high yield potential of modern varieties. There were also claims of disruptions in rural societies produced by the production oriented agri-development of late 60s and 70s (Anderson, 1979).

The observation that new technologies were not trickling down to the small farmer led to the focussing of attention upon presumed barriers to the "transfer of technology". Various reasons such as faulty extension service (discussed earlier), inadequate credit, non-availability of inputs etc., were put forth to explain the non-adoption of recommendation by farmers (Winkelmann and Moscardi, 1982). Each of these explanations has been valid depending on place and time. However, the consensus is that the small farmers are efficient in the allocation of their resources to known and appropriate traditional technologies and seek to balance gains and losses and minimize risk. According to Hildebrand (1982), the problem is not one of motivation but of offering technologies that are not appropriate as perceived by the farmers. It is assumed that decades of experience in farming in a given area has given the farmer an intimate knowledge of the behavior of plants and animals in that area under varying conditions and the agricultural scientist needs to gain access to information and ideas of small farmers to make an useful contribution.

The new research strategy now emerging has two principal elements: (1) shift in emphasis away from monocultural or single crop research toward research in cropping systems especially adopted to the needs and interests of small farmers and (2) emphasis toward, on farm research away from experiment station, with active participation of small farmers. This approach led to systematic farmer oriented research on complex cropping systems mentioned at the start of this review.

A pioneer in systematic research on cropping systems was Richard Bradfield working for IRRI in 1960s. He devised a system involving intensive use of land through intercropping, relay planting and sequential planting so as to get three or four full growing seasons within a given year. Following up Bradfield's work, Richard Harwood took the essential step of moving from Bradfield's experiment station project into the farmers' fields. His experiences with farmers culminated into his important recent book on small farmer development (Harwood, 1979). In Africa David Norman (Norman, 1973) took the leadership in investigation of indigenous mixed cropping. At the begining of 1970s, the multiple cropping research results from The Philippines (Bradfield, 1969, 1970, 1972) stirred interest in the study of cropping systems in tropical America, with emphasis on small scale farming.

In late 1970s scientists were already generating the conclusions regarding the advantages and limitations of multiple cropping systems. Whyte (1982) concluded that as a general rule the productivity of the land under peasant patterns of cultivation is potentially greater than that which is achieved with monocultural systems.

Innes (1980), through exhaustive review of intercropping experiments, stated that there is an enormous body of evidence that shows that a suitable combination of intercrops will always produce a greater total yield than only one crop in a field. Whyte (1981) commented that it would be more accurate to substitute "usually" or "very often" for "always" in the statement made by Innes. Innes (1980) further observed that intercropping reduces loss of nutrients from leaching because numerous root systems of varying depths intercept downward percolating water and retrieve dissolved nutrients which would have otherwise escaped past the root system. Various researchers have noted another important advantage of intercropping as the improvement in pest, disease and weed control. On the other hand, intercropping provides major barrier to mechanization. Often this is not a severe limitation in the farming system and socio-economic environment of the small farmer.

Intercropping aims at utilizing both extra time and spatial arrangements of component crops, and one species may even provide support for another, as in case of climbing beans (Phaseolus species) and maize (Zea mays L.). In a successful crop mixture of both similar and different maturities, the sum of intercrop competition should be less than the sum of the intercrop competion of the component crops, when grown separately. Gain originates in crop mixtures because either individual plants yield more and /or higher total plant population densities are possible. In mixtures of crops of similar maturity, yield advantages accrue basically through lower "instantaneous" intercrop competition in space, both aerial and edaphic. In mixtures of crops of different maturities, yield advantages accrue through low intercrop competition in space and time for the more rapidly growing, early maturing components and through a lower intercrop competition in space and time for the slow growing, later maturing components (Andrews and Kassam, 1976).

Sequential cropping aims at multiplying the returns by growing an extra crop through utilization of the time dimension. New high yielding and short duration varieties have greatly contributed to the flexibility of successive cropping patterns. Utilizing time in crop sequences is complimentary to better utilization of space in mixtures for obtaining higher yields. It follows that theoretically maximum cropping should be obtained with sequences of high yielding crops in compatible mixtures. In practice, this pattern has evolved in relation to traditional resources, where several crops are planted and harvested in mixtures at different times (Baker and Norman, 1975).

It is difficult to assess the yield advantage of mixtures because the land equivalent ratio (LER) is not readily apparent without the corresponding yield figures of all the component crops in the mixture grown as sole crops under similar management. Baker and Norman (1975) have reported LERs of up to 1.6 in farmers' fields in North Nigeria. Experiments on improvement of crop mixtures have yielded LERs of up to 2.0 (Andrews, 1972; Krantz and Singh, 1974 ; and Rao, 1975). Work at IRRI (1974) has shown that some intercrop mixtures give a higher LER at a low level of management, while others such as rice-maize, respond to good management. Willey and Osiru (1972) also reported very good response of maize-bean combination at higher production level.

In semi-arid tropics higher yields have been obtained with crop mixtures, which indicates that total crop water use efficiency of mixtures may well be higher particularly for wet season as a whole (Baker and Norman, 1975). Some studies (IRRI, 1974; Kassam and Stockinger, 1973) show that mixtures can make better use of nitrogen than sole crops. There are also reports that weed control and use of total available labor is better in crop mixtures.

As mentioned elsewhere, another unique feature of multiple cropping is a greater dependability of return compared to sole cropping. This is especially important to small farmers at low yield levels where alternatives to production are much more restrictive and the farmer has to be more certain that his input investments are secure. Many workers (Evans, 1960; Ruthenberg, 1976; Webster and Wilson, 1966) have made it clear that the adoption of sole cropping for many food crops is less dependable. Hence increases in production are more likely to come through multiple cropping which reduces the farmer's risk factor. The fact that two or more crops are grown during the year makes sequential cropping intrinsically more secure to earn returns. For utilization of solar energy sole crop system is at a disadvantage because the energy cannot be utilized fully during the time lag between planting and full development of canopy. The leaf mass of a sole crop developed at a particular height is often not as efficient in utilizing solar energy, as that of a vertically arranged combination of plant species.

Scores of reports are available on the description of multiple cropping from different parts of the world, covering a number of crops. Multiple cropping has been the focus of attention in countries such as India (Kanwar, 1970; Mahapatra et al., 1973; Nair and Singh, 1971; Nair et al., 1973; Nelliat et al., 1974; Singh, 1978; Swaminathan, 1970; Nair 1979 etc.), Taiwan (Chang, 1965; Kung, 1969), The Philippines (Bradfield, 1970, 1973; IRRI ,1974, 1975a), Nigeria (Andrews, 1972; Baker, 1974; Norman, 1974), South America (Francis et al., 1976) and many other. Some workers have published reviews of multiple cropping practices followed in different regions of the world [Harwood and Price, 1976 (Asia); Pinchinat et al., 1976 (Tropical America); Okigbo and Greenland, 1976 (Tropical Africa); Nair, 1979 (India), Norman, 1979 (tropics in general)]. The current status of cropping systems research, has been examined in some excellent publications in book form (Papendick et al., 1976; IRRI, 1977, 1982; Dalrymple, 1971).

The above cited literature indicates that a vast number of cultivated crops is involved in the practice of multiple cropping. Most important among these are the following:

Cereals: Rice (Oryza sativa L.) , Maize (Zea mays L.), Sorghum (Sorghum bicolor Moench) and Millets (Setaria italica Beauv.; Panicum spp.);

Legumes: Beans (Phaseolus spp.) , Soybean (Glycine max Merr), Pigeon pea (Cajanus cajan Huth), Peanut (Arachis hypogea L.);

Root crops: Cassava (Manihot esculenta Crantz) Sweet potato (Ipomea batatas Poir), Yams (Dioscorea spp.), Potato (Solanum tuberosum L.);

Tree crops: Rubber (Hevea brasiliensis Muell. arg.) Cacao (Treobroma cacao L.), Coconut (Cocos nucifera L.), Coffee (Coffea spp.);

Other crops: Sugarcane (Saccharum officinarum L.), Cotton (Gossypium spp.), Banana (Musa paradisiaca L.) and Pineapple (Ananas comosus Merr.).

The nature of a cropping system used by the farmer and benefits derived from it are dictated by the farmer's resources and his understanding of how best to achieve maximum profit and security within the limitations of his total environment. In areas where the rainy season is adequate enough to grow more than one crop of different maturities simultaneously or successively or where irrigation is available, the potential benefits of multiple cropping have long been appreciated and are being realized. However in the sparsely irrigated dryland areas of the developing world the benefits of multiple cropping at a high level of production are yet to be realized (Andrews and Kassam, 1976).

The bulk of the food consumed in Tropical Asia, Latin America and Africa is produced in small farms. One third of the farms in Southeast Asia are less than 0.5 ha in size, one half of all farms are of less than 1 ha and three quarters are of less than 2 ha. (Harwood and Price, 1976). This realization has fundamental implications to research and development policies (Sanchez, 1976). Since the success of small farming systems involving multiple cropping depends largely on the utilization of time, its management becomes important in terms of operations needed in respect to the total agroenvironment, seasons and characteristics of component crops.

Conventional multiple cropping research has often resulted in location specific, crop cultivar specific and management specific technologies. In many studies the description of research sites has been very poor. Substantial progress has been made in the identification of physical determinants of cropping patterns (FAO, 1971; IRRI, 1974), but their measurement and the measurement of associated pattern performance have been sadly lacking. Also the analysis and interpretation of research results have more often than not been related to the site and not to the environmental characteristics of the site.

The description and classification of the environment requires a contribution from land and soil classification specialists (Zandstra, 1982). The quality of land, climate and soil classification will determine the usefulness and interpretation of research results beyond the experimental area. It is against this background that a multiple cropping systems approach on taxonomically and climatically classified sites looks appropriate.

2.2 Cropping systems research - the systems approach

A system is an arrangement of components that function as a unit. Biological and physical systems are open systems that is, they interact with their environment, processing inputs to produce outputs. The systems approach was pioneered in biology by Smuts in 1926 (Becht, 1974).

Traditionally the agricultural production process has been divided into smaller and smaller units to form different agricultural disciplines. These divisions are structural as the separation of plants and animals, and functional as the difference between physiology and entomology. In tropical agricultural research, it has been demonstrated that different disciplines working separately have been less successful than expected (Hart, 1982). Research scientists have recently recognized the necessity of working with units larger than the individual crop or with specific processes such as economic transactions. This was realized when scientists focussed on poorer environments where the wide adaptation philosophy, appropriate for large irrigated areas was not applicable for most rainfed areas (Farmer, 1979). There is a lack of crop and soil management knowledge and improved genotypes for rainfed environments. Hence, research strategy in such areas could not be as narrow as it had been for irrigated areas. The international institutes such as International Crops Research Institute for Semi Arid Tropics (ICRISAT), International Institute for Tropical Agriculture (IITA), and International Center for Agricultural Research in Dryland Areas (ICARDA) were funded to emphasize crop development and land management for less advantaged environment.

Researcher's knowledge of the farmer and his environment has often been inadequate, to design relevant technology. There is now increased emphasis on understanding farming systems in specific environments, to identify research that will provide profitable results for the farmer. Inclusion of man in the research process has challenged biological and social scientists to jointly build improved and acceptable crop technology. Consequently, inter-disciplinary teams of scientists for cropping systems and farming systems research are being formed in many tropical agricultural research institutions. The conceptual frameworks used by such teams have usually developed by an evolutionary process as the team attempts to conceptualize the unit being studied and integrate different disciplines. This trend has encouraged the holistic examination of constraints and opportunities for increasing farm productivity. Social scientists usually economists have been included in this integrative research process.

Shaner et al. (1982) summarized the farming systems research and development as an agricultural research and technology development that views the whole farm as a system and focusses on: (1) The interdependencies among the components under the farm household's control and (2) How these components intereact with the physical, biological and socio-economic factors not under the household's control. According to Zandstra et al. (1981) farming systems research addresses itself to each of the farm's enterprises and to the interrelationships among them and between the farm and its environment. The research uses information about the farm's production and consumption systems (the animal production system, the cropping system etc.) and about the farm's environment (biophysical, institutional, social and economic) to identify ways to increase the efficiency with which the farm uses resources. Many other authors such as Ruthenberg (1976), Norman and Gilbert (1982) have described the farming systems approach. However at present the farming systems research is still in a conceptual and methodology development stage.

Cropping systems research on the other hand, is a subset of farming systems research that is confined to the farm's crop production enterprise. In general, cropping systems research seeks to increase the benefits derived by crop production from available physical (e.g. rainfall, solar radiation, irrigation and soil types that are not easily changed), biological and socio-economic resources. It differs from agronomic research which seeks to optimize input levels of such variable crop production factors as fertilizers and insecticides. Whereas agronomic research increases the resource use efficiency of a given crop, cropping systems research in its quest for more efficient utilization of physical resources considers cropping pattern as a variable (Zandstra et al., 1981). The physical resources considered important to crop are land, water and solar radiation. The efficiency of their use is generally measured by the quantity of crop produced per unit of resource in a unit of time. Crop production may be expressed in produce weight, protein weight, calories or monetary units.

In a comprehensive publication, Zandstra et al. (1981) have summarised the essence of cropping systems research. The activity of a cropping systems researcher has been indicated in a simple relationship:

$$Y = f\ (M,E)$$

Plant growth is the productive base of a cropping system, which is generally measured by crop yield (Y). Crop yield can than be considered to be the result of the environment (E) and the management (M) which are two multidimensional vectors. Management (M) for the cropping systems research includes the arrangement of crops in time and space and their associated cultural techniques (cropping pattern). The cultural techniques include variety, time and method of establishment, fertilization, water management, crop protection and harvest and are collectively called 'component technology'.

The environmental variables considered by the researcher is a result of the extent to which management seeks to control environment. Factors that influence plant growth but are not subject to modification by management are put under E. The environment is composed of such land and climate related variables as rainfall, irrigation, soil profile, ground water level, toxicities, topographic position, daylength, solar radiation and temperature, and cost and availability of such resources as power, labor, cash, markets etc. (Beek and Bennena, 1972; Harwood, 1974). In the above list, rainfall and solar radiation cannot normally be controlled by management, but it may be possible to manage soil toxicities and irrigation.

The relationship Y = f (M,E) is evaluated by focusing on the interaction between E and M so as to determine how to vary cropping pattern to get the highest returns for different environments. The objective is to predict the best management vector (M) from information about the environment factor (E).

Eventually the researcher should determine the effect of different management practices on cropping systems performance for a given environment. Hence

$$Y = f\ (M/Ei)$$

pertains to the evaluation of the relationship of the management vector M to the crop production factor Y for a specific environment (Ei). The symbol Ei constitutes fixed constraints some of which may only be vaguely understood. Evaluation of the above equation for selected performance criteria (yield of produce, protein yield per mm of rain etc.) leads to the identification of management factors that result in high performance, and could therefore be recommended to the farmer.

The present investigation employed a different approach in that it did not seek to arrive at an optimum or best cropping pattern for a given environment. Rather, a suitable cropping pattern was chosen for each of the agroenvironments under study based on the available experience and literature. The crop patterns were evaluated in relation to the agroenvironmental parameters designated by Soil Taxonomy and supplemented by the agroclimatic parameters monitored on a daily basis. The aim was therefore to test the crop performance as well as the suitability of Soil Taxonomy to designate agricultural analogues.

2.3 Evaluation of cropping systems

While evaluating any agricultural system the term productivity is often employed, but seldom well defined. In monoculture it is often considered simply as production per unit of land area or the yield. The term production can be referred to as yield times area. Hildebrand (1976) defines productivity as output of any product per unit (total or additional units) of any particular input or factor of production. Hence, while describing productivity one should define the product and the input to which the reference is made. Productivity therefore can be yield per unit of seed, labor or water as well as unit of land. It can also refer to energy or protein produced per unit of one of the inputs used in the production process.

The use of yield per unit land area as the primary measure of productivity in agriculture, stemmed traditionally from monoculture, and a basic assumption that land was the most limiting factor for a farmer. This was and perhaps is still true in the United States (Hildebrand, 1976). On the other hand, in developing countries, infrastructure is not always capable of supplying sufficient quantities of inputs, so factors other than land are often more limiting to farmers (Hildebrand and Luna, 1974). In such situations, measures of productivity other than yield per unit area become more important. In Punjab (India) for example, yield per unit of water has historically been much more important than yield per unit of land even though the farm size on an average is only 3 ha. In the United States, where farm labor is relatively scarce and high priced, output per man hour of labor is important. This may even be important in areas where rural labor is considered abundant, when farm operations such as planting have to be completed in a very short time simultaneously by all the farmers due to onset of rains.

In monoculture, measurement of output is not a problem as a field of rice produces rice, a field of corn produces corn, and a field of beans produces beans. But the measurement of production from a cropping system is much more complicated. A well defined framework is required within which to examine the intent and content of various cropping systems. The value of cropping systems extends beyond its intensification of land use to something more basic, that is efficiency in generating desired products and quality of products through the use of a set of farm resources.

The necessary test criteria to determine the performance of cropping pattern include (1) agronomic productivity (2) biological stability (3) land use efficiency (4) resource requirements (5) management requirements and (6) economic profitability (Hogue, 1977). The results of testing are eventually used in:

(1) Evaluation and modification of the existing cropping pattern

within a given agroenvironment.

(2) Testing the potential of newly designed cropping patterns.

(3) Agroeconomic comparison of alternative cropping patterns.

(4) Comparison of potential productivity of the selected agroenvironments, by comparing the productivity and variance in productivity of the best performing patterns for each agroenvironment as a measure of cropping pattern potential of that agroenvironment (Zandstra et al., 1981).

(5) Evaluation of the extent to which the cropping pattern determinants stratifying the different agroenvironments explain the difference in pattern adaptation which in turn is useful in future design of cropping patterns.

(6) Assessment of important relationships between individual crop yields and site agroclimatic variables such as rainfall, solar radiation, soil temperature, air temperature, planting dates etc.

Biological stability of the pattern refers to the effect of crop cultivation on soil fertility, soil erosion, changes in weed population and the occurrence of insects and pests (Hoque, 1977). As it is seldom possible to obtain reliable estimates of the above factors, estimates of biological stability of cropping patterns have to be obtained from general observations over many seasons.

Efficiency of land use ordinarily refers to the days of the year the land is utilized by the cropping pattern as well as production per day of a land unit. The resource and management requirements of a cropping pattern may be defined as that amount of resource allocation and management which exibits the cropping patterns's maximum potential for economic profit.

Agronomic evaluation which is the assessment of agronomic performance of the crops, chiefly deals with the yield of the economic produce of the various crops. It may also include data on insect and disease incidence and weeds. Measurement of production in cropping systems involves the recording of yields of a variety of crops. A field might yield both bean and corn and a measure that will help the farmer determine the tradeoff in decreasing or increasing the production of each of these and compare different crop combinations is required.

The productivity criteria are expressed in the form of a ratio between a measure of objectives of the cropping pattern and a measure of resources required to achieve these objectives (Zandstra _et al._, 1981):

$$\text{Productivity criteria} = \frac{\text{Objective}}{\text{Resources used}}$$

The objectives and resources specified in the ratio may be either aggregate measures applicable to the whole cropping pattern or partial measures applicable to a crop component or a single resource used in the production process. Examples of the productivity criteria are, grain produced per mm of rain or net returns per hour of farmer's time (Zandstra _et al._, 1981).

According to Hildebrand (1976) the unit for measuring production from multiple cropping must satisfy the following criteria:

1) It must be common to all the products e.g. protein, energy, drymatter etc.

2) It should be easy to measure.

3) It should be capable of reflecting the quality difference between the products.

4) It must provide a means of comparing different cropping systems.

The energetics approach uses a system of caloric quantification of products and inputs. The oil crisis of the early seventies generated a lot of interest in this approach. The method meets the four criteria cited by Hildebrand (1976), but falls short on one important additional criteria. That is, it fails to be meaningful to the farmer. Caloric quantification is an attempt to indicate the intrinsic value of goods and efforts by a process that is not seriously influenced by the vagaries of the existing market systems. All input materials and efforts and all output goods are converted into energy units. It achieves results equivalent to those obtained by monetary quantification in economics. In both cases, inputs and outputs are reduced to common units. Energy inputs in farming come principally from mechanical, biochemical, animal, human and solar sources. On the output side, energy is stored in the crop and its byproducts. Mechanical energy is principally provided by farm machinery, which characterizes Western agriculture. Biochemical energy comes from the use of agrochemicals, fertilizers, insecticides and other chemicals.

As mentioned earlier, cropping patterns with a multitude of crops can be compared by the conversion of individual crop yields into common units such as protein and calorie. This method has been used by the joint cropping systems research project of the Central Research Institute for Agriculture (CRIA), Indonesia and IRRI, The Philippines (Ismail et al., 1978).

Perhaps the only unit available that meets all the essential criteria indicated by Hildebrand (1976) is the market value of the products. The major weakness as well as the strength of this unit is its variability. This attribute allows it to adjust to changing conditions. Hildebrand (1976) considers market value as the best unit available for measuring products in a multiple cropping system.

Detailed economic pattern evaluation approaches to compare alternate cropping patterns have been discussed by Librero (1977) and also by Zandstra et al. (1981). Librero describes an economic efficiency index, energy efficiency index, and an output parity index. Here, all the inputs and products are converted into common measures of monetary and calorie quantification. The economic efficiency index then measures the rate at which a composite of farm resources generates a set of products, i.e., total output income (benefits) is divided by total costs (cost) which yields the cost: benefit ratio. Similarly, the energy efficiency index is obtained by first converting all inputs and products into calorie equivalents and dividing the total calorie output by total calorie input. Eventually the output parity index measures the parity of energy output to energy input, which is the price per unit of energy output to the price per unit of energy input. These ratios are compared to evaluate alternative cropping systems.

Zandstra et al. (1981) recommend returns above variable costs (RAVC) and marginal benefit cost ratio (MBCR) as promising performance criteria to compare cropping patterns, where sites are sufficiently market oriented. RAVC is the difference between the value of all the crops produced in a cropping pattern and value of all the variable inputs including those not purchased in the market place but used to grow the crops. An experimental cropping pattern is first tested by comparing the RAVC of the experimental pattern with that of the prevalent pattern in the same land type. According to the experience at the International Rice Research Institute, new cropping systems whose RAVC is less than 30 percent greater than that of the prevalent pattern has doubtful promise of farmer adoption. This evaluation sometimes gives erroneous conclusions regarding the likelihood of farmer's adoption. For instance a new pattern while giving 30 percent higher net returns, might give a lower rate of return on additional costs than a prevalent farmer's pattern that can yet be expanded on the same land type.

The above error is corrected by using an additional MBCR (marginal benefit cost ratio) test. The MBCR of a prevailing pattern (F) and any potential replacement (E) for it may be computed as follows:

$$\text{MBCR} = \frac{\text{Gross returns (E)} - \text{Gross returns (F)}}{\text{Total variable costs (E)} - \text{Total variable costs}}$$

where MVP is marginal value product and MVC is marginal value cost. This is applied accross different cropping patterns, with inputs and products standardized in value terms. When the farmer has several alternatives to choose from for the additional investment he is prepared to make, the MBCR evaluates which pattern of a series of alternatives is most likely to replace an existing pattern. This will be the alternative that offers the highest MBCR for switching from the pattern in question to the alternative pattern. The purpose of this test therefore is to suggest caution if a new technology offering 30 percent higher net return also implies an additional cash outlay on which the rate of return is low.

2.4 Design of cropping patterns

Matching of crop requirements with agroenvironmental characteristics is the basis for design of cropping patterns. This activity therefore depends on what is known about the performance of cultivars and the management practices under conditions that prevail in the target area.

The environment can be divided into five major factors (Banta, 1977) which act as determinants for cropping patterns:

1) Physical
2) Biological
3) Economic
4) Social
5) Political

Ultimately, the prescribed cropping pattern should be adapted to each of these environmental factors. When we deal with food crops political suitability is taken for granted. Operationally we can consider three levels of suitability (Zandstra et al., 1981): 1) Biological feasibility 2) Technical feasibility and 3) Economic feasibility. In this listing, biological feasibility includes both the physical (edaphic and climatological) and biotic factors. Availability of resources such as labor, agrochemicals, traction power, market etc determine the technical feasibility. The economic viability is determined by the costs of the above cited resources and prices of the products produced by the cropping pattern. In this review only biological feasibility will be discussed in some detail.

2.4.1 Biological feasibility

The design of biologically feasible cropping pattern is a process that matches the crop's physical requirements to physical conditions of the particular agroenvironment. Agroenvironments vary widely. Common variables considered are rainfall, soil moisture holding capacity, temperature (max.and min.), soil fertility, solar radiation, photoperiod etc. Harwood (1979) mentioned rainfall, topography, temperature, tillage capability and fertility as the five most important and practical physical determinants. The matching process is extremely important in tropical agriculture as we cannot hope to adjust the environment to the needs of the crops due to resource constraints. Hence different crops are chosen according to the agroenvironment, the goal being to indicate the best possible crop sequence matching the prevailing agroclimatic conditions during the year.

The matching can be achieved in many ways. In one instance tables are developed for individual crop requirements for soil water, temperature, daylength and solar radiation (Panabokke, 1974; Doorenbos and Kassam, 1979). Crop damage conditions such as flooding depth, excessive evaporation demands, and excessive winds are also tabulated. Further the conditions of land type for soil water, temperature, solar radiation and daylength during the year (weekly) are expressed in graphic or tabular form. These tables are than matched with yearly plots for each agroclimatic factor at periods considered for a particular crop production. Riley (1980) further improved this method by incorporating the frequency of severe storms into the environmental analysis. In this method the relative monthly variation of solar radiation, maximum and minimum temperature, rainfall, severe storm frequency and environmental limit for each crop is estimated. Environmental data is then summarized by crop length and is used in conjunction with tabulated biological tolerance limits to determine the planting months that meet the specific growing conditions for each crop. Harwood (1977) emphasized the importance of determining the maximum and minimum rainfall levels for crop management operations such as seed bed preparation, planting and harvesting. He attributed the failure of sorghum production schemes throughout South East Asia, to the coincidence of harvest operations with high rainfall (> 25 mm) weeks. Crop requirements and environmental description should match in type and levels of classification. However, such descriptions will always be imprecise and design will therefore be on the basis of probabilities (Harwood, 1977).

Since plant growth is a function not only of available water, nutrients, atmospheric gases, temperature and light but also of a mechanical support, any environmental study should include description of soil as well as climate. Here, both systems are discussed separately due to two factors:

1) The soil system varies only in place, while climate varies not only in place but also in time (Oldeman and Suardi, 1977).

2) Cropping systems research implies a combination of agri-practices throughout the year or major portion of the year.

Climatic determinants of cropping patterns have been discussed effectively by Oldeman and Suardi (1977). They pointed out that core areas of certain crops give information about specific environmental factors. For instance, the rice core area is characterized by a long rainy season and monthly mean temperature above 25°C.

The climatic variable that shows greatest variation with place and time is rainfall. Although the seasonal rainfall variations are understood, there are great variations from year to year. One of the major deficiencies of climatic classification is that they are based on statistical averages that may never occur (Oldeman and Suardi, 1977). Hence rainfall probability curves are required for proper crop scheduling. The amount of rainfall with 75 percent probability of occurrence is considered a better guide (Virmani, 1980). Oldeman and Suardi (1977) observed a very good correlation between mean monthly rainfall and 75 percent probability of rainfall and derived a regression equation ($y = 0.82 x - 29$) to calculate the rainfall that may be expected at least 3 years out of 4 (y), when the mean monthly rainfall (x) is known. Another factor that they emphasized was the effective precipitation, which depends on rainfall intensity, cultivation practices, topography and soil/crop characteristics. For upland crops effective rainfall will be less in early stages because of runoff as well as low consumptive use. The major constraint to traditional agriculture in the humid tropics is the amount of available water for evapotranspiration by the crop canopy. In the absence of irrigation the climatic determinant that has the highest priority is precipitation. According to Oldeman and Suardi (1977) the crop water requirement for upland crops varies from 30 mm per month in the initial stage to 120 mm/month when the crop is fully developed. Assuming a water holding capacity of 50 mm at 75 cm rooting depth, the average monthly rainfall should be 100 to 140 mm per month. The cropping system in Java (Indonesia) is closely related to climatic pattern, especially to rainfall profiles. The cropping systems are more complicated in areas with continuous wet climates and in those with a very short rainy season. McIntosh (1982) also rationalized cropping systems in Indonesia on the basis of rainfall. Rice is planted if rainfall is of adequate duration and steadiness. Corn would follow in terms of value and length of rainy season. Sweet potato would be grown under conditions favorable to corn where there is a lack of resources. Cassava would be the most stable crop in drier regions. Legumes would be grown as catch crops depending upon the availability of water.

Soil and air temperatures of an agroenvironment determine the types of crops that can be grown successfully. In the tropics, crops such as potato and vegetables (head cabbage, cauliflower, beans) are planted during the cooler part of the year. On the other hand corn, soybean, sorghum, cowpea, mungbean, and millet can be grown in summer as these crops prefer a warm environment.

Numerous studies have established a positive correlation between solar radiation and crop yields. Solar radiation is determined by special sensors or estimated by the type and duration of cloud cover and is indirectly related to rainfall. However due to insufficient research data and the lack of proper understanding of the relationship, solar radiation is not considered as the determinant of crops to be grown (Harwood, 1979).

Relative humidity and windspeed in Southeast Asia generally do not inhibit crop production except when devastating storms occur. These occur only outside a 7 degree belt North and South of the equator mostly during later summer and over tropical oceans. The Northern Philippines is frequently affected by typhoons. Evaporation, an important factor for crops with reference to water requirement, is related to solar radiation particularly in the humid tropics where relative humidity is high and windspeed is low.

Generally any soil whose texture and chemistry are not too extreme is suited for crop production, unless it is too shallow to allow appropriate rooting, too dry to adequately support plant growth and eventually has salt or alkalinity problems, or too wet for upland field crops because of high perched or ground water tables.

Discussion of soil moisture status inevitably involves both soil and climate related determinants of cropping patterns. Even at a very basic level there exist soil and climate related differences in the photosynthetic mechanism. In the temperate environment mainly the "normal" Calvin type C-3 mechanism is encountered; under hot climatic conditions, especially associated with corn, sorghum, sugarcane and grasses, the Hatch and Slack C-4 type mechanism prevails. Under semi-arid and arid conditions, particularly with Opuntia, Cactus and other succulents, the mixed CAM mechanism occurs. Very little is known about how a climatic and edaphic environment might affect the photosynthetic mechanism of an unadapted plant species, or how far growth failures might sometimes be associated with climatically influenced factors affecting the photosynthetic pathway (Sharpenseel, 1977).

2.5 Stratification of agro-environments

Today it is widely accepted that much agricultural technology is environment specific and as pointed out earlier, is a manifestation of the physical, biological, and socio-economic conditions of the environment of its origin. Hayami and Ruttan (1971) rightfully observed that the conduct, analysis, testing, interpretation and application of agricultural research should be accomplished within a relatively decentralized system. It follows therefore that cropping systems technology for tropical agriculture must be devised in the tropics.

Variations in climate and soil are responsible for the site specificity of agricultural research and technology. Adequate assessment of these environmental variables is an essential prerequisite for agricultural development and planning. Failures or poor performance of agricultural development projects in the tropics have been largely due to failure to properly assess and classify agroclimates (Williams and Masterton, 1980). Some examples are projects to produce pineapples in The Philippines, sugar in Puerto Rico, rubber in the Amazon basin (Chang, 1968) and a groundnut scheme in East Africa (Wood, 1950). Systematic groupings to stratify the population of climates and soils is therefore important and comes within the domain of agroenvironmental classifications. Such classifications attempt to convert the infinite and complex variability to a finite number of discrete entities with a limited range in characteristics that conform more nearly to agricultural management units (Beinroth et al., 1980). In this review, a resume is made of different climatic and agroclimatic classifications designed to stratify agroenvironments, followed by a discussion of Soil Taxonomy, on which the present study is based.

According to Virmani (1980) there are two basic functions of climatic classification. First, to identify organize and name climatic types in an orderly fashion, and stimulate the revelation and formulation of relationships within climatic populations. Second, to serve as a base for application of technology, for interpretation of resources as classified and deliniated on soil climatic maps and for the transfer of experience. The users of climatic classification are from all disciplines as climate and weather affect all human activities. In this review climatic classification will be discussed in relation to crop production.

There are several limitations to most climatic classifications, that seriously restrict their usefulness for either agricultural applications or other resource analysis purposes. In systems that are developed principally for world overviews, one category often covers for too wide a range of climates to be of use for national or local agricultural planning and often no mechanism is provided for subdividing categories.

Characterization of an environment is closely knit with the prevailing natural vegetation and introduced or existing cropping systems. To start with, the prevailing variations in natural vegetations or biomass prompted the need for stratification of the environment to rationalize the diversity. Now, the type of probable natural vegetation in an area can be predicted based on its climatic classification.

The natural vegetation is often an useful indicator of agricultural potential, as both are determined by the nature of soil, climate and topography. However, their interrelationship leading to an ecosystem often complicates the situation. The vegetation itself influences the formation and nature of soil. Also, forest vegetation may influence climate. The activity of man further complicates the ecosystem.

The degree to which vegetation reflects the soil type is especially variable. In many places the same type of vegetation may occur on several soils or different type of vegetation may occur on same soil, partly due to the influence of man. In some cases soils can be readily recognized by the nature of plants growing on them, for instance the marshy lands which support salt tolerant and flood tolerant species. Despite many limitations, a vegetation survey is often a useful aid in assessing agricultural potential especially in underdeveloped areas where soil surveys are not available and meteorological data is scanty or absent.

The most important way in which climate, soil and topography affect the vegetation is by their influence on the moisture storage, surface runoff, subsoil drainage and evaporation. Other climatic variables of temperature, humidity, sunlight duration and intensity, and wind affect moisture relation by controlling evapotranspiration. Soil type is most important in terms of those physical features which determine its moisture relations and thus modify the effect of rainfall.

Availability of relevant meteorological and other data makes it possible to use the various climatic and agroclimatic classifications. The objectives of such classifications from the cropping systems point of view are the following:

1) To assess the feasibility and risks associated with introduction of new cropping pattern in a particular location.

2) To assist in stratifying the agroenvironment particularly for the purpose of transfer of experience or technology.

Operationally classifications of agroenvironment are of two types:

(1) Those, considering only climatic parameters without reference to soils.

(2) Those, stratifying the environment based on climatic as well as edaphic variables.

2.5.1 Climatic classifications

Numerous attempts have been made to group or classify climates of the world into areas having similar climatic conditions. A few of these systems of classification are discussed below.

Koppen is considered to be the father of modern climatic classification. He hypothesized that the deliniation of vegetation boundaries can be accomplished by means of quantitative averages of climatic parameters. Koppen's classification was first published in 1918. It is based on annual and monthly mean values of temperature and precipitation, and the assumption that a given amount of rain is more effective in meeting vegetation demand at lower temperature. Based on the above method, Koppen (1936) divided world climate into five groups.

Thornthwaite (1948) improved on this by introducing the water balance concept in his classification. He introduced the concept of potential evapotranspiration and devised an elaborate method for its computation. He compared the potential evapotranspiration with precipitation in order to obtain a moisture index.

Classification using ratios of precipitation to evaporation: Transeau (1905) suggested the use of both precipitation and evaporation data in an attempt to combine in a single number the influences of temperature and moisture on the distribution of forest trees in Eastern U.S.A.. The ratio of precipitation to evaporation, may explain the vegetation better. The scanty availability of evaporation data, is the main limitation of this method (Krishnan, 1980).

Classification based on the duration of moisture availability period: Troll (1965) proposed a classification in which the emphasis is on the duration of dry and humid months, rather than on assignement of climatic boundaries, based on annual values of precipitation, temperature and humidity. He defined humid months as those having a mean rainfall in excess of potential evapotranspiration. He divided tropical climates into several classes based on the number of humid months in a year. The International Crops Research Institute for Semi Arid Tropics (India) adopted this method for classification of semi-arid tropics in India. However, their recent study shows that application of this system using the mean monthly potential evapotranspiration (PET) computed by Penman's method (Penman, 1948) places the normally subhumid to humid areas, into the semiarid zone.

Hargreaves (1971) defined a moisture availability index (MAI) as the ratio of rainfall expected with 75 percent probability (for the concerned period) to the estimated PET. If this ratio is 0 to 0.33 during all months, the climate of the region is classified as very arid. If there are 1 or 3 months with MAI values exceeding 0.34 in the year, the climate is classified as arid and if there are 3 or 4 such consecutive months, the climate is considered semi-arid.

Burgos (1958) studied the values of descriptive, rational and genetic classification of climates, for the solution of practical problems in agriculture. He concluded that descriptive classifications are of very limited use in solving biological and agricultural problems. Genetic classifications are purely of climatic and geographical value and do not aid the solution of problems relating to agricultural productivity. Similarly, rational climatic classifications are of interest in the study of climatology and geography but their use in the field of agriculture is limited for comparing the suitability of areas having the same climatic type for crop production. This imperfection is due to the use of monthly or annual means, which over-simplifies a complex climatic situation. Burgos further observed that areas classified as having similar climates may differ markedly in the crops that can be grown successfully while the same crop can be grown economically in areas with different climatic classifications.

2.5.2 Agroclimatic classifications

Due to the realization that the usual climatic classifications were not very well suited for agronomic interpretation, attention was given to the classification of climates based on the concepts of agroclimate and agroclimatic indices.

Villiers (1968) defined agroclimate as that climate of which the integrated effects of all its elements on the plant contribute towards the economic production of the crop or variety. Simple values of climatic elements critical for crop production (rainfall, temperature etc.) or processed climatic values (day degrees, drought or frost free periods) or more complex expressions combining different elements of climate are called agroclimatic indices.

Agroclimatic indices, such as the mean temperature or the hottest or coldest months and the frost free or growing season, have been used in agroclimatic classifications of a more descriptive nature. Indices of greater agricultural significance have been the basis in attempts at more rational agroclimatic classifications.

Papadakis (1961, 1975) evolved a new rational agroclimatic classification of the world incorporating the following special features:

a) Average daily maximum and minimum temperatures and vernalization effect of low temperatures.

b) Winter severety and length of the frost free season as a fundamental characteristic of climate.

c) Use of water balance concept with potential evapotranspiration being determined as a function of the saturation deficit at mid-day.

d) Recognition of a large number of thermic and hydric types for classifying monthly climates of different locations in the world.

Nuttonson (1962, 1965) did agroclimatic zoning of U.S. and determined agroclimatic analogues in various countries of the world. In these studies use was made of the vegetative period, the average date of the first and last frost, monthly values of temperature and rainfall, absolute minimum temperatures and temperature effectiveness, precipitation effectiveness indices and ratios (Thornthwaite's method). This work is a good example of the use that can be made of comparative agroclimatology in determining the feasibility of growing a crop in a new region.

All the methods employed for stratification of the agroenvironment, discussed so far, are conspicuous by no reference to soil, the medium in which the crop grows. To determine the suitability of a site for growing a particular crop or cropping pattern, its agroenvironment should be considered in totality. While the climatic methods do help, the main soil characteristics such as soil depth, texture, structure, moisture, and temperature must receive due consideration because of their influence on the agricultural potential of an area.

Soil Taxonomy, the new U.S. system of soil classification, is unique in that it includes the important climatic parameters as soil properties. These are represented by soil moisture and soil temperature regimes. The system is an attempt for a comprehensive classification of soils. It represents a modern effort to tackle the three main problems encountered in setting up a taxonomic system, 1) the selection of differentiating criteria, 2) the definition of classes and their grouping in categories and 3) the nomenclature of taxa (Beinroth, 1978). Soil Taxonomy has been developed in about two decades by the Soil Conservation Service of U.S.D.A. under the leadership of G.D.Smith, and with the cooperation of soil scientists of U.S. Universities and certain pedologists from other countries.

The system went through a series of approximations of which the seventh approximation was published in 1960 (U.S.D.A., 1960). After substantial revisions, it has been published as a book entitled "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys" (Soil Survey Staff, 1975).

Like most taxonomic systems, Soil Taxonomy is a multicategoric system. Each category is an aggregate of taxa, defined at about the same level of abstraction, with the smallest number of classes in the highest category. In order of decreasing rank, these categories are order, suborder, great group, subgroup, family and series. About cropping pattern interpretations and transfer of experience, Smith (1965) contended that to be useful the lower categories having large number of taxa must be as specific as possible about a great many soil properties. Uehara (1978) also observed that soils which belong to the same phase of a soil family category can be considered sufficiently similar to enable planners to transfer agrotechnology from one region to another. He further described how the name of a soil family brings in mind not only an image of a soil in a particular environment but also a picture of a well defined management system. Thus, soils that occur in widely separated parts of the world but are all members of the same phases of a soil family should have similar management requirement for any particular use.

Ikawa (1978) has made an excellent resume of the occurrence and significance of climatic parameters in Soil Taxonomy. Soil moisture and temperature regimes are precisely defined in Soil Taxonomy (Soil Survey Staff, 1975) and expressed to a different degree at various categoric levels. The different taxa in effect can express different ecosystems. The system of soil classification and nomenclature indicates whether a soil is moist or dry or of a cool or warm area and also whether it belongs to a temperate or a tropical region. Other properties such as organic matter, soil pH and base saturation can be associated with the climatic parameters. Climatic parameters are expressed at the various categorical levels above the series level. When the moisture and temperature regimes are associated with soil genesis and with soil properties that serve as differentiating characteristics, they are expressed in higher categories. When the climatic parameter of soil temperature class is more related to plant growth, it is expressed specifically in the lower category, the family.

To a large extent, Soil Taxonomy has been developed using soil data base available in the United States. The use of Soil Taxonomy in tropical and sub-tropical regions has pointed out that definitions and class limits similar to those used for soils of the U.S. did not provide satisfactory groupings for the broad range of soils and conditions in the tropics. Hence, cropping experiments in typical tropical soil sites may indicate important features leading to revision and improvement of certain differentiating criteria as applicable to the tropics.

Predictions of crop performance on the basis of a soil's taxonomic category may not be realistic in any year because of the marked influence of local factors such as solar radiation, precipitation and pests and diseases that respond to the uniqueness of a particular season at a particular site. According to Beinroth et al. (1980) such parameters that are usually non-transferable must be measured and evaluated throughout a decentralized system, for effective agrotechnology transfer. If experiments are conducted on similar soils at different locations, site-specific conditions can be evaluated and prediction of crop response can be improved.

2.6 Crop response to environmental factors

Growth and production of a crop depend on the interaction of a biological system which is the plant or more often a population of plants and the physical environment in which the plant grows. The total growth and production are in fact derived from the environment through a special mechanism and properties possessed by the biological system. The genotype, affects the way in which a crop will react to the environmemt, and this can often be modified by cultural treatment (Williams and Joseph, 1970).

For consideration of the interaction between the plant or crop and the physical environment, Williams and Joseph (1970) divided the total physical environment into the following areas which affect plant growth:

1) Light (controls photosynthesis and photoperiodic reactions).

2) Atmosphere (saturation deficit, wind, availability of CO_2 and O_2).

3) Root environment (soil physical structure, nutrient and

moisture availability, aeration, salinity and so on, affect plant growth).

4) Temperature.

Although, the division of environmental factors in different categories is convenient for discussion, actually the various phases of environment interact with each other in complex ways. For instance, the way in which the leaves of crops respond to light may depend on availability of water to the roots. However, under certain conditions only one environmental factor may limit crop performance. For successful adaptation, a cultivar should be equipped to overcome a particular limiting environmental factor or set of limiting factors, which occur in a given geographical and climatic situation.

The root environment universally consists of soil, which can be manipulated in various ways to suit the establishment. growth and harvest of crops. The suitability of a soil for crop production is dependent on climatic factors of rainfall, rainfall distribution and saturation deficit of air which in turn is determined by rainfall, humidity, solar radiation and movement of air. A very poor soil such as coarse sand, may yield excellent crops if adequate watering and fertilization is done (e.g. sand culture). In seasonally dry areas, the nature of the soil, particularly its moisture holding capacity and storing properties, become very important in crop production, and hence the soil must be deep and capable of holding sufficient water to last through the unfavourable period. Plant genetic factors also influence its performance under different soil conditions.

Structure, porosity and heaviness of soil, which determine its tilth is important as it affects the ability of plant roots to penetrate and ramify in the soil mass, the nutrient status, the soil reaction and availability of nutrients. Nutrient content can be modified by fertilizers but the nutrient or water holding capacity is a property of the colloidal fraction of the soil and hence a permanent feature of the soil, or organic matter. The latter fluctuates with the addition of organic residues. Also, nutrient requirement and use by plants is strongly modified by climatic factors.

Oldeman and Frere (1982) discussed the climate crop relationship by separating them into two sections. First they considered the environment where water is not a constraint and neither too dry nor too wet conditions prevail throughout the growth of the crop. This is the case in irrigated areas or in climates without a dry spell, with landscape positions allowing drainage of excess water. Under such conditions the crop growth and yield are governed by radiation intensity and temperature. Here the constraints are high air humidity favouring pests and diseases and high winds leading to lodging and uprooting.

Secondly there are situations where water might be a constraint. Large areas are dependent solely on precipitation for water supply. Under such conditions an estimate of water balance is essential. This depends on precipitation, transpiration, evaporation, landscape position, soil physical conditions, crop species, development stage of the plant and finally on the applied technology.

2.6.1 Solar radiation

Light energy provided by solar radiation is trapped by chlorophyll in the processes of photosynthesis, to provide the substance of plant growth and crop yield. Absorbed by other pigments, it controls the partitioning of that substance among various plant organs through the processes of photomorphogenesis and the reproductive cycle through the processes of photoperiodism. The relation between crop yield and radiation can therefore be very complex, and is by no means dominated by the effects on photosynthesis (Evans, 1973).

The effects of light on yield can be separated into those during early vegetative growth and differentiation of storage organs and those which follow and determine the extent to which they are filled. According to Evans (1973) photosynthesis is dominant at latter stage. Assimilates stored earlier in the life of the plant usually contribute little to the growth of the seed, fruit and tuber which depends mainly on concurrent photosynthesis. Neverthless, the early light environment may have a profound influence on yield through effects on characters which determine the potential storage capacity and the timing of development cycle in relation to seasonal changes of radiation. An important challenge to scientists is to determine whether storage capacity as determined by morphogenic effects of radiation early in the season is more limiting to yield than is photosynthesis during filling period.

Evans and Rawson (1970) found that photosynthesis can be more than sufficient to meet even the maximum demands for grain development. They further reveal that crop photosynthesis can approach the assumed efficiency and that the gap between the actual and potential yield may therefore reflect insufficient storage capacity. Ritchie (1980) also observed that any factor affecting growth or storage should influence the rate of photosynthesis. If grain yields are not frequently limited by the supply of assimilates, only rarely will there be a simple relation between yield and incident radiation during grain filling. Morphogenic effects of light on the components of storage capacity can be as important as photosynthesis in determining yield and are far more complex in their interactions, with the result that our ability to develop satisfactory models of the effects of radiation on yield remain severely limited.

Photoperiodism: The response of plants to daylength is known as photoperiodism i.e. day night periodicity (Garner and Allard, 1920). It largely concerns flowering. Short day plants flower only when the daylight duration is less than a critical length (e.g. soybean). Long day plants flower only when the day light duration is greater than some critical length (e.g. spinach); day neutral plants flower as a result of environmental factors other than daylength (e.g. tomato).

It has been shown subsequently that the response is due to the length of the night rather than the length of day. Thus a small amount of light given to a long day plant (short night) induces flowering, even under conditions of short day length.

In comparison to the temperate species, the majority of the important crop plants of humid tropics do not show any marked photoperiodic response. In many cases tropical crops appear to flower and bear fruit in response to accumulation of sufficient photosynthate and other nutrient substances. With many other tropical crop plants, flowering and fruiting also depend on basic physiological functions of the plant and are largely independent of special physiological mechanism which trigger flowering and other growth phases in temperate crops. For example maize and tapioca (cassava) appear to have no photoperiodic or other triggering requirement for flowering. Within the photosensitive species, a great range of types will generally be found showing varying degrees of sensitivity to photoperiod. On the other hand some annual tropical and subtropical crop plants such as cowpea, rice, and sorghum are known to be highly photosensitive (Andrews, 1968).

In photosensitive plants the photoreactions are central in induction of flowering, but it is also found that the accumulation of photosynthate and other nutrients is required for the expression or completion of flowering. Thus, in addition to photoperiodic requirement, many photosensitive plants also require to receive a certain minimum amount of light for photosynthesis and for attainment of a certain size or age before flowering will occur. In rice for example there is a basic vegetative phase before the photosensitive phase. The length of the vegetative phase varies with varieties and with growing conditions.

According to Ferwerda (1968) an important point requiring much more investigation is the critical lowest light intensity which is still photoperiodically active. There is evidence to suggest that this intensity is not the same for all plants and lower in the morning than in the afternoon so that the same civil day length may have a different effective length for different crops.

2.6.2 Temperature

To a large extent, temperature determines the type of crops that can be grown in a given region. In fact, temperature and moisture control the distribution, growth and yield of plants throughout the world.

In addition to its direct effect temperature interacts with water availability, daylength, nutrition and light intensity. Temperature effects on plants are further complicated as plant components are usually exposed to different temperatures due to differences in air and soil temperatures and the amount of direct solar radiation striking the individual leaves. Hence, though temperature is recognized as the key factor in crop productivity, temperature effects on field crop yields per se, are hard to be distinguished and isolated from the effects of other environmental factors. Robertson (1973) observed very little progress in the development of rational methods having universal application for processing meteorological temperature data to explain how plants may be expected to react under given environmental conditions. Neverthless, field experience of long past and recent controlled environment studies, have given considerable insight into the role of temperature in plant growth and development.

Temperature needs of crops are related to the genetic components that determine the presence or absence of specific enzymes and rates of specific physiological processes (Hellmers and Warrington, 1982). Thus, genetic information on species and varieties can be used by every farmer for selecting crops and sowing dates suited to a particular site.

Temperature begins to influence crop yields when the seeds from previous crop are being formed and continues to have an effect through all stages of growth until the day of harvest. The range of temperature in which plant growth occurs is known as the physiological range and is characterized by lower, optimum and upper cardinal temperatures. Most physiological processes in plants function between a few degrees of 0 to 45°C with an overall optimum for many agricultural plants occurring between 20 and 30°C. Some tropical and subtropical plants have temperature optima above 35°C (Hellmers and Warrington, 1982; Pisek et al., 1973). When temperatures are below the optimum, chemical reactions slow down so that maximum utilization cannot be made of the available photosynthate. Above optimum temperatures, substrates that could go into yield are lost through excessive respiration. At temperatures higher than 45°C most physiological processes decline due to destruction of enzyme systems. Optimum temperature and tolerances to high and low temperature can vary with age, size and environmental history of the plant (Summerfield, 1975). The average day temperature as well as night temperature are important factors for growth and development. Many crop plants grow better if the day temperature is higher than the night temperature, but there are exceptions such as peanuts (Ferwerda, 1968). The delicate relationship between flowering and fecundation with air temperature was shown by Beer (1963). He found that peanuts flower abundantly at temperatures as high as 33^{o}C but they hardly produce pods. This appears to be due to a smaller production of pollen, lower viability, longer hypanthia, shorter living flowers and occurrence of dormant ovaries, as compared to plants grown at the optimum temperature of 28^{o}C. Seed quality can be adversely affected by temperature conditions during its formation.

In temperate subtropical regions, temperature constitutes a major limiting factor in crop production during Winter and early Spring. On the other hand, in humid tropical zone, it is very unlikely that temperature alone is ever a serious limiting factor in crop production (Williams and Joseph, 1970). However in some tropical situations such as high altitude cultivation, and in semi-arid tropics, temperature becomes important due to greater fluctuations. Even in the humid tropics the matching of crops to seasonal variation in temperature is important. For instance, potatoes require cool conditions for tuberization, hence in lower latitudes the crop is grown in the cool Fall season.

Growth of crops can be related to cumulative heat units (degree hour or degree days) computed as the accumulated temperature above a certain threshhold value. The fact that maturation of peas and sweet corn is closely related to heat units in temperate regions, is used in the economy of canning industry to schedule staggered planting and harvesting. Because temperature interacts with photoperiod, the total heat units required at one latitude may be different for the same species grown at another latitude (Wilsie, 1962).

Despite of the importance of temperature in the productivity of each and every crop, no extensive field study of plant response coordinated with world geography and climate has been undertaken. Currently, plant growth modelling is being used for predicting success and diagnosing failure of agricultural crops from data obtained in field and laboratory, where temperature is repeatedly shown to be a key factor (Duncan, 1975; Moorby and Milthorpe, 1975). However, elaborate field studies using standardized procedures for soil and climate data collection are lacking.

2.6.3 Soil temperature

Comparatively little attention has been given up to the present time for evaluating the importance of soil temperature as a factor in crop production. However, seed germination, the rooting of cuttings, uptake of nutrients and growth are known to depend to a large extent on soil temperature.

Soil temperature in humid zones does not show the large diurnal variations common near the surface of arid zone soils, and daily range becomes essentially zero at a depth of 50 cm. At normal planting depth, the minimum heat requirements for the germination of most crops of the tropical humid zone will be satisfied (Ferwerda, 1968). Soil temperatures upto 33°C and perhaps even higher favor the elongation of radicle of groundnuts (Beer, 1963). Brouwer et al. (1973) found that in maize the root temperature which is influenced by the soil temperature, controls the rate of leaf appearance upto the 8th leaf stage, while air temperature gradually takes over the control of this process when the growing point emerges out in the air. Bierhuizen (1973) reported that the soil temperature during the day is often of greater importance than that during the night since it is necessary to maintain a favorable internal crop-water status in the presence of a high evaporation rate during the day. In practice the diurnal variation in soil temperature lags behind the diurnal evaporation demand.

2.6.4 Atmospheric environment

The availability of CO_2 affects the rate of photosynthesis and the utilization of incoming energy if this is in short supply. Average concentration of CO_2 in atmosphere is about 0.03 percent hence CO_2 availability and not light energy is more often a limiting factor in the photosynthetic process in a fully exposed leaf surface. However, deep within a plant canopy, light quantity may become a major limiting factor in the photosynthetic process. Also air movement and wind, influence photosynthesis through their effects on the distribution of CO_2 in the crop canopy (Williams and Joseph, 1970). A third characteristic of the atmospheric environment which affects plant growth, is the saturation deficit of air, which imposes moisture stress on the plants, and which is partly controlled by the humidity.

Relative humidity: O'Leary (1975) has reviewed the complex effects of humidity on plant productivity. Higher humidities may increase or decrease productivity depending upon the particular species and circumstances. There are interactions between humidity and other environmental factors such as temperature, salinity, nutrition and plant pathogens.

Hoffman (1979) pointed out that increased humidity resulted in increased growth of 20 out of the 26 species he studied. Generally higher humidities result in greater vegetative growth and sometimes in greater yield of the economic product. These could be due to higher turgor pressures, greater stomatal conductances and increased photosynthesis at higher humidities.

Hoffman (1973) found that the yield of beans increased from 284 g per plant at vapour pressure density of 16 m bars to 359 g per plant at vapour pressure density of 4 m bars. In few cases higher humidity may result in poor crop performance due to the detrimental effects of higher plant temperatures, increased damage due to fungal diseases or air pollution or disturbances in hormonal metabolism (O'Leary, 1975). Higher humidities result in greater stem elongation, increased leaf area, higher shoot:root ratios and sometimes in less root growth (Hoffman _et_ _al_., 1971). Flowering in peanuts was shown to be stimulated by transferring plants from low to high humidity (Lee _et_ _al_., 1972).

2.7 _Environmental_ _adaptability_ _of_ _selected_ _crops_

The way in which the agroenvironment determines what crop species will thrive, and the extent to which yields are dependent on sequences of weather from month to month and year to year are formidable problems. Workers have attempted to understand these crop-environment relationships from different angles, but the problems are still largely unsolved (Monteith, 1977). As pointed out by Haun (1982) a large portion of year to year fluctuation in crop yields is due to weather variations. This fact led to many efforts to model crop-environment relationship and develop operational yield prediction systems. However, this effort has been complicated by the fact that the end product (yield) is the summation of many diverse daily responses of plants to environmental factors. Further, most plant responses are not linear, therefore effect of extreme conditions are lost if daily weather variables are averaged over periods of days or weeks and then correlated with plant growth and/or development.

Despite all the problems cited above, generalized information on adaptability and response of different crops to environmental parameters does exist and is useful and vital to match crop requirements with agroenvironments. In this review, an attempt has been made to gather the pertinent information on environmental adaptability of different crops included in the present investigation.

2.7.1 Rice

Oryza sativa, the dominant rice species, is believed to have originated in South East Asia. Asia is not only the "home" area of rice, but also continues to be overwhelmingly the major rice growing area of the world.

Generally, rice culture of the "indica" strain is highly successful in warm areas, with mean temperatures above 20 °C and where ample sunlight is prevalent (Arnon, 1972). Yoshida (1977) reviewed ecophysiology of rice crop and came up with many interesting observations which are summarized as follow.

Temperature greatly influences growth rate in rice just after germination. The higher the temperature the greater the growth rate. At later stages (3 to 5 weeks after sowing) temperature only slightly affects the tillering rate except at lowest temperature studied. During the reproductive stage, within a temperature range of 22 to 31°C the spikelet number per plant increases as temperature drops. Thus the optimal temperature shifts from high to low as growth advances from vegetative to reproductive stage. In the tropics daily mean temperature as high as 28 to 29°C does not appear to be detrimental when solar radiation is high. Combination of low solar radiation and high temperature can seriously impair ripening. In terms of grain yield, solar radiation influence is most marked at reproductive stage followed by ripening, but is very small during vegetative stage. Ten days before flowering to flowering is the most critical stage for yield as far as moisture is concerned (Yoshida, 1977). As a rule of thumb it is generally accepted that upland rice requires a rainfall of about 50-60 mm over each running 10 day period, during the growing season (Leakey and Wills, 1977).

Upland rice is generally planted during the periods when the daylength is increasing, as in Brazil, in the Asian countries and in most of the African countries. Varieties that are insensitive to photoperiod are needed in areas that are planted during relatively long days. For example, Cartuna an Indonesian variety takes 72 and 89 days when the photoperiods are 10 hours and 14 hours respectively

(IRRI, 1975 b). Almost all of the improved lowland varieties are insensitive to photoperiod.

As far as soils are concerned, texture may be the most important property of rice soils, when moisture regimes are equal and mineral composition is comparable. Soils with high moisture retention are favourable.

2.7.2 Irish potato

Irish potato is a very important crop of the temperate region, though it originated in tropical highlands and is now spreading rapidly to other tropical areas. High yields of temperate potato cultivars are obtained, where average temperatures during growing season range between 15 to 18°C, and tuber formation is retarded and virtually stops at 20°C and above 29°C respectively (Kassam, 1976; Kay, 1973). Night temperatures are considered to be more critical and some workers (Kay, 1973; Wilson, 1977; Milthorpe, 1967) have determined that cool nights with average temperatures of 10 to 14°C are essential. In the tropics cultivars are found to produce good tubers at temperatures below 24°C (Kassam, 1976; Wilson, 1977). Wilson (1977) suggested that 18 to 24°C is the optimum range of average air temperature for growth, development and tuberization of potato crop in the tropics. The worker further reported the occurrence of potato production in tropical low lands in a temperature range of 22 to 30°C. The reason for satisfactory tuberization at higher temperatures in the tropics could be the modification of the effect of day length and temperature by radiation intensity.

According to Kassam (1976) higher radiation intensity raises the maximum temperature permitting tuberization. Most cultivars in temperate regions produce tubers only during periods of lengthening days. In tropical region, potatoes must produce tubers in short days. Even when the daylength requirement is satisfied, Irish potato is usually adopted in the tropics only to high altitudes of 1000 m or more, to meet the temperature requirement. The shorter photoperiod in the tropics tends to accelerate tuber initiation as compared to temperate regions (Milthorpe, 1967). The influence of soil temperature on growth of tubers was found to be greatest when air temperature was unfavourable for tuber growth.

In contrast to several reports, Hay and Allen (1978) demonstrated in an experiment that tuber initiation can be very rapid at average air and soil temperature of 24 to 25°C, and low night temperatures below 15°C are not essential. They reasoned as mentioned earlier that exposure to high solar radiation coupled with moderate daylengths (11 to 13 hours) probably can overcome the inhibitory influence of high soil and air temperatures to give early and normal initiation of tubers.

A short duration potato crop requires 500-700 mm and a long duration crop about 750-900 mm of well distributed rainfall (Kassam, 1976; Kay, 1973). The crop can be grown on all types of soils except heavy waterlogged clays. A deep, well drained loam or sandy loam with a pH of 5.5 to 6.0 is considered ideal. When grown under humid tropical conditions, the control of late blight (Phytophthera infestans) is difficult. Drought during last 9 weeks has very serious consequences on yield.

2.7.3 Corn

Corn is a warm weather crop grown where mean summer temperature is more than 19°C. Growth of corn early in the season has been shown to increase linearly with mean soil temperatures (10 cm depth) from 15 to 27°C, and to decrease with higher temperatures. Air temperatures above 30 to 35°C were found to cause significant reduction in nitrate reductase activity of maize seedlings and hence disturb N metabolism. Excessively high temperatures and low air humidity at the time of pollination have adverse effect on pollination and fertilization. Critical temperatures affecting yield appear to be around 32°C (Arnon, 1972).

A desirable climate for corn is one in which the precipitation is sufficient to wet soil to field capacity down to root length before the sowing season, and a rainfall of atleast 375 mm during the growing season. Runge (1968) reported that high temperatures (32.2 - 37.8°C) can be beneficial to corn if moisture availability is adequate. Some workers have reported that high night temperatures reduce yield due to early senescence and maturity giving a shorter grain filling period. Low night temperatures reduce the rate of development and increase the time period between "development events" thereby increasing the plant dry weight.

Corn is a short day plant and long days increase the duration of the vegetative stage, the number of leaves and the size of the plant. Optimum pH is acid to neutral, and medium textured deep, well drained soils with a high water holding capacity are considered ideal (Arnon, 1972).

2.7.4 Cabbage

Cabbage has been traditionally cultivated in the tropics at a high elevation. But in recent years cultivars such as "KK Cross" have been widely grown in the lowlands of equatorial South East Asia (Williams, 1979). Cabbage is adapted to cool and moist climates. Tumuhairwe and Gumbs (1983) observed that the afternoon temperatures were negatively correlated with the plant growth indices including yield. The optimum monthly average temperature is 15.5 to 18.0°C, and the average monthly maximum temperature should not exceed 24°C (Knott and Deanon, 1967). Favorable pH for cabbage growth is reported to be 6 to 6.8.

2.7.5 Mustard cabbage

Mustard cabbage or Chinese cabbage is also normally a cool weather crop, but grown extensively in other climates. Development is influenced both by photoperiod and temperature.

According to Knott and Deanon (1967) mustard cabbage tends to remain vegetative, and flowering is inhibited at a temperature range of 27 to 32°C, under short days. The crop is tolerant of soil acidity.

2.7.6 Carrot

Carrot is well adapted to cool climate and high elevations. The variety "Red Cored Chantenay" is found to develop normal roots at a temperature range of 15.6 to 21.1°C, and a pH of 6 to 6.8 (Knott and Deanon, 1967). Mc Collum and Ware (1980) also reported that temperature has a marked effect on the growth and shape of carrot variety "Red Cored Chantenay". As temperature was increased, roots of this variety became shortened; whereas decrease of temperature resulted in long and pointed roots. Carrot requires deep, loose and well drained sandy loam or loamy soils with slightly acid reaction.

2.7.7 Legumes

Grain legumes form a major component of cropping systems in the low land tropics of Asia, Africa and Americas. Several species have unexplored potential for contributing both protein, and calories to the diet of humans, and domestic animals. Dry legume seeds are the most practical source of storable and transportable protein in regions lacking refrigeration facilities (Rachie, 1978).

Their ability to grow vigorously in diverse environments and especially on poor, N-deficient soils is particularly advantageous in subsistence agriculture. The consistently high yields of peanuts, the rapid vegetative growth of cowpeas and drybeans, the extended reproductive period of viny species and the persistence of woody perennials such as pigeon peas offer complimentary uses in complex farming systems.

The range of genetic diversity within species is often considerable, sometimes exceeding variability between species. Characteristics like resistance to pests and diseases, quick germination, rapid growth, earliness, tolerance of high temperature, deep rooting, indeterminancy, day length sensitivity, yield potential and other heritable factors have profound influence on fitness for specific ecological situations (Rachie and Roberts, 1974). Inspite of the broad range diversity and adaptation within species, certain generalities can be assumed regarding tolerance of variable stresses, genotype environment interaction and utilization.

Soybean: The soybean, Glycine Max Merr is predominantly a crop of temperate regions and intermediate elevations in the tropics, and is probably the most advanced and best developed of all legumes. It has been extensively grown for a long time as a basic food crop of the low elevations in Southeastern Asia (Indonesia, The Philippines and Malaysia). Recent investigations in India, the West Indies and both East and West Africa have demonstrated that soybean can be successfully grown in lowland tropics under favorable conditions (Rachie and Roberts, 1974).

Soybean grows best at a maximum air temperature range of 27 to 32°C, and has a wide range of adaptation to soil types, but thrives best on sandy loams or clayey loams in areas with hot and damp weather. Heartherly and Russell (1979) found that silt loam soil promoted a significantly higher level of growth than that of a clay soil, and suggested that the lower hydraulic conductivity of clay allowed fewer hours during the night conducive to leaf enlargement. The crop is somewhat less drought resistant than cowpeas, but tolerates waterlogging better. Kassam (1976) reported an optimum pH range of 5.7 to 6.2 for the successful cultivation of the crop.

Soybeans are mostly short day plants requiring 14 to 16 hours of darkness for flower induction, but a wide range of maturities and determinancies exist. Milthorpe (1967) observed that daylength has greater control over the termination of vegetative growth, and maturity of soybean. In an unfavorable environment a determinate variety may grow as though it were indeterminate or vice-versa.

Rachie and Silvestre (1977) reported that soybean maturity was delayed by 20 days when night temperature was reduced from 24 to 19°C under similar daylength conditions.

According to Rachie (1978), one of the problems of cultivating soybean in the tropics is the low viability of seed.

Peanut: Peanut is a leguminous oilseed crop which is of major importance in lowland tropics, comprising an estimated 60 percent of all tropical grain legumes.

The highest yields of good quality peanuts are obtained on well drained light sandy loam soils with a pH above 5.0. A pH range of 6.0 to 6.4 is considered optimum (Arnon, 1972; Rachie and Roberts, 1974). Dark soils tend to stain the hulls and heavy clayey soils may become waterlogged to allow optimum growth, or hard for penetration of pegs (gynophores) and digging to harvest the crop.

The crop favors moderate rainfall of about 1000 - 3000 mm per year and between 500 - 600 mm per season; the heaviest demand for moisture being from beginning of blooming to two weeks prior to harvest (Rachie and Roberts, 1974; Rachie and Silvestre, 1977). For maturity of pods, a reliable period of soil drying is needed. Peanuts are not well adapted to more humid tropics (> 1300mm) owing to high diseases and pest conditions.

According to Beer (1963) and Rachie and Silvestre (1977) optimum growing temperatures for peanut are between 24 to 33°C. Initiation of flowering is unaffected by photoperiod (Beer, 1963). Spanish varieties take about 27 days to first flower and period of flowering is about 67 days.

Peanut prefers high relative humidity and is also highly resistant to drought. Salter and Goode (1967) found that flowering period is most sensitive to drought conditions.

Bushbean: The bushbean also referred to as common, french or snap bean (Phaseolus vulgaris L.) is the most widely grown and best known of all Phaseolus species. Although extensively cultivated at intermediate and higher elevations, it is grown to a limited extent in the lowland tropics (Rachie and Roberts, 1974).

Guazelli (1978) observed that a precipitation of 200-300 mm is sufficient for bushbean cultivation in Brazil, the peak water requirement being between germination and complete flowering with a demand of 110 to 180 mm. Research in South Africa (Coertze, 1978) also indicated a total water requirement of about 355 mm. However, Ohlander (1980) reporting research in Ethiopia (conducted between 1972-76) found that bushbean needed 350-500 mm of rainfall. A dry period of 15 days before flowering can be critical for the crop since it causes flower abortions and a reduction in number of pods and dry weight of the beans.

Guazelli (1978) further found that bushbean yields are favoured by a minimum daily temperature above 17°C, diurnal difference in temperature of less than 10.5°C, daily evaporation less than 4.7 mm, wind velocity less than 11.5 km per hour, relative humidity more than 85.5 percent and solar radiation less than 412.8 calories/m^2/day.

Knott and Deanon (1967) observed that bushbean thrives best between 16 to 24°C mean monthly temperature. Ohlander (1980) working in Ethiopia envisaged that maximum temperature of 30 to 32°C and minimum of 10 to 12°C was suitable for bushbean production. Arruda et al. (1980) found that bushbean yield was linearly correlated to daily mean temperature for different periods of growth.

Work in Puerto Rico (Rauseo, 1974) indicated that bushbean yields were positively correlated with average temperature, sunshine and evaporation, whereas relative humidity and duration of rainfall had a negative effect on productivity. O'Leary and Knecht (1971) found no significant reduction in bean yields by continuous growth at near saturation relative humidity levels.

Cowpea: Cowpea (Vigna unguiculata Walp.) is a predominantly hot weather crop, well adapted to the semi-arid and forest margin tropics. It is frequently mixed with other crops like corn, sorghum, millet and cassava but sometimes grown as pure crop. Cowpeas are grown on wide range of soils, from sands to heavy expandable clays. Most cultivars do not tolerate waterlogging as well as soybean. Being deep rooted the cowpea has a drought escaping ability (Rachie and Rawal, 1976).

Cowpea is considered to be either a short day or day neutral plant (Steele, 1964). Photoperiodic plants flower earlier in shorter days while high temperature can drastically hasten the onset of flowering in both photoperiodic and non photoperiodic plants. Consequently, the effects of longer days in delaying flowering in photoperiodic plants and the higher night temperature in hastening can in some cases almost exactly offset one another (Kassam, 1976). Wienk (1963) as quoted by Rachie and Roberts (1974) found the optimal photoperiod for induction of flowering in cowpeas to be 8-14 hours. The same workers further reported maximum cowpea dry matter production at 27^{o}C day and 22^{o}C night temperatures. The range of 20 to 35^{o}C is considered good for cowpea production. Temperatures above 35^{o}C cause pod and flower shedding. Air temperature is reported to have greater influence than light intensity or N fertilizer.

Moisture stress during the period from emergence to flowering can reduce productivity to a great extent.

Mungbean: Mungbean is an important crop in South Eastern Asia and India. India produces about 0.3 million tons of green grams and 0.44 million tons of blackgrams annually. In Southeast Asia the crop is grown at low to intermediate elevations, on rainfed lands and is frequently preceded by rice. Mungbean performs best on good loamy soils with a well distributed rainfall of 750-900 mm per year, but is reasonably resistant to drought and susceptible to waterlogging (Rachie and Roberts, 1974). According to Arnon (1972) mungbean has a better heat resistance, compared to its drought resistance. The crop grows well in a temperature range of 30 to 36°C; the optimum temperature range for germination being 24 to 32°C.

Mungbean has both day neutral and short day cultivars. Research in Asian Vegetable Research and Development Center (AVRDC, 1979) with three varieties of mungbeans (V1104, V2013 and V2184) indicated that temperature is a very critical factor. At optimum temperature, daylength is critical for reproductive growth of the photoperiod sensitive cultivar (V1104). There was a strong positive correlation ($r = 0.81$) between yield of the cultivars V2013 and V2184 and temperature, during a 20 day period after plant emergence, which means, the warmer the weather, the higher is the mungbean yield. The same type of relationship was also found between yield of the two cultivars and temperature during 30 days after flowering ($r = 0.52$). Yields of V2013 and V2184 planted in March to early May and September to October, were found to be highly associated with total solar radiation received after the initial flowering ($r = 0.62$).

Pigeon pea: Pigeon pea is widely adapted to climates and soils. It is highly drought and heat resistant having deep tap root system, but grows better when rainfall exceeds 500 mm per annum (Rachie and Roberts, 1974). The crop prefers well drained sandy or clayey soils in warm climates and does not tolerate waterlogging. Growth is exceptionally good in residual moisture once it is established. The early growth is slow and it is susceptible to diseases and pests (pod borers). Most cultivars are highly photoperiod sensitive but some are insensitive (Rachie, 1978).

2.7.8 Cassava

Cassava is a crop of low land tropics. It does best in a warm and moist climate where mean temperature ranges from 25 to 29°C (Onwueme, 1978; Kay, 1973). For good growth rainfall must be between 1000 to 1500 mm per year distributed uniformly. At the same time cassava can withstand prolongued drought except at planting and thus could be grown under 500 mm of rainfall (Onwueme, 1978; Kay, 1973).

Best soil for cassava cultivation is light sandy loam of medium fertility, but it can be grown successfully in soils ranging from stiff maritime clays with pH of 8.0 to 9.0, to sands or loose laterite with pH of 5.0 to 5.5. When grown on heavy clay soils it produces stem and leaf growth at the expense of roots (Kay, 1973; Kassam, 1976).

According to Kassam (1976) tuber formation in cassava is under photoperiodic control. Under short days, tuberization occurs readily but when daylength is greater than 10 to 12 hours, tuber formation is delayed and yields are lower. Therefore cassava is grown between latitudes 15° N to 15° S. In terms of calories per hectare per unit time, cassava can out-yield all other food crops except sugarcane.

2.7.9 Taro

Taro in common with other aroid root crops is of much greater and more widespread importance in the Pacific ocean islands. It is adapted to most environments but grows well under irrigation in upland area, provided temperature is not a limiting factor. It is also grown under flooded culture. It prefers hot humid conditions with daily average temperatures of 21 to 27°C and annual rainfall of about 250 cm (Kay, 1973; Onwueme, 1978). Yields are best in loamy soils with a pH of 5.5 to 6.6.

CHAPTER III

MATERIAL AND METHODS

The cropping systems experiments were conducted in a network of experimental sites in Indonesia, The Philippines and Hawaii established by the Benchmark Soils Project (BSP). The sites represent three benchmark soils of the tropics:

i) Thixotropic, isothermic family of Hydric Dystrandepts, a cool and humid agroenvironment.

ii) Clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, a warm and dry agroenvironment.

iii) Clayey, kaolinitic, isohyperthermic family of Typic Paleudults, a warm and humid agroenvironment.

3.1 General characteristics of the benchmark soils

Hydric Dystrandepts: The Hydric Dystrandepts, thixotropic, isothermic are volcanic ash soils of low bulk density and base saturation, that are thixotropic due to large amounts of materials of pyroclastic nature and possess properties such as smeariness that are associated with a humid climate. The surface horizon is generally at least 25 cm thick and dark due to high organic matter content. The soils have a mean annual soil temperature ranging from 15 to 22°C, the difference between the mean summer and winter temperatures being less than 5°C. The soils require supplementary irrigation during dry months, but are well suited for rainfed agriculture. Because of cloud cover associated with frequent rains and cool temperatures, less solar energy is available for biological activity. Hydric Dystrandepts are easily tilled and highly prized for their excellent physical properties. The soils have a subhorizon that is thixotropic and which dehydrates irreversibly into sand size particles. Intensive cultivation on steep slopes is common in Hydric Dystrandepts, attesting to the non-erosive natural feature of this soil.

Because of their good tilth and ease of workability, Hydric Dystrandepts are ideal soils for producing root crops in typhoon prone areas. Other crops better suited than corn are vegetable crops and Irish potato, requiring cool temperatures.

From the soil fertility stand point, P deficiency is the most frequently encountered limitation in this soil. Large amounts of P are needed to correct the deficiency due to high affinity of the soil to P, rendering P unavailable to plants. Thixotropic soil families are generally high in organic N. but this is not easily mineralized to NH_4^+ or NO_3^- form. Large quantities of lime are needed to raise the pH.

Tropeptic Eutrustox: Tropeptic Eutrustox clayey, kaolinitic, isohyperthermic family are mineral soils having an oxic horizon with low cation exchange capacity, being composed of oxides of iron, aluminum, and kaolin minerals. As indicated by the great group name (Eutr) the soils have a high base saturation. The soils generally occur in regions with hot, dry summers and have an ustic moisture regime. The Tropeptic subgroup of Oxisols have a discernible structure in the major part of the oxic horizon or have a moderate and strong blocky, prismatic structure. The fine earth fraction is clayey having 35 percent or more clay by weight and rock fragments less than 35 percent by volume. Kaolinite is the dominant clay mineral. The mean annual soil temperature is 22°C or higher, the difference between the mean summer and winter temperatures being less than 5°C.

Due to high potential evapotranspiration, and low plant available water, even a few rainless days may create drought conditions, especially for shallow rooted crops. Abundant energy is associated with Eutrustox due to high solar radiation.

The soils are readily workable due to the high degree and stability of soil aggregates, however drying tends to harden the surface soil. A moisture content midway between field capacity and wilting point is ideal for tillage. The high infiltration rates and permeability of Eutrustox reduce erosion hazards and allow field work to begin shortly after heavy rains. Excellent trafficability and level topography generally associated with Eutrustox are favorable for mechanized agriculture.

For year-round crop production, moisture availability is the most serious constraint of Eutrustox. Because of the susceptibility to leaching, N is deficient in most cultivated Eutrustox, hence in general N is consistently a limiting factor for crop production. The soils have a low to moderate P fixation capacity. Because of low CEC the absolute amount of K retained in the soil is small and may be depleted under prolongued cropping. Since there are no or few primary minerals to weather and release bases, K fertilization is required for sustained crop production. Assuming that the moisture and fertility requirement are efficiently overcome and pests and diseases are controlled, the Tropeptic Eutrustox have a high potential for crop production.

Typic Paleudults: Typic Paleudults, clayey, kaolinitic, isohyperthermic family are acid, weathered, mineral soils having an argillic horizon with low base saturation. The soils are more or less freely drained, deep, occurring on very old stable landscapes. Although they occur in an area of adequate soil moisture. they are not saturated with water. These Ultisols have a udic moisture regime but with less than 0.9 percent organic carbon in the upper 15 cm of argillic horizon or with less than 12 kg organic carbon per surface cubic meter of soil. Being old Udults these soils have less than 10 percent weatherable minerals in the 20 to 200 micron fraction in the upper 50 cm of the argillic horizon. The fine earth fraction of the soil is 35 percent or more clay by weight and rock fragments are less than 35 percent by volume. Kaolinite is the dominant clay mineral in these soils and the mean annual soil temperature is 22°C or higher. The difference between the mean summer and winter temperatures is less than 5°C.

Due to a generally well distributed annual rainfall pattern, the Udults have adequate moisture available for crop production throughout the year. Because of its clayey particle size class the subsoil has a high moisture storage capacity. Due to greater cloud cover, less radiant energy is available and lower crop yields are expected in these soils.

Soil workability varies with surface textures. In clayey families, deep tillage is often necessary to promote deep rooting. Typic Paleudults on steep slopes are subject to erosion, and reestablishment of vegetation is very difficult because the exposed subsoil is extremely infertile. High winds and probable high incidence of diseases and pests are common management considerations on Typic Paleudults.

Although water supply is adequate, high night temperatures and short day length reduce the yield potential for some crops. Because these soils are highly leached of bases and have little or no weatherable minerals, crop response to P and N, lime and other nutrients is virtually assured. Subsoil acidity and low fertility are the major constraints to crop production in this soil.

3.2 Description of the experimental sites

The geographic location, altitude and soil family name of the experimental sites are depicted in Table 3.1. A brief introduction to each experimental site, is presented below:

Niulii (IOLE), Hawaii: The site is situated approximately 5.6 km SE of the town of Hawi in North Kohala, island of Hawaii, Hawaii county, Hawaii. It is approximately 7.2 km SW of village of Kapaau. The soil is classified as thixotropic, isothermic, Hydric Dystrandepts.

The dominant vegetation is pangola grass and was formerly in

Table 3.1 Benchmark Sites for Cropping Systems Experiments

Soil	Site (abbr.)	Location	Elevation (m)	Longitude	Latitude
Hydric Dystrandepts, thixotropic, isothermic	IOLE	Island of Hawaii, Hawaii, USA	545	155°49'W	20°13'N
	KUK	Island of Hawaii Hawaii, USA	395	155°27'W	20°03'N
	PAL	Luzon, Philippines	275	123°20'E	13°40'N
	LPH	Java, Indonesia	1100	107°03'E	6°43'S
	ITKA	Java, Indonesia	1250	107°38'E	6°45'S
Tropeptic Eutrustox clayey, kaolinitic, isohyperthermic	WAI	Oahu, Hawaii, USA	150	158°00'W	21°26'N
	MOL	Molokai, Hawaii, USA	275	157°14'W	21°08'N
Typic Paleudult clayey, kaolinitic, isohyperthermic	BPI	Mindanao, Philippines	50	125°50'E	7°04'N
	SOR	Luzon, Philippines	100	105°02'E	2°57'S
	NAK	Sumatra, Indonesia	50	--	--

sugarcane. Annual precipitation is 2000 to 2550 mm and mean annual temperature is 20 to 22°C. The terrain is moderately to strongly sloping with a 6 percent N slope. The soil is well drained with moderately rapid permeability with medium to slow runoff.

Kukaiau (KUK), Hawaii: This site is located approximately 2.5 km SE of the town of Honokaa on the island of Hawaii, Hawaii County, Hawaii, approximately 0.6 km on a plantation road SE of the junction of Highways 19 and 24, 0.3 km SE of an abandoned church. The soils are classified as thixotropic, isothermic, Hydric Dystrandepts.

The vegetation around the site is sugarcane. The average annual precipitation is 1780 to 2500 mm, the mean annual temperature being 20 °C. The site is moderately to strongly sloping with a 6 percent N slope, and the parent material is volcanic ash over pohoehoe lava. The soil is well drained with moderately rapid permeability and slow runoff.

Palestina (PAL), The Philippines: The site is located in the island of Luzon, Camarines Sur province, The Philippines. It is approximately 8 km from Quipaya to Mangiring. The parent material is volcanic ash. The land is moderately sloping with well drained and moderately permeable soils, classified as thixotropic, isothermic Hydric Dystrandepts.

Segunung (LPH), Indonesia: The location of this site is in the Lembaga Penelitian Hortikultura (LPH), Segunung Horticulture experiment station, Cipanas, island of Java, West Java province, Indonesia. The soils are generally grown to vegetables. The climate is tropical with mean annual soil temperature of 17°C. The mean annual rainfall is above 3000 mm with fewer than seventy non-rainy days. The terrain is on the foot slope of Mt. Gede and is terraced, with a slope of 9 percent. The soils are well drained, moderately permeable with slow runoff and classified as thixotropic, isothermic Hydric Dystrandepts.

ITKA, Indonesia: This site is located in Areng, Cibodas, Bandung province, island of Java, Indonesia. It is approximately 9.5 km E of Lembang. The mean annual soil temperature is 21°C. The soils are classified as thixotropic, isothermic Hydric Dystrandepts.

The terrain is semi-isolated, by faulting piedmont slope of Mt. Bukit Tunggul, gently sloping with 1 percent accross 3.5 percent slope, SE aspect. The soil is well drained with moderately rapid permeability and slow runoff. The parent material is volcanic ash.

Wahiawa (WAI), Hawaii: The site is located in Waipio, island of Oahu, Hawaii, approximately 8 km N of Waipahu, and is an abandoned pineapple field under the ownership of Gentry estate. The mean annual temperature and precipitation are 22°C and 1000 mm, respectively. The soils are classified as clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox.

The parent material is weathered olivine basalt. The topography is level upland with 2 percent slope. The soils are well drained, moderate to moderately rapid in permeability with slow runoff.

Lahaina Taxadjunct (MOL), Hawaii: This site is in Maunaloa, island of Molokai, Hawaii, approximately 15 km W of Hoolehua and approximately 1.5 km NNW of the Maunaloa village in an abandoned pineapple field. The mean annual precipitation is 680 mm with a mean annual temperature of 22°C. The parent material is weathered olivine basalt or basalt. The soils are classified as clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox. The soil is gently sloping with 5 percent slope, well drained with moderately rapid permeability.

Davao (BPI), The Philippines: The site is in the Bureau of Plant Industry (BPI) experimental station at San Gabriel, Davao city, Mindanao, The Philippines. It is about 25 km from Davao city proper. The soils in the area are normally used for the production of seeds of maize and upland rice. The parent material is andesite. Physiographically the site is in the lower part of volcanic piedmont plain, gently sloping 2 percent with 3 to 5 percent accross. Soils are well drained and classified as clayey, kaolinitic, isohyperthermic, Typic Paleudults.

Sorsogon (SOR), The Philippines: The site is located in Luzon, about 45 minute drive from the city of Legaspy along the national highway. The experimental field is within a large private coconut plantation. The area is traditionally planted to coconut with intercrops of cassava and occasionally some rice or corn is grown when weather is favourable. The soils are classified as clayey, kaolinitic, isohyperthermic Typic Paleudults.

Nakau (NAK), Indonesia: The site is located in Nakau estate, Teluk Manuk, approximately 4.5 km S of Kotabumi, North Lampung, Lampung province, South Sumatra, Indonesia. The landscape is undulating to rolling. The maximum temperature in Summer may go as high as 37°C. The soils are classified as clayey, kaolinitic, isohyperthermic Typic Paleudults.

3.3 Chemical properties of the soils

The chemical properties of the surface soils of the experimental sites are presented in Table 3.2. The surface soils were collected at the time of soil profile description and analysed in the BSP laboratory in Honolulu. Ikawa (1979) has given the detailed profile descriptions and analytical data for all the sites, with the exception of SOR site.

3.4 Design of cropping patterns for the three soil families

The design of cropping patterns is accomplished by matching the crop requirements to agroenvironmental characteristics, which include the soil properties as well as climate of the area. This process is facilitated to some extent by the information inferred from the soil family name, classified according to Soil Taxonomy (Soil Survey Staff, 1975) and the knowledge of climatic requirements of the crop or crops under consideration. The drawback however is the lack of specific

Table 3.2 Chemical properties of the surface soils at the experimental sites

Site	Organic C (%)	Extractable bases meq/100 g soil				NH_4OAC Cation Exchange Capacity meq/100 g	Ext. Al meq/100 g	pH H_2O	pH KCl
		Ca	Mg	Na	K				
KUK	7.34	2.53	0.03	0.12	0.51	58.69	<0.01	6.00	5.35
IOLE	8.12	7.93	0.94	0.27	0.86	64.76	0.02	6.01	4.90
PAL	12.89	3.54	0.82	0.11	0.31	45.05	2.10	4.80	4.40
LPH	6.41	6.00	0.80	<0.1	0.2	53.3	0.03	5.70	5.10
ITKA	5.68	0.60	0.10	0.10	0.10	47.80	0.62	4.60	4.10
WAI	2.27	6.52	4.35	0.17	2.69	20.81	0.03	5.41	4.80
MOL	3.73	5.52	2.29	0.15	2.07	19.54	0.05	5.49	4.88
BPI	1.49	7.49	1.84	0.06	1.98	20.58	0.06	5.05	4.40
NAK	2.73	7.44	1.14	0.07	0.76	12.92	0.05	4.82	4.16
SOR	–	–	–	–	–	–	–	–	–

Source : Ikawa (1979)

information on the requirements of many crops. Socio-economic conditions also play an important role in choosing the proper cropping pattern for a particular region. As the present study was designed to evaluate only the agroenvironmental factors affecting a cropping system, the socio-economic factors were not considered.

In the cropping pattern design process, due consideration was given to the knowledge accumulated through soil survey and classification, climate, past experience, as well as the technology available from other similar regions. Besides selecting crops on the basis of general agroenvironmental data derived from the soil family nomenclature, seasonal climatic variations were also considered to fit a sequence of crops. Mainly, seasonal rainfall and air temperature fluctuations were examined to choose crops suited for each of the three growing periods of the year.

The cropping patterns designed for the three agroenvironments had three crops or combinations of crops in a sequence and one or more long duration side crops. The first crop of the sequence was planted as far as possible at the onset of the rainy season or cooler season. The rationale of the cropping pattern design process is described below.

Cropping pattern design for Hydric Dystrandepts (henceforth referred to as the HD pattern): The HD pattern is shown in Figure 3.1, in relation to fluctuations of temperature and rainfall in a typical calendar year. The pattern consists of the vegetable crop combination "cabbage + carrot + bushbean" and Irish potato as an alternate crop

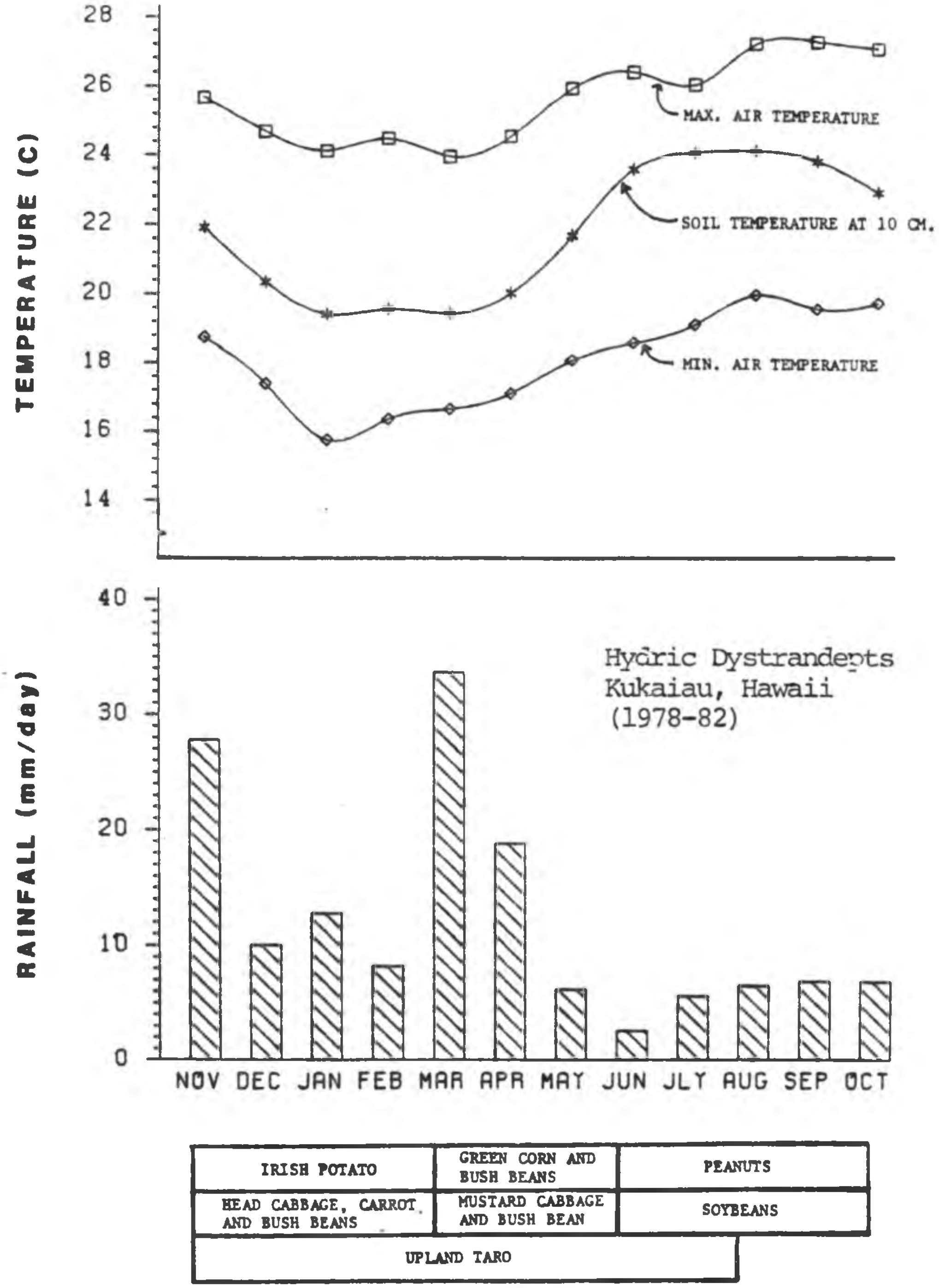


Figure 3.1. Cropping pattern designed for Hydric Dystrandepts in relation to site agroclimatic parameters.

during the first season followed by two alternative vegetable crop combinations of bushbean and mustard cabbage and bushbean and green corn, then followed by a grain crop such as soybean or peanut. A long term crop, cassava is planted on wide rows for additional production.

Because of the cool isothermic environment of Hydric Dystrandepts, the average soil temperature during the year is 15°C or higher but lower than 22°C, making the cool weather vegetable crops and Irish potato suitable alternatives. The first season crops of vegetables and Irish potato were planted during the start of the rainy season which is also the cool period (November-December for sites in Hawaii and October-November for sites in The Philippines and Indonesia). For the second season, a comparatively dry and warm period, the inclusion of green corn was justified due to the crop's preference for warmer climate. The Benchmark Soils Project experience (BSP, 1982) has also indicated that corn is well adapted to the second season period in the Hydric Dystrandepts. The third season which coincides with Summer and is expected to be dry during the harvest period, was conceivably the better period for warm season crops such as soybean and peanut.

The udic moisture regime and excellent physical properties of Hydric Dystrandepts are other factors making these soils ideal for vegetable crops known for their high water requirements and preference for good soil aeration.

Cropping pattern design for Typic Paleudults (henceforth referred to as the TP pattern): The TP pattern is depicted in Figure 3.2, in

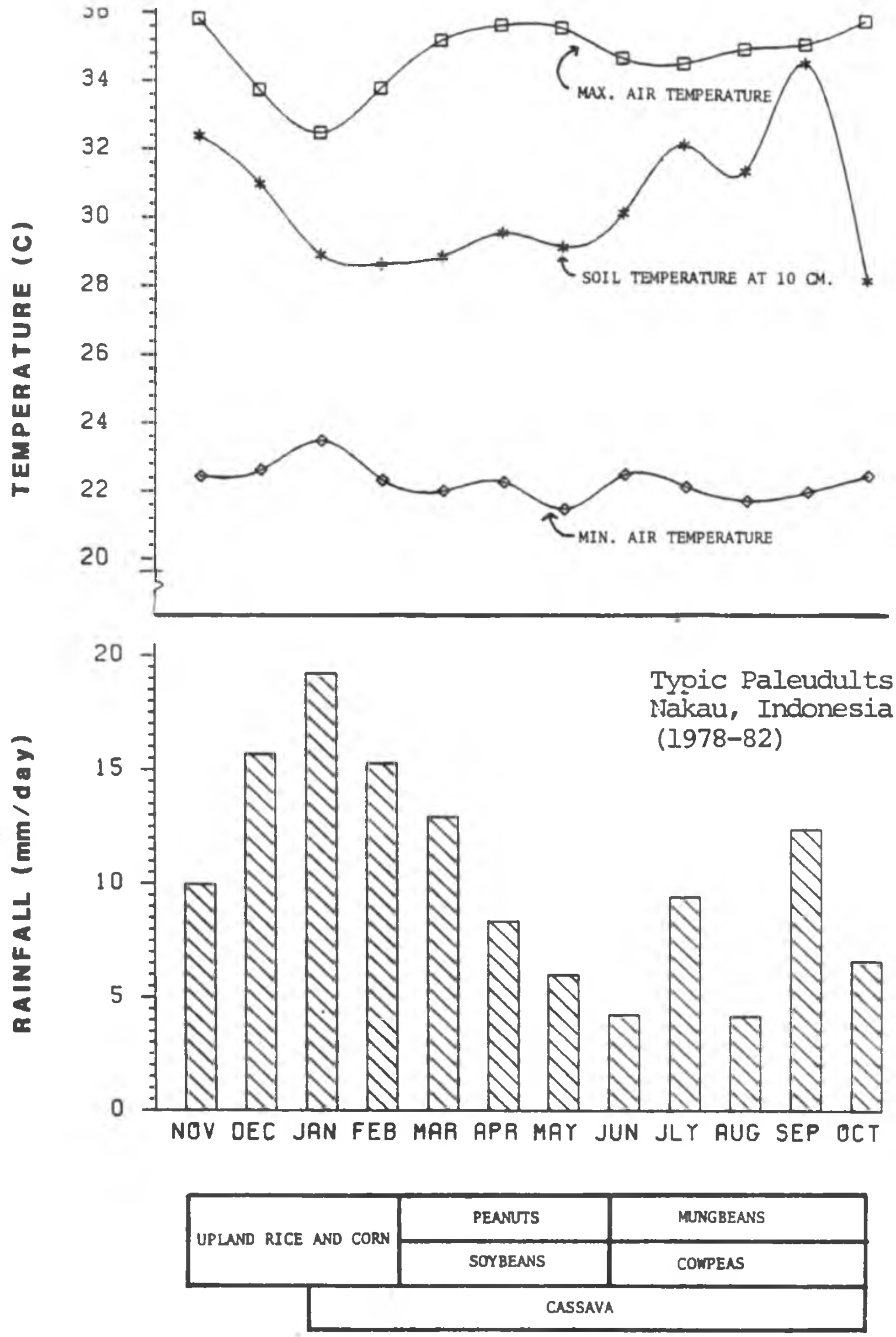


Figure 3.2. Cropping pattern designed for Typic Paleudult in relation to site agroclimatic parameters.

relation to temperature and rainfall fluctuations during a typical calendar year. The pattern consists of upland rice, during the first season followed by soybean and peanut as alternate crops, then followed by cowpea and mungbean. The long term side crop is cassava. Due to the isohyperthermic temperature and udic moisture regime of the soil. rice was chosen as the crop to be grown during the first season, which is the rainy period. Field corn was planted as the side crop intercropped with rice in wide rows. The second season is the start of the dry period, but is still expected to carry sufficient moisture to provide for part of the moisture requirement of a grain crop. Also during this period the temperatures are higher which justifies the selection of soybean and peanut as the alternate crops. Cowpea and mungbean are adapted to warm temperature and are also drought tolerant crops. These crops therefore, were chosen for the third season which is the hot and dry period of the year. When corn started silking during the first season, cassava was planted in wide rows for additional starch production.

Cropping pattern for Tropeptic Eutrustox (henceforth referred to as the TE pattern): The TE pattern is presented in Figure 3.3, in relation to temperature and rainfall fluctuations in a typical calendar year. The cropping sequence for Tropeptic Eutrustox is Irish potato followed by soybean and then by corn. Pigeon pea/taro intercrop and cassava are included as side crops for additional production.

The crops were selected for the isohyperthermic temperature and

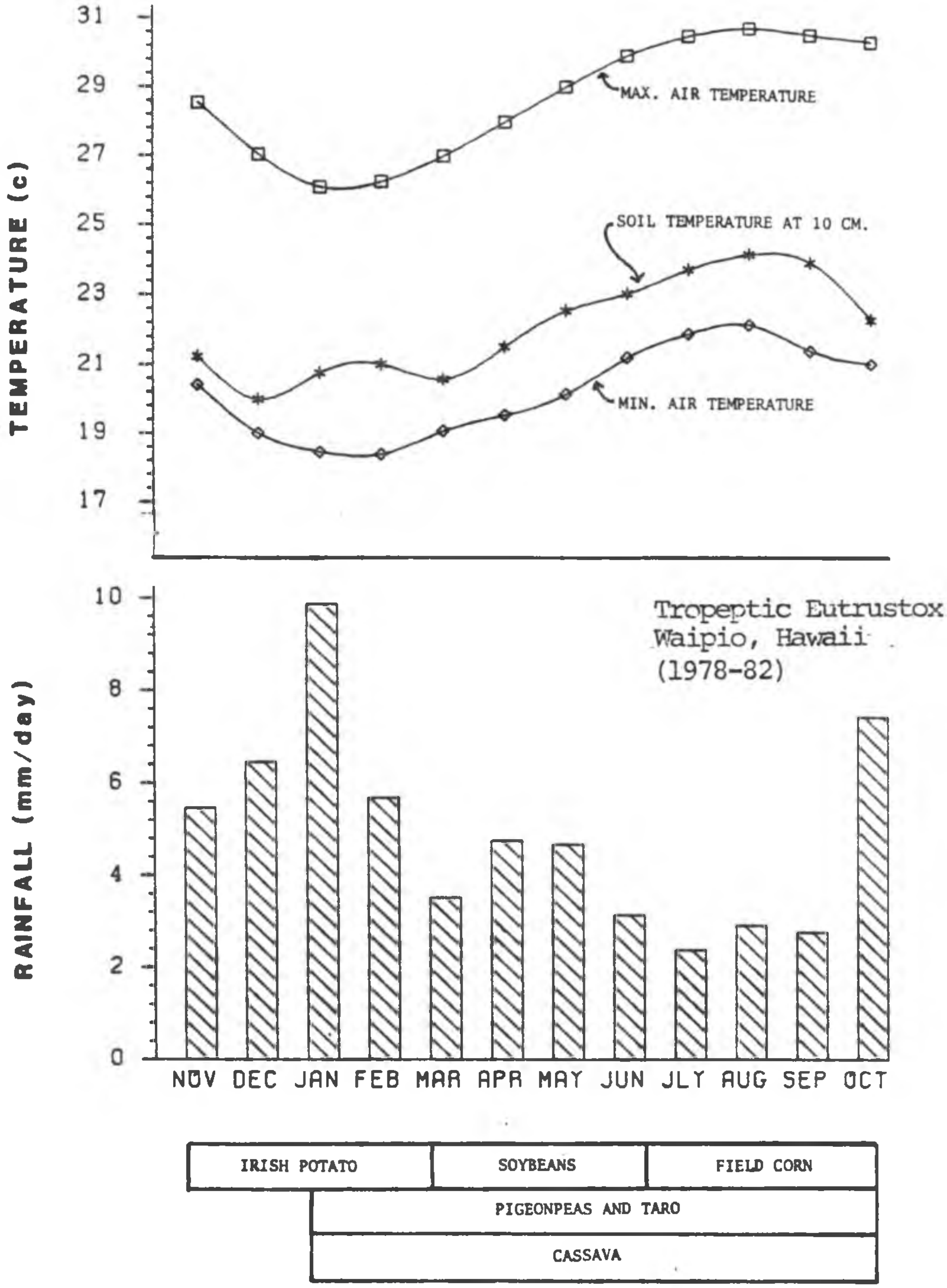


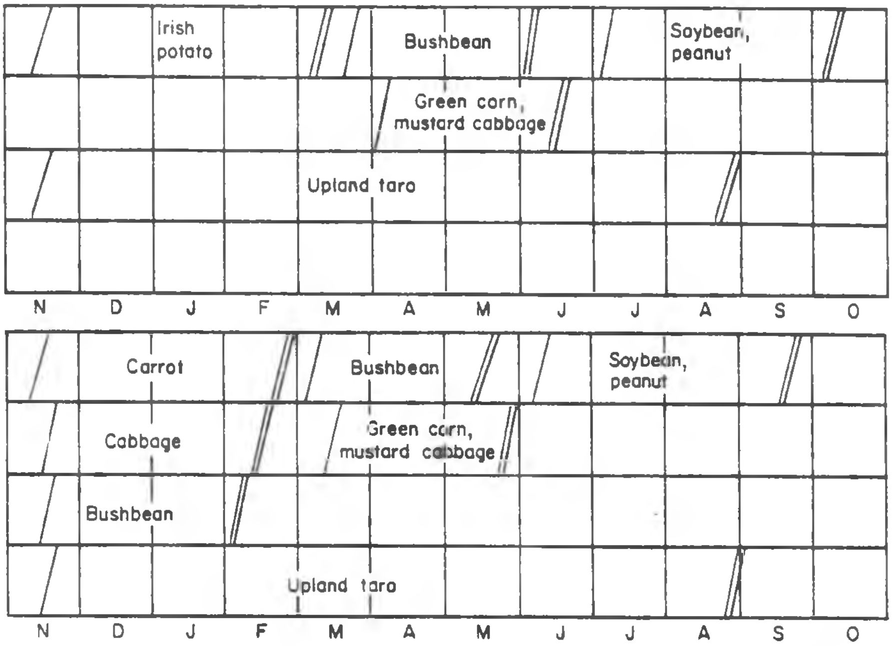
Figure 3. 3. Cropping pattern designed for Tropeptic Eutrustox in relation to site agroclimatic parameters.

ustic moisture regime of the soil. The cool wet season in Tropeptic Eutrustox, starting from November was utilized for growing Irish potato which is the first crop of the sequence. Manrique (1982) found that low temperatures prevalent during the wet season in Tropeptic Eutrustox are conducive to good tuberization in Irish potatoes. During the second season, temperatures are slightly higher and hence soybean was the recommended crop. The third season coincides with the warmest temperatures of the year, with high solar radiation. This period has been demonstrated to produce the highest yields of corn (BSP, 1979). Pigeon pea, taro and cassava were planted in wide rows as side crops in the first season and continued till the third season. Pigeon pea is particularly noted as a drought tolerant legume and therefore an appropiate crop for ustic moisture regimes. It has a maturity period comparable to taro and cassava.

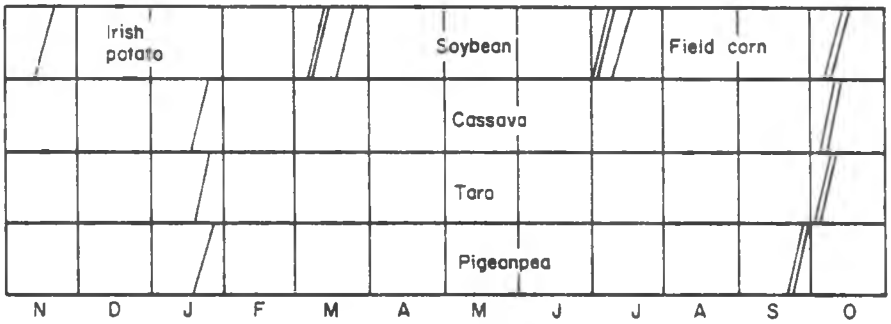
3.5 Figurative description of cropping patterns and their layout

The different cropping patterns under scrutiny are presented notationally in Figure 3.4.

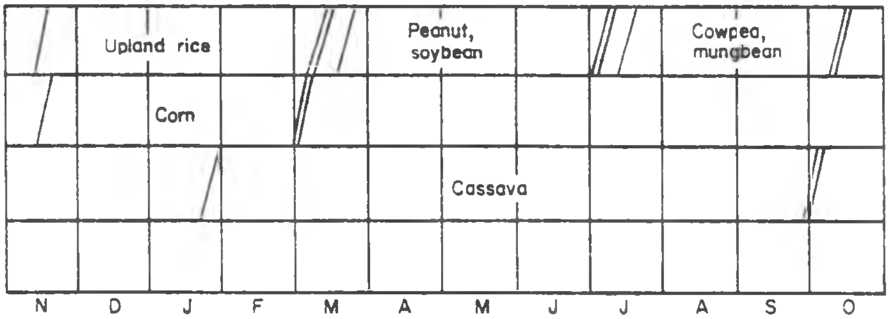
The generalized field layouts of the three cropping patterns are depicted in Figures 3.5, 3.6, and 3.7. However. the exact layouts for individual sites were dependent on the local randomization for assigning treatments. The term 'season' in the Figures refers to different crops grown in a given period on the experimental block. Subsequent crops in the second and third seasons are planted on the same location after the harvest of the preceding crops.



HD PATTERNS



TE PATTERN



TP PATTERN

Figure 3.4. Diagrammatic representation of cropping patterns designed for the three soil families.

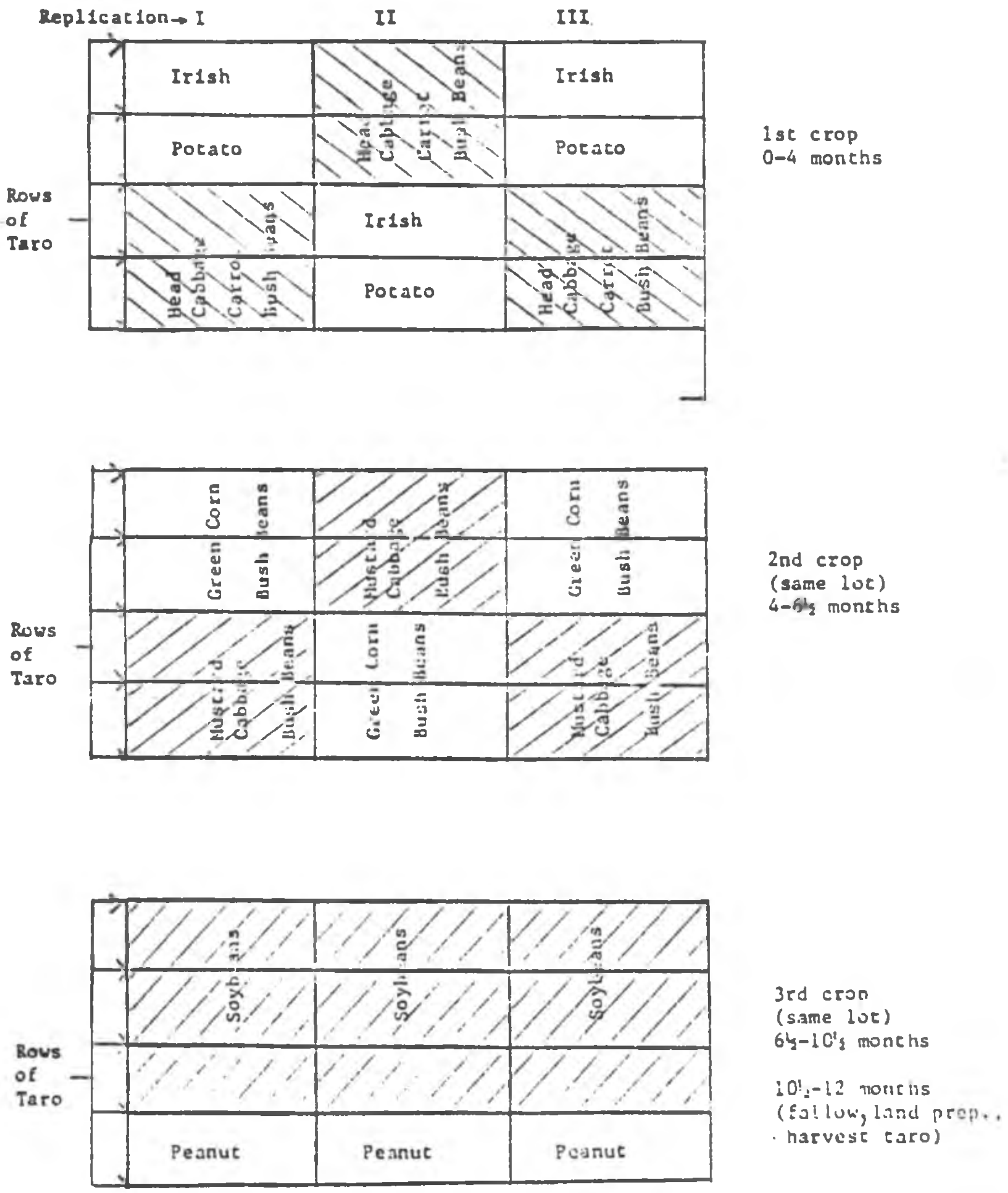


Figure 3.5. General field layout for crop sequences of the Hydric Dystrandept cropping pattern.

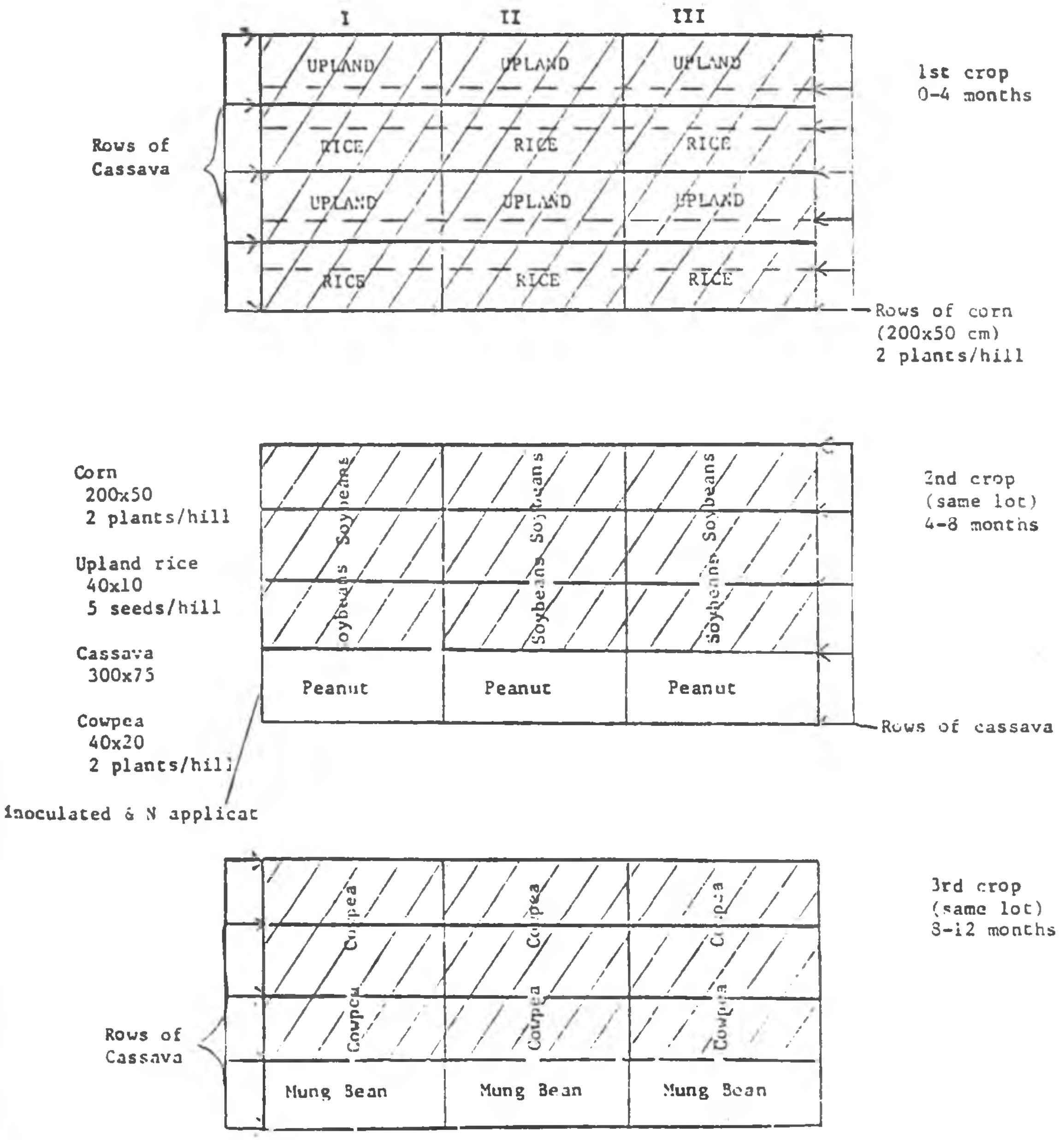


Figure 3.6. General field layout for crop sequences of the Typic Paleudult cropping pattern.

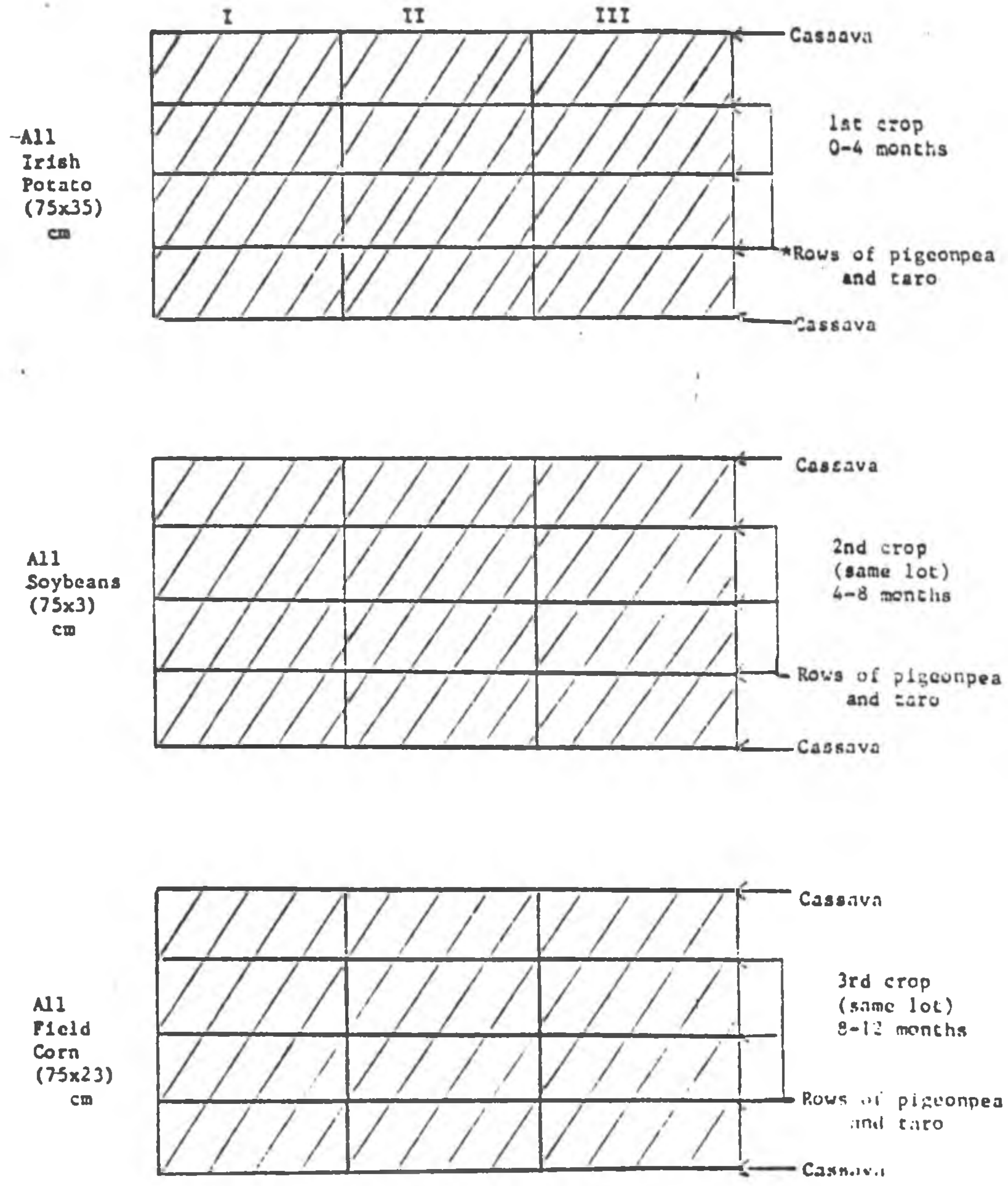


Figure 3.7. General field layout for crop sequences of the Tropeptic Eutrustox cropping pattern.

3.6 Procedure for soil management

Proper crop establishment and growth is a function of the total agroenvironment which consists of climatic, weather as well as edaphic factors. The main concern in this study was to maintain to the extent possible an optimum soil nutrient level for crop growth so that crop performance could be rated based on the agroclimatological factors typifying each soil family.

The achievement of the so called optimum level of nutrients is not an easy task, and any procedure used to optimize the fertility level could be questioned for its validity. However, every effort was made to accomplish an uniform fertility level in all sites to the extent allowed by the present technology.

3.6.1 Field block selection

The Benchmark Soils Project had several blocks on each site, designed primarily for transfer experiments conducted with differential P and N levels. For cropping systems experiments, selection was made of old transfer experiment blocks preferably those that had been planted with two or three residual transfer trials without reapplication of P.

Dimension-wise there were two types of experimental blocks, depending on the site:

(1) Blocks with 12, 3 m x 8 m plots.

(2) Blocks with 12, 3 m x 6 m plots.

3.6.2 Soil analysis

Initial soil preparation was done in each plot by rototilling and levelling. Before application of any fertilizer material, soil samples were collected from each plot of the experimental blocks. Eight subsamples were collected to a depth of 15 cm from each plot, thoroughly mixed in the field and a representative sample was taken in a plastic bag. In the case of Hydric Dystrandept sites, where soils are normally prone to irreversible drying, the samples were passed through a 2 mm sieve and sealed in plastic bags, so as to maintain the original moisture content. In Tropeptic Eutrustox and Typic Paleudult soils the samples were air dried and ground by hand to pass through a 2 mm sieve and packed in plastic bags. Soil samples were also collected at the end of the third cropping season on all sites, counting the crop season before which the first sampling was done, as the first.

All soil samples from The Philippines and Indonesia were shipped by air to the BSP (Benchmark Soils Project) laboratory at the University of Hawaii, Manoa campus for analysis. A 5 g subsample of each soil was placed in an Al dish and dried for 24 hours in an oven at 105°C for determination of moisture content. Using this moisture factor, moist samples were weighed such that the calculated weight of the moist soil taken gave the desired equivalent of oven-dry soil for each analysis.

Soil pH was determined using a combination glass electrode and Corning Digital pH meter in 1:1 soil to water and 1:1 soil to 1 N KCl solution mixtures. Extractable Al was determined by a 30 minute extraction of 10 g soil with 50 ml of 1 N KCl followed by leaching with an additional 50 ml of KCl solution (SCS-USDA, 1972). The filtrate was titrated with 0.05 N NaOH to the end point using phenolphthalein as an indicator. This was followed by addition of 10 ml of 1 N KF to form the AlF complex and release hydroxide which had reacted with Al. The solution was then titrated with 0.05 N H_2SO_4 to the colorless phenolphthalein end point. The equivalents of H_2SO_4 to reach the second end point (SCS-USDA, 1972) gave the measure of extractable Al. The bases, Ca, Mg and K were determined by extracting 25 g of dry soil or its moist equivalent with 1 N NH_4OAC pH 7.0 followed by leaching. Quantitative analysis of bases was done by atomic absorption spectrophotometry.

The "available" P was estimated using a modified Truog extractant [0.02 N H_2SO_4 + 0.3 % $(NH_4)_2SO_4$] in a 100:1 solution to soil ratio for a period of 30 minutes on a reciprocating shaker.

3.6.3 Soil nutrient optimization

The aim was to assure that nutrients were not limiting and hence crop performance is the consequence of the match or mismatch of the crop requirements and agroenvironmental characteristics.

At the initial stage of the experimentation the rate of P and lime application on each site was estimated based on the individual soil P level and extractable Al levels. The average miliequivalents of KCl extractable Al multiplied by 2 in Hydric Dystrandepts and by 1.5 in Tropeptic Eutrustox and Typic Paleudults, were taken as the milequivalents of lime to be applied for 100 g of soil. Later, based on the experience gained as well as for convenience, it was decided to implement general P application level for each season on all sites depending on the soil family. Thus for Tropeptic Eutrustox and Typic Paleudult soils a P level of 25 kg per ha per season was applied on all sites uniformly and mixed thoroughly with the soil. In Hydric Dystrandepts, considering the thixotropic characteristics a higher P rate of 50 kg P per ha per season was implemented. Due to the high original level of modified Truog extractable P (> 20 ppm) in most of the sites and the further application of P as described above, no P limitation was expected.

As depicted in Table 3.2 all sites included in this study have surface soils that are slightly acid to acid. The pH range is 3.67 to 5.35 in KCl and 4.51 to 6.01 in water. The direct detrimental effects of soil acidity on crop production are caused by the presence of exchangeable Al (Sanchez, 1976). The strategy used for liming was therefore to neutralize the Al and not to cause an appreciable shift in pH. This consideration coupled with the general low content of KCl extractable Al, on all the sites, led to the decision to apply 750 kg $CaCO_3$ per ha per year in Typic Paleudults and Tropeptic Eutrustox and 1000 kg $CaCO_3$ per ha per year on Hydric Dystrandept sites. Lime application was done at least three weeks before planting. Uniform manual application was followed by thorough mixing by rototilling. During the three weeks following lime application the plots were kept moist to enhance soil reaction with lime.

On all sites a post harvest soil sample was taken two cropping seasons after lime application to determine the necessity of lime reapplication for subsequent crops.

Nitrogen application: Table 3.3 gives the rates of N and K application for different soils and crops. For corn, green corn, Irish potato, head cabbage, mustard cabbage, carrot and bushbean 50 kg N/ha was given at planting and 50 kg N/ha was top dressed thirty days after emergence. For soybean, cowpea, mungbean and peanut 20 kg N/ha was given at planting and the balance of N requirement was supplied through inoculation with Rhizobium. The peat based inoculum was obtained from NIFTAL project.

Rhizobium inoculation: Batches of seed (100 g) were placed in a polyethylene bag and 3 ml of gum arabic solution (40 g gum arabic powder + 100 ml water + 2.4 g precipitated $CaCO_3$ was added to it. The neck of the bag was secured so as to permit it to be inflated and clasped to close. The bag was swirled for about a minute, coating all the seeds thoroughly with gum. Then, 10 g of peat based inoculant was added to the bag and it was inflated and swirled again, stopping immediately after the seed coating appeared uniformly black. The seeds were then spread on a clean paper and allowed to dry in the shade.

Potash application: For soybean, cowpea, head cabbage, mustard cabbage, carrot and bushbean crops, 100 kg K/ha was given at planting. In Hydric Dystrandepts corn and Irish potato received 150 and 170 kg

Table 3.3 Nitrogen and potassium application rates for different crops supplies through Urea and Muriate of Potash

Crop	N (kg/ha/crop)		K (kg/ha/crop)		
	Preplant	Topdress	HD	TP	TE
Corn	50	50	150	100	100
Soybean	20*	--	100	100	100
Head Cabbage, Mustard Cabbage, Carrot, Bushbeans	50	50	100	100	100
Peanut, Mungbean	20*	--	50	50	50
Cowpea	20*	--	100	100	100
Irish Potato	50	50	170	100	100

HD - Hydric Dystrandepts
TP - Typic Paleudults
TE - Tropeptic Eutrustox
* - Balance of N requirement was supplied through rhizobium inoculum.

K/ha respectively due to the higher K requirements of the crops and greater K fixation in these soils.

To further assure the adequacy of all nutrients to the crops, a blanket application of Zn, Mg, B and Mo (only for soybean) was carried out in all sites. The sources and quantities of these nutrients are presented in Table 3.4. The blanket application was made only once for a full year cropping sequence during the planting of the first implemented cropping season.

The long term crops relayed throughout the sequential cropping (cassava, taro and pigeonpea) were not fertilized separately, as these were designated as "side" crops and hence expected to benefit from the fertilizer applied to the main crops.

3.6.4 Superimposed Rhizobium treatment and N application experiment on soybean

This experiment was conducted in collaboration with the NIFTAL project of the University of Hawaii. As indicated in the general layout diagrams (Figures 3.5, 3.6, and 3.7), each soybean replication was made up of at least three 3 m x 6 m or 3m x 8m plots. Each of these three plots received one of the following treatments at random:

M_1 --- No inoculum, No nitrogen

M_2 --- No inoculum, 100 kg N/ha (split
50 kg N/ha at planting and 50
kg N/ha 30 days after emergence

M_3 --- With inoculum, No nitrogen

An additional treatment designated as M_4 was implemented in Hawaii

Table 3.4 Preplant application rates of the micronutrients

Nutrient	Source	Rate of application (kg nutrient/ha/year) Hydric Dystrandept	 Typic Paleudult	 Tropeptic Eutrustox
Zn	$ZnSO_4 \cdot H_2O$	15	10	15
Mg	$MgSO_4 \cdot 7H_2O$	100	100	100
B	$Na_2B_4O_7 \cdot 10H_2O$ (Borax)	5	2	2
Mo (For soybean only)	$(NH_4)_6 MO_7O_{24} \cdot 4H_2O$ (Ammonium Molybdate)	1.5	1.5	1.5

(WAI, KUK, MOL, and IOLE) which received inoculum and 20 kg N/ha.

3.7 Installation of cropping patterns

The first season crops were planted as far as possible, during the 'zero' month. "Zero" month refers to the month during which the rainy season begins. For most of the sites, November is the "Zero" month. However, it differed slightly from year to year. The planting and harvest dates for all the crops are listed in Appendices 4.1 to 4.23.

The plots for each crop were selected at random. Figures 3.5, 3.6, and 3.7 depict the generalized layouts for various crops. However, as pointed out earlier the position of individual crops were not necessarily the same for all the sites.

3.7.1 Varieties

The most difficult and crucial task in comparative cropping systems experiments involving a network of widely separated sites, is varietal selection. The ideal situation would be one in which a single variety equally adapted to all sites is available. In reality, such a situation is seldom encountered and in some crops is impossible. The use of same variety for all sites may not solve the problem often times because of the lack of adaptability of the variety in some locations due to differential pest and disease incidences. In a few cases the varietal selection was also hampered by logistics alone. Certain sites could not be supplied with the intended seed material in time, and hence the best adapted local variety had to be used. Such hurdles are not unexpected in a study involving ten sites located in three different countries.

The paucity or complete absence of literature on varietal performance calibration, and genotype-environment interaction in most of the crops, did not permit a precise selection of varieties for all crops. Neverthless every effort was made to select the best available variety. whenever adaptability and logistical problems prevented the use of an identical variety. As far as possible same or similar varieties were used for crops on all the sites. To facilitate the varietal selection process, information about varietal performance was gathered from Benchmark Soils Project transfer experiments, IRRI cropping systems data. PCARR experiments (The Philippines), CRIA (Indonesia), and from local farmers.

3.7.2 Land preparation for the first and subsequent seasons.

The original 8 m x 3 m or 6 m x 3 m plots were relocated by metal corner stakes. A non-selective herbicide such as Roundup (glyphosate) or Paraquat (gramaxone) with no residual phytotoxicity was used one month prior to tilling. The weeds were hoed before tilling and removed from the block. The plots were rototilled individually with a hand operated tiller, to a depth of 15 cm. On Eutrustox sites the block was irrigated 3 days before land preparation to make the soil sufficiently moist for tilling. The predetermined fertilizer dose was applied uniformly for each plot and rototilled for thorough mixing with the soil. For subsequent seasons in a one year sequence the plots were prepared by general clearing and one rototilling.

3.7.3 Planting methods (HD pattern)

(a) Procedure for planting head cabbage, carrot and bushbean combination

The layout for one plot is diagrammatically shown in Figure 3.8 (A). Head cabbage seedlings were grown in raised seed beds and transplanted when 5 inches tall in rows 75 cm apart, with a seedling to seedling distance of 50 cm. On the day of cabbage seed bed sowing, carrot seeds were planted in 1/2" furrows dug in two rows adjacent to cabbage row spaced 25 cm apart. After emergence the carrot seedlings were thinned to 25 plants per meter. Inoculated bushbean seeds were planted in rows adjacent to carrot on the day the cabbage seedlings were transplanted. Three seeds of bushbean were sown per hill and thinned to two plants per hill after emergence. The distance between the bushbean hills was maintained at 20 cm and the sowing depth was about 5 cm.

(b) Procedure for planting green corn and bushbean combination

Figure 3.8 (B) shows the plot layout for this combination. Three inoculated bushbean seeds were planted per hill, at a depth of 5 cm with a hill to hill spacing of 50 cm. Two weeks after the emergence of bushbean seedlings three isotox treated corn seeds per hill were planted in the bushbean row, halfway between the hills of the beans and thinned to two seedlings per hill one week after emergence. The row to row spacing was 75 cm. Corn seeds were treated with isotox to prevent bird damage.

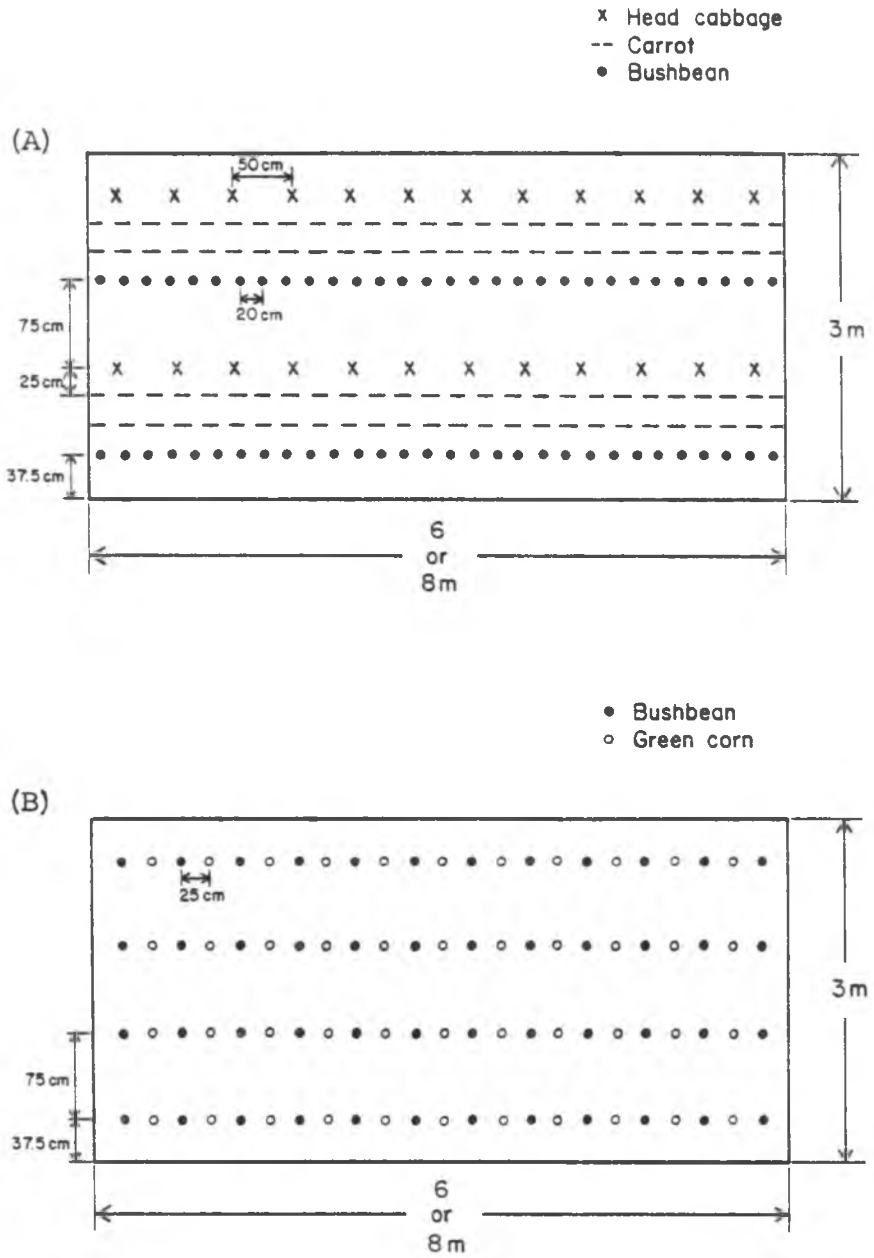


Figure 3.8. Plot layout for "Head cabbage+Carrot+Bushbean" (A) and "Bushbean+Green corn" (B), intercrop combinations.

(c) Procedure for planting mustard cabbage and bushbean combination

The plot layout for this combination is shown in Figure 3.9. Mustard cabbage seeds were dibbled 1 cm deep in rows 75 cm apart so as to approximately produce 25 seedlings per meter. Ten days after emergence the plots were thinned to ten seedlings per meter. One row of bushbean alternated with two consecutive rows of mustard cabbage . Three seeds per hill of bushbean were sown with a hill to hill spacing of 20 cm, and later thinned to two seeds per hill one week after emergence.

(d) Planting procedure for Irish potato

Seed preparation: Potatoes were placed 2 to 3 pieces high in trays with screen bottoms and kept in a dark room with high humidity, good aeration and a temperature between 80°F to 85°F. After the sprouting of eyes the large potatoes were cut into smaller block shaped seed pieces weighing approximately 2 to 4 ounces with 1 to 3 active "eyes". The cut seed pieces were dipped in captan fungicide solution to prevent mould rots. The treated seed pieces were stacked in trays in a single layer and dried in sun for about one hour. The thoroughly dry seeds were put in trays with vent holes and stored in a cool and dry room for two days.

Planting: Five cm deep furrows were dug with a row spacing of 75 cm. Furadan 10 G granules were sprinkled in the furrows at a rate of 3 g per meter of row. Seed pieces were planted with "eyes" facing up at 35 cm spacing and eventually covered with 8 to 10 cm of soil.

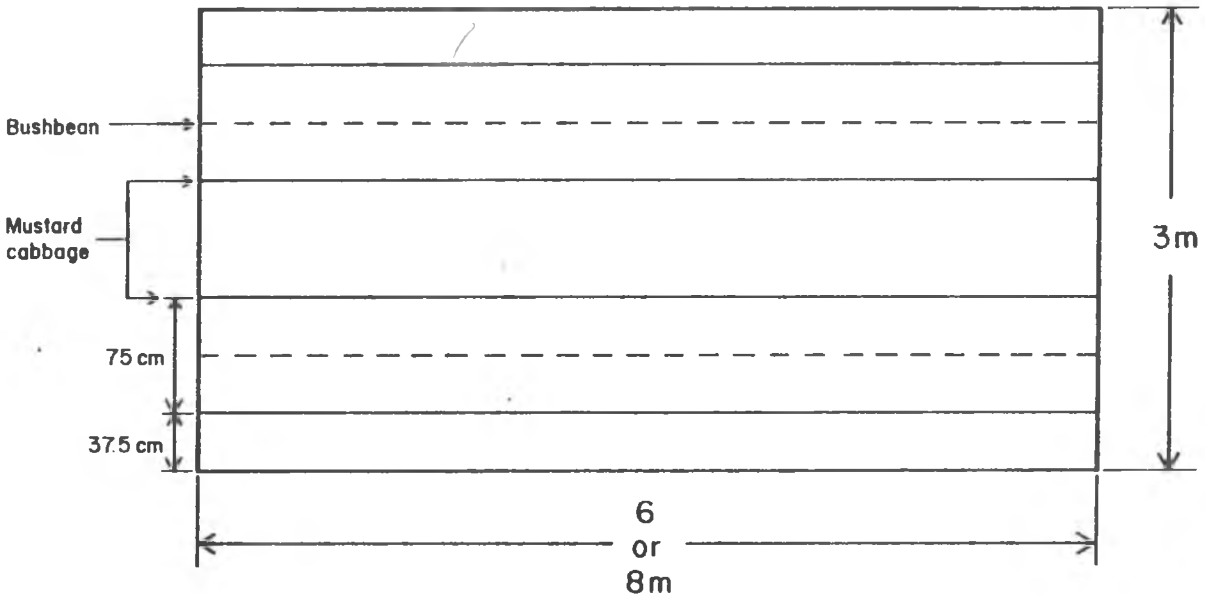


Figure 3.9. Plot layout for "Mustard cabbage+Bushbean" intercrop combination.

(e) Planting procedure for taro

Taro corms were planted on the plot boundaries as shown in the crop layout (Figure 3.5). The distance between hills was 50 cm. This planting coincided with the planting of first season crops.

(f) Planting procedure for soybean

Soybean seeds were planted in rows 75 cm apart with a seeding rate of 38 seeds per meter to attain a final population goal of 44000 plants /ha. The depth of planting was about 5 to 8 cm. Furadan 10 G granules were sprinkled in furrows at a rate of 2 g per meter of the row. The uninoculated treatments M_1 and M_2 were planted first followed by inoculated treatment (M_3) to avoid contamination problems.

3.7.4 Planting methods (TP pattern)

(a) Procedure for planting upland rice and green corn combination

Five rice seeds were sown per hill in rows spaced 40 cm apart, with a hill to hill distance of 10 cm. Corn was planted starting from the edge of the block in rows two meters apart, with a hill to hill spacing of 50 cm. After emergence corn seedlings were thinned to two plants per hill.

(b) Procedure for planting peanut

Inoculated peanut seeds were planted in furrows spaced 75 cm apart, with a seed to seed spacing of 10 cm. The depth of planting was about 5 cm. Furadan application was conducted as in soybean.

(c) Procedure for planting cowpea

Three Rhizobium inoculated cowpea seeds were sown per hill in rows spaced 40 cm apart. The hill to hill distance was 20 cm. After emergence, thinning was done to maintain two plants per hill.

(d) Procedure for planting mungbean

The planting procedure was identical to that of soybean, described under the HD pattern. However the seedlings were thinned to maintain ten plants per meter.

(e) Procedure for planting cassava

The position of cassava rows has been illustrated in the general layout of the TP pattern (Figure 3.6). At the silking stage of corn in the rice-corn combination of the first season, cassava cuttings were planted on the boundaries of the individual plots. The seed to seed spacing was kept at 75 cm.

The method of planting soybean has been described under the HD pattern.

3.7.5 Planting methods (TE pattern)

(a) Procedure for planting field corn

Field corn seeds were planted in rows 75 cm apart with a hill to hill spacing of 23 cm. Initially two seeds were planted per hill and after emergence were thinned to one plant per hill. At the time of planting Furadan 10 G granules were sprinkled in rows at the rate of 2 g/ meter.

(b) Planting procedure for cassava (Figure 3.7)

Cassava was planted on the two end boundaries of the experimental block, sixty to seventy days after the emergence of Irish potatoes. The planting method is described under the TP pattern.

(c) Planting procedure for pigeon pea and taro combination (Figure 3.7)

Sixty to seventy days after the emergence of Irish potatoes two pigeon pea seeds per hill were sown with a hill to hill distance of 50 cm on the inner plot boundaries of the block. Taro corms were planted midway between two pigeon pea hills within the rows and one plant per hill was retained.

(d) Other crops

The planting methods for Irish potato and soybean have been described under the HD pattern.

3.7.6 Irrigation method

The crops on all sites were irrigated by a drip irrigation system installed immediately after planting. A separate lateral drip line was used for each row, to assure adequate water distribution. The first irrigation was given immediately after planting except where soil was sufficiently moist to insure germination and emergence. Subsequent irrigations were scheduled on the basis of tensiometer readings.

Immediately after planting, two tensiometers were placed in one of the plots of the irrigated block. The tensiometers were positioned between two plants and between two drip tube emitter orifices within the row, at depths of 15 and 45 cm. Irrigations were adjusted so as to maintain a reading of less than 20 (0.2 bars) on both tensiometers.

3.7.7 Crop maintenance

Weed control: The plots were kept weed free by handweeding and hoeing. Care was taken to see that the drip lines remained unclogged and that soil disturbance was minimal. For the first six weeks after emergence handweeding was done every two weeks or at shorter intervals if needed. At later stages light hoeing was found to be sufficient to keep the plots weed free.

Pest control: For all crops, Furadan 10 G granules were used at planting to control pests at the seedling stage. Bird damage was prevented by the treatment of seeds with Isotox. Foliage insects were controlled by the use of Sevin 50 WP, Diazinon AG 500, Pydrin 24 EC, Malathion 25 WP or Dimethioate 2.67 EC. Sevin 50 WP was used only on plants older than three weeks. In all cases recommended concentrations of pesticides were used.

Disease control: Fungicides such as Terraclor 75 WP, Dithane Z 78, Dithane M 45 or wettable sulfur were used as and when required. Application rates and intervals for different crops were obtained from published guides.

3.8 Experimental setup at each site

Figure 3.10 depicts the experimental setup for testing cropping patterns on different sites representing the three soil families. On a particular soil family site, a cropping pattern designed specifically for that family was tested with and without irrigation to assess the need for irrigation under different moisture regimes. Thus, on Hydric Dystrandepts, Typic Paleudults and Tropeptic Eutrustox

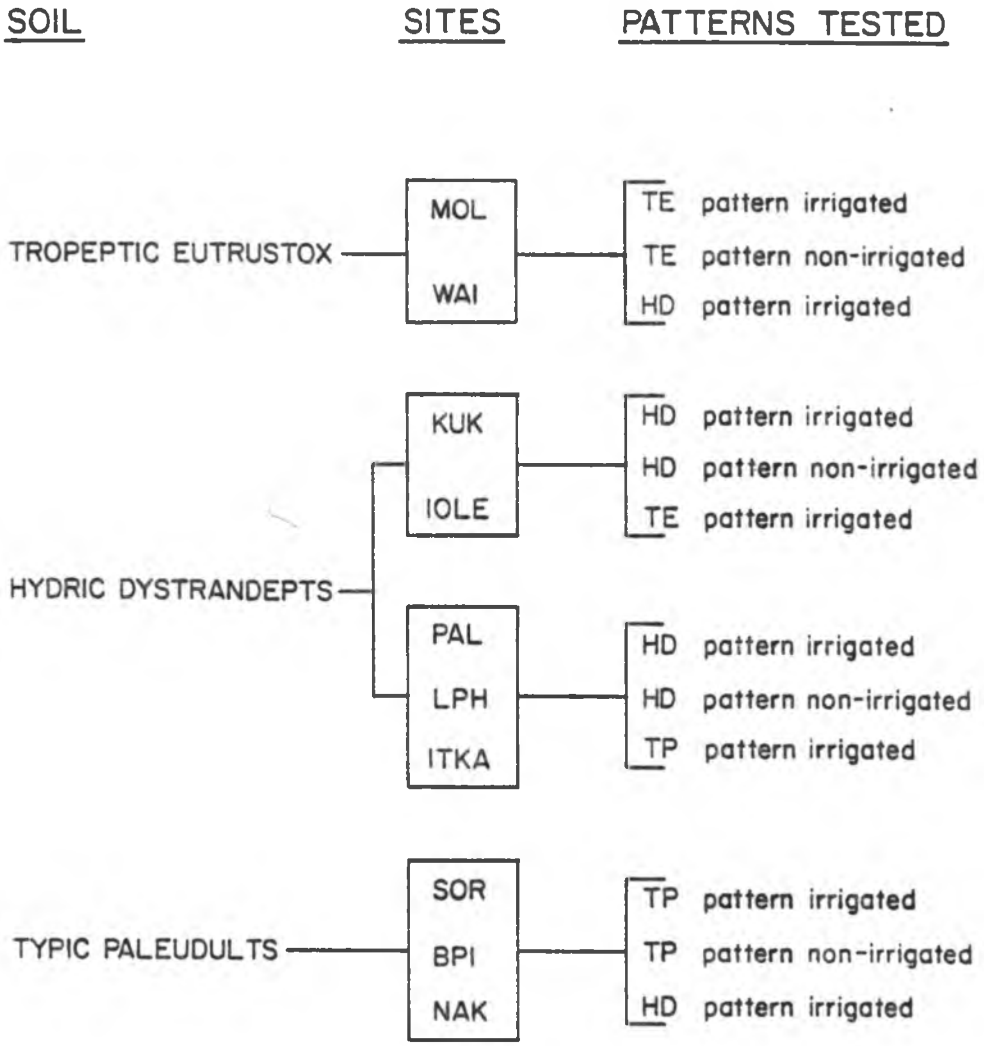


Figure 3.10. General experimental setup for cropping pattern testing on Benchmark sites.

sites, the cropping patterns HD, TP and TE were planted, respectively, with and without irrigation.

In addition to testing a specifically designed cropping pattern, an alternate cropping pattern with irrigation was also installed on each soil family. Accordingly the HD pattern (irrigated) was installed on the Tropeptic Eutrustox sites and the TE pattern (irrigated) on the Hydric Dystrandept sites. However on the Hydric Dystrandept sites in Indonesia and The Philippines the TP pattern (irrigated) was installed while on the Typic Paleudult sites the HD pattern (irrigated) was installed. In summary each site had three sets of cropping pattern experiments:

(1) A specifically designed cropping pattern with irrigation.

(2) A specifically designed cropping pattern without irrigation.

(3) An alternate cropping pattern with irrigation.

The three experiments on each site are collectively referred to as the "cropping systems experiment".

3.9 Harvesting procedures and recording of yield data

All plants from every plot were harvested but yields were recorded separately for harvest rows and borders. The border plants that were excluded in yield calculations, were those within one meter distance from each end of the plot. The side borders excluded from yield calculation were the ones at either extreme sides of the entire block. Yields were recorded separately for each row to measure the effect of border crops (cassava, pigeonpea, taro and corn) if any, on the yield of the main crop.

In grain crops, a subsample of the grains was taken for moisture determination using a digital moisture meter. Grain yield was then adjusted to a standard moisture content of 15.5 percent. The yield data has been reported on a per hectare basis.

3.9.1 Specific guidelines employed in scheduling harvest operations

Irish potato: Senescence of crop leaves beyond 50 percent was taken as an objective guideline to decide the time of harvest in conjunction with tuber inspection and personal judgement. After removing the top of the plants, potatoes were dug out with spading forks.

Carrot: To assure uniformity, 115 days after planting was fixed as the rough time period required to obtain harvestable carrots. Periodical inspection of roots around this period was done to fix the right time for harvest. Fresh weight of carrots was recorded.

Cabbage: Cabbage heads were harvested when firm and before splitting. Prior to weighing, the non-edible leaves were trimmed off. The first two heads at both ends of a row were considered as the border plants.

Bushbean: Bushbeans were harvested when firm and the bulge of the seeds first became apparent on the pod. On an average three harvests were required. The first harvest usually yielded 40 to 50 percent of the total yield. Fresh weight was recorded.

Mustard cabbage: The crop was harvested when of good size before bolting, and fresh weight was recorded. Generally two harvests were required.

Green corn: Corn ears were harvested 25 days after 50 percent tasselling or at dough stage whichever came first. Picking was started with the third plant from the end of the plot. The number of ears and ear fresh weight were recorded.

Soybean: Dry pods were harvested after leaf fall but before the occurrence of shattering. The beans were further dried if necessary and shelled. Yield data was based on the weight of the shelled grains.

Field corn: Ears were harvested soon after the observation of the "black" layer. The ears were dried overnight in an oven and shelled. The shelled grains were weighed and the yield was adjusted to the standard moisture content (15.5 %).

Peanut: Plants were pulled up when 70 to 80 percent of the pods were mature as indicated by their firmness and light brownish yellow colour associated with the senescence of leaves. The pods were picked up, washed and air dried in sun for one week. The dried pods were weighed.

Other crops: Cowpea, mungbean and pigeonpea were harvested when the pods started to dry up. Taro was harvested after the senescence of leaves of the original mother plant, whereas cassava was uprooted just before the preparation of the field for the first season crops.

3.10 Recording of agrometeorological data

The unique feature of this study is the recording of agrometeorological data on individual experimental sites on a daily basis. Each site was equipped with a meteorological station installed on an open grassy area of about 25 square meters, located within 50 m of the experimental block. The meteorological station was maintained green by periodical watering. The following parameters were measured and recorded:

(i) Air temperature
(ii) Relative humidity
(iii) Wind velocity
(iv) Solar radiation
(v) Rainfall
(vi) Maximum and minimum soil temperature at 10 cm and 50 cm depths
(vii) Maximum and minimum air temperature

Meteorological station equipment: A battery powered weather station enclosed in a cast aluminum case was utilized to record air temperature, relative humidity, wind speed, wind direction and rainfall. The station was mounted on a tripod mast, 120 cm high. Rainfall was measured by a collecting gauge outside the aluminum case which is connected to a tipping bucket recording system inside the record case. Wind run was measured by a three cup Robinson anemometer. The instrument has a recording register with a 25 cm wide inkless pressure sensitive chart, with a separate channel for each of the recorded parameters. The chart moves at a speed of 1 cm/hr. To confirm rainfall data from the mechanical station, rainfall was also measured by using a regular rain gauge. For the sake of reliability it was decided to record the rainfall data as indicated by the regular rain gauge.

A lambda pyranometer sensor with a recording integrator was used to measure solar radiation. Daily readings were recorded. The number of counts reflects the solar radiation over the period. The following relationship was used to calculate the solar radiation:

$$SR = (\text{counts}/CR * C * P) * 0.001433$$

where SR = solar radiation (langley/min)

CR = count rate as per the factor setting

C = sensor calibration constant

P = time interval between readings in hours

The factor 0.001433 is obtained from the conversion of 1 Watt/m^2 to langley/min. This is converted to langley/day on multiplying by 1440.

Thermistor probes installed at 10 and 50 cm depths in the grass covered area at the meteorological station measured, the soil temperatures.

3.11 Data analysis

Analysis and interpretation of cropping systems experiments is extremely complex. It involves a multitude of relations that cannot be easily indexed or measured by a few variables. However, a critical assumption underlying the approach of this experiment is that inspite of complexities the essential features of crop behavior are determined by a limited number of key processes controlled by a few key variables.

Oftentimes, unpredictable and abnormal weather conditions completely disturb the "normal" agroclimate of a site. The first step in the analysis of the data was to carefully screen out and discard the crop yield data affected by abnormal weather extremes (excessive wind, storms etc). In some cases, data were not used because of significant varietal differences.

Agroclimatic site variables such as solar radiation, soil temperature. air temperature, relative humidity and wind velocity were averaged for individual crop growth periods from planting to harvest. Yield data were tabulated cropwise along with the agroclimatic parameters. Such tables were used for interpretation of crop performance in relation to the respective environmental variables. Performance of year round patterns within and between the soil families was compared by conversion of individual irrigated crop yields into common units such as calories and protein. The conversion factors used were obtained from an F.A.O. (Food and Agriculture Organization of the U. N.) publication (F.A.O., 1972). Soil family productivities were judged from the results of complete year-round patterns, where all the component crops escaped abnormal weather.

The relation between individual irrigated crop performances and the agroclimatic variables of all the sites, was evaluated by examining the correlation matrices obtained using the SAS computer package. Significant relationships, were plotted using the PROC PLOT procedure (SAS). The differences between irrigated and non-irrigated yields were tested using the PROC TTEST (SAS) procedure. This test was also used for comparing the bushbean yields in association with mustard cabbage with the same in association with green corn. This T test procedure also tests for the equality of variances of the two populations, and gives a alternate test if the two variances are unequal.

In certain cases under adequate rainfall the irrigated yields were found to be lower than the non-irrigated yields. In such cases the average of irrigated and non-irrigated yields were used for correlation and plotting purposes.

The soybean experiment on Rhizobium inoculation and N application was statistically analysed by using the PROC ANOVA (SAS) procedure, and the means for different treatments (M_1, M_2, M_3, M_4) were compared by the Waller Duncan test.

Yield prediction equations: Due to the provision of adequate nutrient levels in soil, and the uniform management practices followed on all sites, the yields were assumed to be affected only by the agroclimatic parameters. Multiple regression equations, were therefore fitted to the individual crop data.

Correlation matrices were used to verify the relationships between crop yields and agroclimatic parameters and also for preliminary screening of multicolliniarity. The PROC RSQUARE (SAS) procedure was employed to compute all possible regressions. The R square values and Mallow's C P values were examined to select the best set of variables, with due consideration to their agronomic significance. The intercepts and b values for the linear regression equations were estimated using the PROC REG (SAS) option. Further screening of the selected equations was based on the examination of various statistics provided in the same SAS procedure.

The multicolliniarity diagnosis (COLLIN procedure in SAS) gave the estimate of colliniarity problems. Cook'D value was utilized for identifying the most influential observation. The comparison of predicted and observed values, significance of parameter estimates, and the total residual sum of squares, further aided the selection of one equation from a set of equations that gave similar R squares and adjusted R squares. Different transformations including the square root transformation of parameters, were tested to improve the R square. The transformation of parameters was based on the trend of the relationship shown when these were plotted against crop yields. In some cases interaction terms were used. For example, in the regression equation for mustard cabbage yields, an interaction term "solar radiation * rainfall" was used to obtain a high R square.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Performance of cropping patterns in relation to agroenvironments

Measurement of crop performance is comparatively simple when dealing only with single crop monoculture. But, the measurement of production from a multiple cropping system is much more complicated. Added to this is the problem of comparing production of cropping patterns consisting of different crops. It is not possible to compare soybean yields with peanut yields on a physical basis, hence the output of a cropping system has to be considered as a whole irrespective of crops and measured with a common unit.

Hildebrand (1976) identified five criteria that should be satisfied by a unit selected for measuring cropping pattern production. First, it must be common to all the products. Second, it should be relatively easy to measure. Third, it must be capable of reflecting quality differences between the products. Fourth, it must provide a means of comparing different cropping systems, and fifth, for possible vertical transfer of technology the method of measurement should be meaningful to a farmer. Units of protein and energy satisfy the first four criteria, but the market value of products may be the only unit available which also meets the fifth criteria. The main purpose of evaluating different cropping patterns in this study was to compare performance of patterns in relation to their agroenvironmental adaptability for possible horizontal transfer and hence the units of calorie (energy) and protein were considered appropriate. It is recognized however, that the comparisons made using common nutritional units are influenced depending on the crop constitution of patterns. For example, calorie as an unit will be advantageous for a cropping pattern with Irish potato as one of the crops.

Unusual weather conditions sometimes resulted in failure of normally feasible patterns. Hence the comparisons and evaluation made here are based on year-round irrigated cropping pattern experiments that escaped environmental abnormalities.

Individual crop production data arranged pattern wise for different sites and years are detailed in Appendices 4.1 to 4.23. The summary of total calorie and protein production based on irrigated crop yields for each cropping combination is presented in Tables 4.1 and 4.2, respectively. As depicted in the footnotes for these tables, the general cropping pattern designed for Hydric Dystrandepts (HD pattern) has 8 alternate crop combinations and the TP pattern (designed for Typic Paleudults) has four alternate combinations of crops.

4.1.1 <u>Calorie production</u> (Table 4.1)

In Tropeptic Eutrustox soils the TE pattern gave higher calorie yields compared to all HD pattern combinations. This indicates that the TE pattern was a proper choice for Eutrustox agroenvironment. In the KUK site the specifically designed HD pattern combinations produced less calories then the TE pattern. Perusal of Appendices

Table 4.1 Calorie production of different cropping patterns on the benchmark sites of three soil families.

Cropping Pattern*	Year	Sitewise Calorie Yield (K cal/ha)							
		Tropeptic Eutrustox		Hydric Dystrandept			Typic Paleudult		
		WAI	MOL	KUK	PAL	LPH	NAK	SOR	BPI
TE	1981-82	46581	NA	36357	--	--	--	--	--
	1982-83	27501	27913	34027	--	--	--	--	--
HD-A	1981-82	25979	NA	20312	NA	NA	NA	NA	NA
	1982-83	19379	13218	17758	12195	NA	5017	15586	NA
HD-B	1981-82	24941	NA	19019	NA	NA	NA	NA	7886
	1982-83	19505	14640	16306	11800	NA	NA	13716	15165
HD-C	1981-82	NA	NA	NA	NA	NA	NA	NA	NA
	1982-83	17647	NA	17731	7873	14391	3116	12668	NA
HD-D	1981-82	NA	NA	NA	NA	NA	NA	NA	4938
	1982-83	17773	NA	15879	7478	NA	NA	10798	13377
HD-E	1981-82	38548	NA	21595	NA	NA	NA	NA	NA
	1982-83	23079	17696	25560	16041	NA	4176	12974	NA
HD-F	1981-82	37510	NA	20302	NA	NA	NA	NA	6570
	1982-83	23205	19118	24108	15646	NA	NA	11104	12891
HD-G	1981-82	NA	NA	NA	NA	NA	NA	NA	NA
	1982-83	21347	NA	25133	11719	12989	2275	10056	NA
HD-H	1981-82	NA	NA	NA	NA	NA	NA	NA	3627
	1983-83	21473	NA	23681	11324	NA	NA	8186	11103
TP-A	1981-82	----	----	----	NA	NA	NA	NA	NA
	1982-83	----	----	----	25585	7161	9876	19910	25409
TP-B	1981-82	----	----	----	NA	NA	NA	NA	NA
	1982-83	----	----	----	NA	5766	NA	17643	26450
TP-C	1981-82	----	----	----	NA	NA	NA	NA	22809
	1982-83	----	----	----	23136	NA	7066	17408	26348
TP-D	1981-82	----	----	----	NA	NA	NA	NA	22942
	1982-83	----	----	----	NA	NA	NA	15141	27389

NA = Not available

4.10 and 4.11 indicates that the higher production of the TE pattern is mainly due to the high yields of the soybean crop during the second crop season (TE pattern) from April to August as compared to its yield in the third cropping season between September to January. As expected, the HD patterns performed better than the TP patterns on the Hydric Dystrandept site of LPH. However, the PAL site behaved differently compared to other Dystrandept sites. In this case the TP pattern gave higher calorie yields compared to the HD pattern. This behavior can be attributed to the mismatch between the cool temperature crops of the HD pattern and the high temperatures recorded on the PAL site. During the period of this study, the mean air and soil temperatures in PAL were consistently over 24^{O}C, and sometimes as high as 27^{O}C. Such temperatures are favorable to warm climate crops such as rice, soybean, peanut, cowpea and mungbean constituting the TP pattern. The behavior of the PAL site reemphasizes two points.

(1) Soil and air temperature regimes of a site are very important determinants of crop performance. Hence, these parameters should be monitored and characterized carefully to accomplish agroenvironment stratifications useful for interpretation or prediction of crop behavior.

(2) The actual measurement of an agroclimatic parameter for a given period can differ substantially from the average ranges estimated for soil classification purposes, from the past climatic data.

The higher calorie production of the TP pattern compared to the HD pattern on all Typic Paleudult sites, reflects the proper selection of crops for this warm and humid environment.

Comparison of identical patterns on different sites shows that the TE pattern had higher production potential in the Tropeptic Eutrustox environment than in the Hydric Dystrandept environment of KUK. In fact the highest calorie yield of 46581 k cal/ha in the entire cropping systems experimentation was obtained on the Tropeptic Eutrustox site of WAI. This demonstrates the excellent agricultural potential of Eutrustox soils, when nutrients and water are not limiting. The low calorie production of the TE pattern on WAI and MOL sites during 1982-83 was due to abnormally low potato yields. The HD patterns had a similar yield performance on Eutrustox (WAI) and Dystrandept (KUK) sites, and in most cases the WAI site had an yield advantage. The lower calorie production on the MOL site could be due to high daily wind velocities (> 15 km/hr) recorded throughout the cropping periods. The superior calorie production of the HD pattern on the Dystrandept site of KUK than on the LPH and PAL sites is probably due to the following reasons:

(1) The soil and air temperatures at the KUK site are at least 2°C (sometimes as much as 4°C) lower than those at LPH and PAL (temperature effects are discussed in detail under individual crop performances). This cooler temperature is favorable for the growth of vegetables and potato which constitute the HD pattern.

(2) The climate in PAL (The Philippines) and LPH (Indonesia) is controlled by the monsoon currents resulting in generally higher rainfall intensities, higher humidities and greater incidence of pests and diseases, compared to the agroenvironment of the Hawaiian islands. Perusal of the HD pattern performance in Typic Paleudults (NAK, SOR

and BPI) shows that the calorie production potential for SOR and BPI sites is similar to that at LPH and PAL (Dystrandepts). However, the extremely poor performance of the HD pattern in NAK is evidently due to the high (> 30°C) average air and soil temperatures in this site compared to rest of the sites.

Calorie production of TP patterns is consistently high on the BPI site (Paleudults) followed closely by the Dystrandept site of PAL (> 23000 k cal/ha). As discussed earlier, the PAL site behaves akin to Paleudults due to similar temperatures. The LPH site (Dystrandepts) behaved as expected giving the lowest TP pattern calorie yields (< 8000 kg/ha). The cool and wet environment of the Hydric Dystrandept is not conducive to good growth of crops adapted to warm temperature which constitute the TP pattern. The lower production on the SOR site than on the BPI site is apparently due to the higher rainfall quantities and intensities encountered in the former. Crops such as cowpea, mungbean and peanut were found to be susceptible to excess moisture. The lowest TP pattern calorie production (< 10000 k cal/ha) was obtained on the Paleudult site of NAK. This site is unique because of its proximity to the equator with maximum air temperatures going as high as 36°C.

4.1.2 <u>Protein Production</u> (Table 4.2)

The general trends observed from the data on protein production of the cropping patterns, are identical to those discussed under calorie production. However, the protein data reduces the yield gap between patterns with high calorie crops (e.g., Irish potato) and

Table 4.2 Protein production of different cropping patterns on the benchmark sites of three soil families.

Cropping Pattern*	Year	Sitewise Protein Yield (kg/ha)							
		Tropeptic Eutrustox		Hydric Dystrandept			Typic Paleudult		
		WAI	MOL	KUK	PAL	LPH	NAK	SOR	BPI
TE	1981-82	2101	NA	1792	---	---	---	---	---
	1982-83	1730	1299	1565	---	---	---	---	---
HD-A	1981-82	1832	NA	1257	NA	NA	NA	NA	NA
	1982-83	1106	744	1085	797	NA	288	1092	NA
HD-B	1981-82	1256	NA	908	NA	NA	NA	NA	322
	1982-83	873	659	735	500	NA	NA	589	695
HD-C	1981-82	NA	NA	NA	NA	NA	NA	NA	NA
	1982-83	1250	NA	1399	689	1192	266	1111	NA
HD-D	1981-82	NA	NA	NA	NA	NA	NA	NA	268
	1982-83	1017	NA	1049	394	NA	NA	608	678
HD-E	1981-82	1866	NA	1055	NA	NA	NA	NA	NA
	1982-83	1023	724	1089	832	NA	256	984	NA
HD-F	1981-82	1290	NA	706	NA	NA	NA	NA	269
	1982-83	790	639	739	537	NA	NA	481	609
HD-G	1981-82	NA	NA	NA	NA	NA	NA	NA	NA
	1982-83	1167	NA	1403	724	1061	234	1003	NA
HD-H	1981-82	NA	NA	NA	NA	NA	NA	NA	215
	1983-83	934	NA	1053	429	NA	NA	500	592
TP-A	1981-82	----	----	----	NA	NA	NA	NA	---
	1982-83	----	----	----	1432	638	537	1128	941
TP-B	1981-82	----	----	----	NA	NA	NA	NA	---
	1982-83	----	----	----	NA	259	NA	970	1001
TP-C	1981-82	----	----	----	NA	NA	NA	NA	736
	1982-83	----	----	----	829	NA	194	659	833
TP-D	1981-82	----	----	----	NA	NA	NA	NA	740
	1982-83	----	----	----	NA	NA	NA	501	893

NA = Not available

those with low calorie high protein crops (e.g., soybean, peanut etc.). For instance, the calorie yield of the HD-A pattern (1981-82) in the WAI site (25979 k cal/ha) is about 56 percent of the yield for the TE pattern (46581 k cal/ha) during 1981-82. In contrast, the respective protein production of the HD-A pattern (1832 kg/ha) is 87 percent of the same for the TE pattern (2101 kg/ha). Obviously the patterns having soybean as one of the crops, produce considerably higher quantities of protein. Another illustration is the comparison of calorie and protein production of the TP pattern on the BPI site. Extremely low protein yield compared to calorie yield in this case is due to very good yield of rice which has a high calorie to protein ratio.

Effendi et al. (1982) have reported similar evaluation of cropping patterns based on calorie and protein production. Based on cropping pattern tests conducted in Way Abung, Indonesia the workers reported a maximum protein yield of 843 kg/ha for a year-round sequence of "corn + rice + cassava" intercrop followed by peanut and then by rice bean. However present results suggest that higher protein yields (> 1100 kg/ha) are possible by growing the following sequences on similar soils:

1) Rice + green corn —— Soybean —— Cowpea
2) Rice + green corn —— Soybean —— Mungbean.

Zandstra et al. (1981) suggested that the productivity of the best performing patterns for each land type could be used as a measure of the cropping pattern potential of that land type. Using this criteria different sites could be ranked in the order of their productivity based on the pattern producing maximum calorie and protein yields. The rankings in descending order are as follows:

i) Calorie production

(1) WAI (2) KUK (3) MOL (4) BPI (5) PAL (6) SOR (7) LPH (8) NAK.

ii) Protein production

(1) WAI (2) KUK (3) PAL (4) MOL (5) LPH (6) SOR (7) BPI (8) NAK.

Due to the differences in calorie and protein composition of the crops, some sites differ in their production potential as per the unit of measurement. WAI and KUK sites demonstrate a high yield potential irrespective of the unit of measurement. By the same standards NAK was found to be the least productive site. Other sites of IOLE, and ITKA could not be assessed because of the lack of year-round data.

4.1.3 Conclusion

The present data illustrate the difficulty of interpreting crop performance solely on the basis of general soil family characteristics. Crop response varies in any year because of the marked influence of locational weather factors, such as temperature, solar radiation, precipitation and pests that respond to the uniqueness of a particular season at a particular site. Neverthless some general trends in productivity were apparent:

(1) Except for PAL and KUK sites, the result demonstrated the success of specifically designed patterns for each soil family, over the other pattern (e.g., on the Dystrandept site of LPH, the HD pattern performed better than the TP pattern)

(2) The highest yield potential was shown by the Eutrustox site

of WAI followed by KUK (Dystrandept). The NAK site (Typic Paleudults) was found to be the least productive.

(3) Contrary to expectation, the TE pattern was found to be better suited for the Hydric Dystrandept site of KUK than the HD pattern combinations.

4.2 Performance of individual crops in relation to agroenvironments

Analysis of individual crop performances is very important in cropping systems research (Zandstra *et al*., 1981). Behavior of component crops of a cropping pattern gives clues of the environmental requirements of crops and points to relationships that are important for future cropping pattern design.

As described in Chapter III, this study employed the technique of matching crop requirements with the environmental characteristics to design cropping patterns for the three soil families. Primarily, soil temperature regime, seasonal temperature variations, soil moisture regime, seasonal rainfall and solar radiation fluctuations were the parameters considered for the choice of crops. As regards the agroclimatic requirements of crops, the information available is mostly qualitative and perhaps highly subjective. The ranges of temperature suitability available from the literature, for crops like vegetables (head cabbage, bushbeans etc.) and Irish potato are largely based on temperate region experience. One of the premises of this study was therefore to test the crop-environment (soil family) matching process and eventually make some quantitative suggestions about the agroclimatic requirements of various crops, under tropical conditions.

In the present study, fifteen crops were tested on a network of ten experimental sites, as components of the three cropping systems. The rationale of crop selection for the TE pattern (designed for Tropeptic Eutrustox soils), HD pattern (for Hydric Dystrandepts) and TP pattern (for Typic Paleudults) has been discussed in Chapter III (material and methods).

Based on the response to agroclimatic parameters, the crops can be placed into two groups:

(1) Crops that were found to be highly sensitive to temperature and moisture variation. Their variability could be effectively explained on the basis of soil and air temperatures and rainfall intensities, irrespective of soil family affiliation. This group includes head cabbage, mustard cabbage, Irish potato, carrot and bushbean.

(2) Crops with a wide range of adaptability to temperature and moisture conditions. Their performance could not be accounted for satisfactorily by site variables when comparisons were made over all the soil families. However, some relationships were apparent, when their performance was analysed within the same soil family. Peanut and soybean belong to this group.

The remaining crops namely cowpea, mungbean, corn, rice, pigeonpea, taro and cassava did not show significant trends, mainly because of limited data. The foregoing discussion is based on irrigated crop yields.

4.2.1 Performance of head cabbage

Head cabbage is adapted to cool and moist climate and has been traditionally cultivated in the tropics at high elevations. In recent years cultivars such as "KK cross" have been widely grown in low levels of equatorial South East Asia (Williams, 1979). Table 4.3 gives the site wise head cabbage yield (irrigated) and the pertinent agroclimatic data. The failure of head cabbage on all Typic Paleudult sites readily distinguishes this environment from the rest. Perusal of the agroclimatic data points out that high temperature is the probable reason for crop failure on Paleudults. The average soil and air temperatures on Paleudult sites are between 25.5 and 30.2°C, respectively, whereas on Dystrandept and Eutrustox sites the temperature range is 18 to 25.4°C. Within the Dystrandepts the poor cabbage performance on LPH and PAL sites was conceivably due to the detrimental effects of higher rainfall and higher soil and air temperatures compared to other sites. Low yields in IOLE (1981) and WAI (1982) could be due to lower solar radiation and higher rainfall that occured in comparison to other years in the same locations. The reason for low yields on the MOL site is not apparent from the tabular agroclimatic data. However the consistent recording of daily average wind velocities normally above 12 km/hr (Appendix 1) makes MOL site different from WAI with respect to this parameter(< 4 km/hr).

The plots of head cabbage yields versus minimum air temperature, maximum air temperature, soil temperature and rainfall for the crop periods are presented in Figures 4.1 to 4.5. All the above cited parameters were negatively related to yield. The correlation

Table 4.3 Cabbage yields and selected agroclimatic data for benchmark sites in the first cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1981	6127	595	781	280	18.2	18.0	24.4	15.7	20.0
	IOLE	1982	14353	329	298	364	18.9	18.2	23.0	13.1	18.0
	KUK	1981	18437	1874	234	440	19.8	18.9	23.3	15.2	19.2
	KUK	1982	10777	876	783	306	20.0	19.1	24.0	15.6	19.8
	KUK	1983	18491	476	412	397	21.0	20.2	24.9	16.8	20.8
	LPH	1981	4284	357	1450	245	23.1	22.0	25.4	15.8	20.6
	LPH	1982	5686	470	1151	376	23.9	22.6	26.3	16.1	21.2
	PAL	1981	1539	222	1699	302	24.6	22.5	29.1	20.6	24.8
	PAL	1982	4187	381	766	293	24.5	22.5	30.5	20.2	25.4
Tropeptic Eutrustox	MOL	1982	6967	627	445	454	20.1	19.9	23.9	17.0	20.4
	MOL	1983	8740	1110	52	521	19.8	19.6	27.8	18.2	23.0
	WAI	1981	15990	651	137	356	18.9	18.8	28.1	18.2	23.2
	WAI	1982	8900	115	386	289	19.7	19.0	27.1	18.2	22.6
	WAI	1983	14480	350	56	740	21.0	20.7	28.0	15.4	21.7
Typic Paleudult	NAK	1981	0	0	497	400	28.6	27.6	33.2	22.0	27.6
	NAK	1982	0	0	1861	438	31.8	27.3	35.7	24.6	30.2
	BPI	1981	847	153	353	418	29.1	29.1	34.4	22.5	28.4
	BPI	1982	0	0	643	422	28.4	28.4	33.5	22.4	28.0
	SOR	1981	0	0	1793	333	26.9	25.7	29.0	22.0	25.5
	SOR	1982	1808	466	381	322	27.0	25.7	30.4	21.6	26.0

coefficients of the relationship between yield and air temperature were -0.70^{**} and -0.76^{**} for maximum and minimum air temperatures, respectively. The highest yields were obtained within minimum air temperatures of 13 to 19°C, and maximum air temperatures of 23 to 28°C. Accordingly, good head cabbage yields can be expected between average air temperatures of 18 to 23.5°C. However the optimum air temperature range, normally reported for head cabbage is 15.5 to 18.0°C (Purseglove, 1974) which obviously is based on temperate region experience and therefore could be misleading.

The better relationship (Figure 4.3) between mean soil temperature and head cabbage yield ($r = -0.79^{**}$) suggests that soil temperature is a good indicator of crop performance. Best yields were obtained between soil temperatures of 18 to 22°C. Crop failure occurred when the soil temperature exceeded 26°C (all Paleudult sites).

Figure 4.4 shows the detrimental effect of excess rain on head cabbage performance ($r = -0.58^{**}$). A rainfall above 800 mm for the crop period is likely to damage the crop. In some cases the detrimental effects of high rainfall and high temperature are confounded. For instance, on the Typic Paleudult sites of SOR and NAK (rainfall > 1500 mm), the crop failure could be the result either of high temperature or high rainfall or both acting together. However, the poor yields on BPI, SOR and NAK at low rainfall levels, are attributable to high temperature alone. With assured supplemental irrigation, high head cabbage yields are likely when total rainfall is below 500 mm.

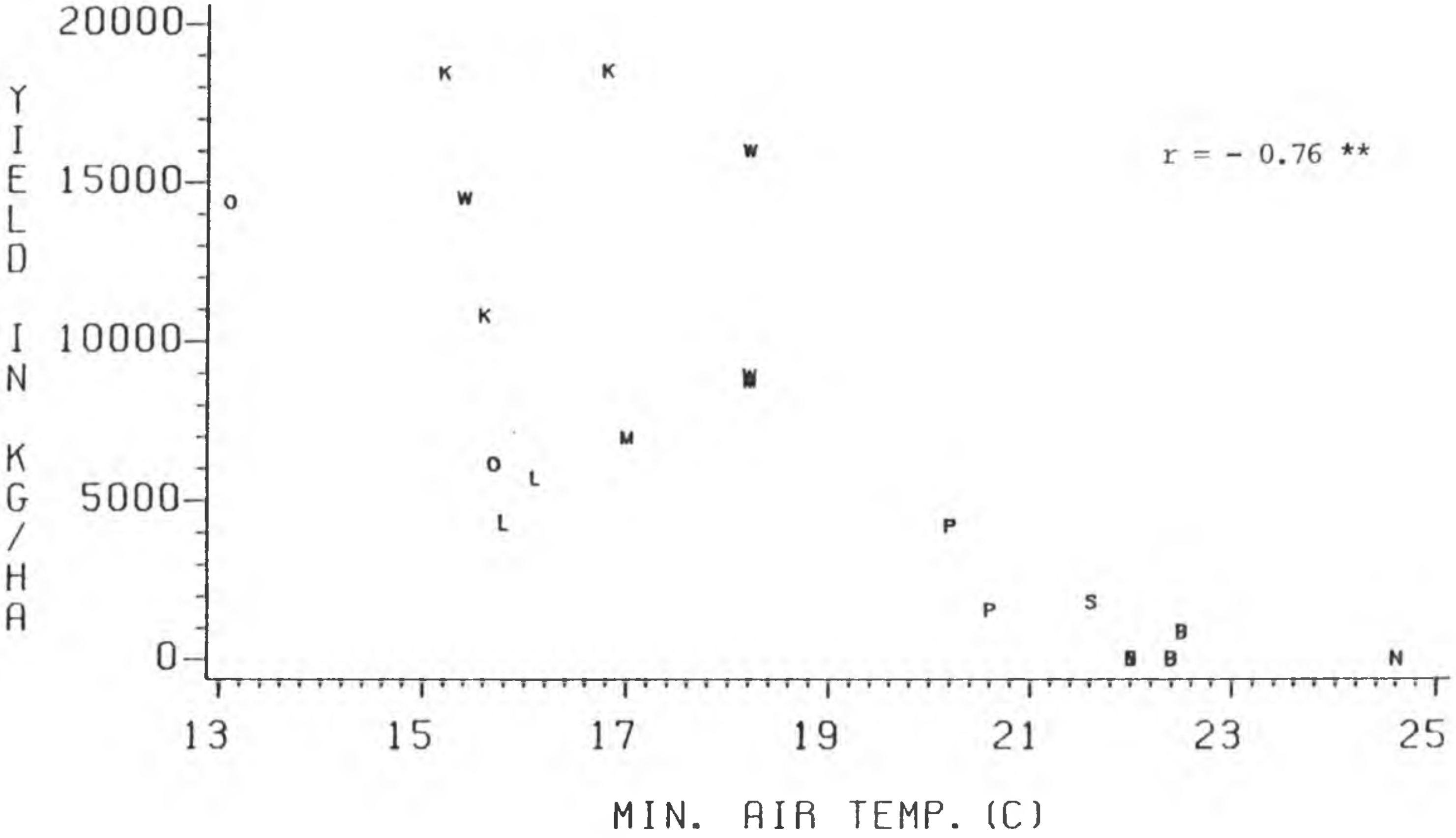


Figure 4.1. The relationship between minimum air temperature and irrigated head cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

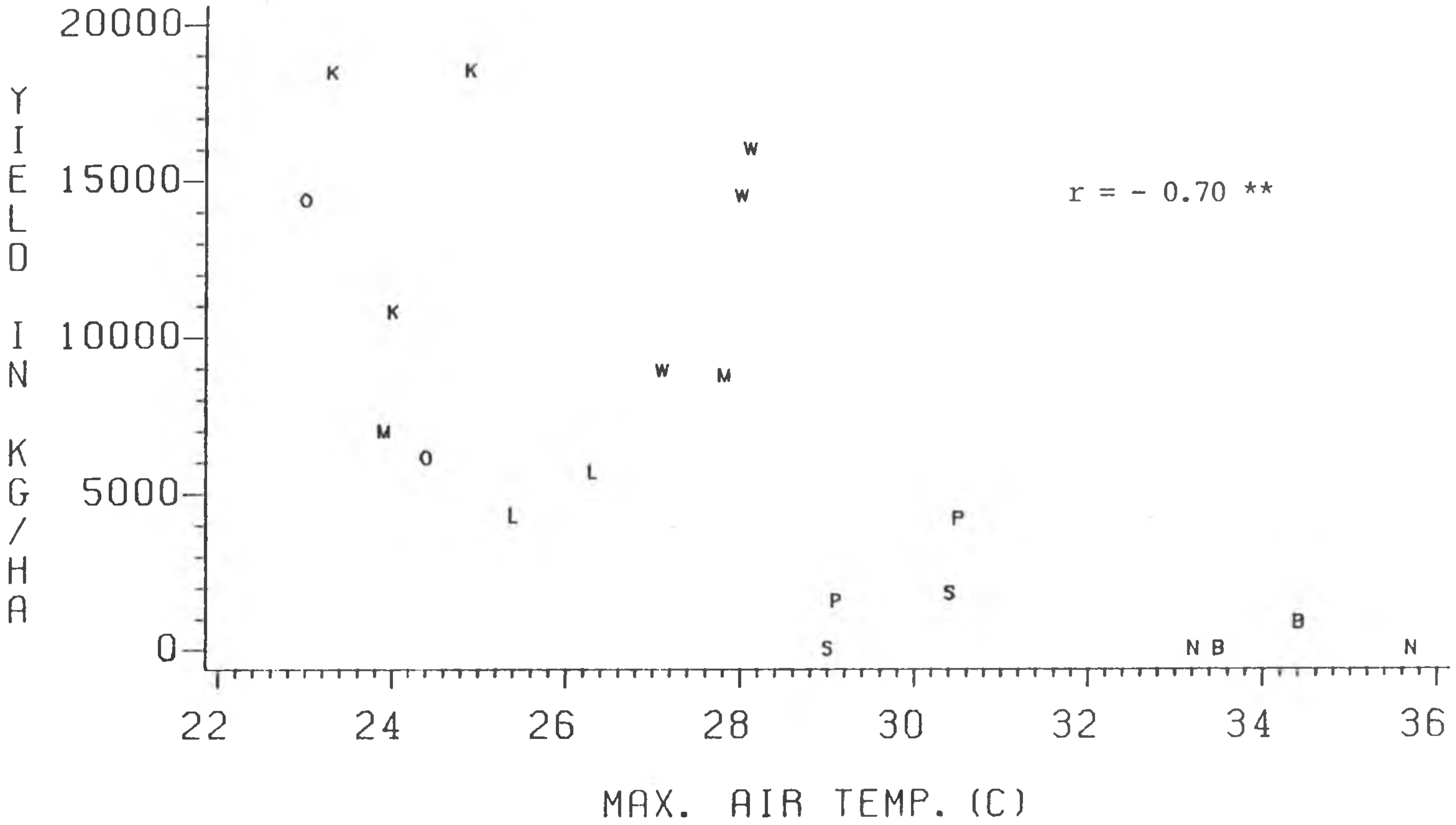


Figure 4.2. The relationship between maximum air temperature and irrigated head cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

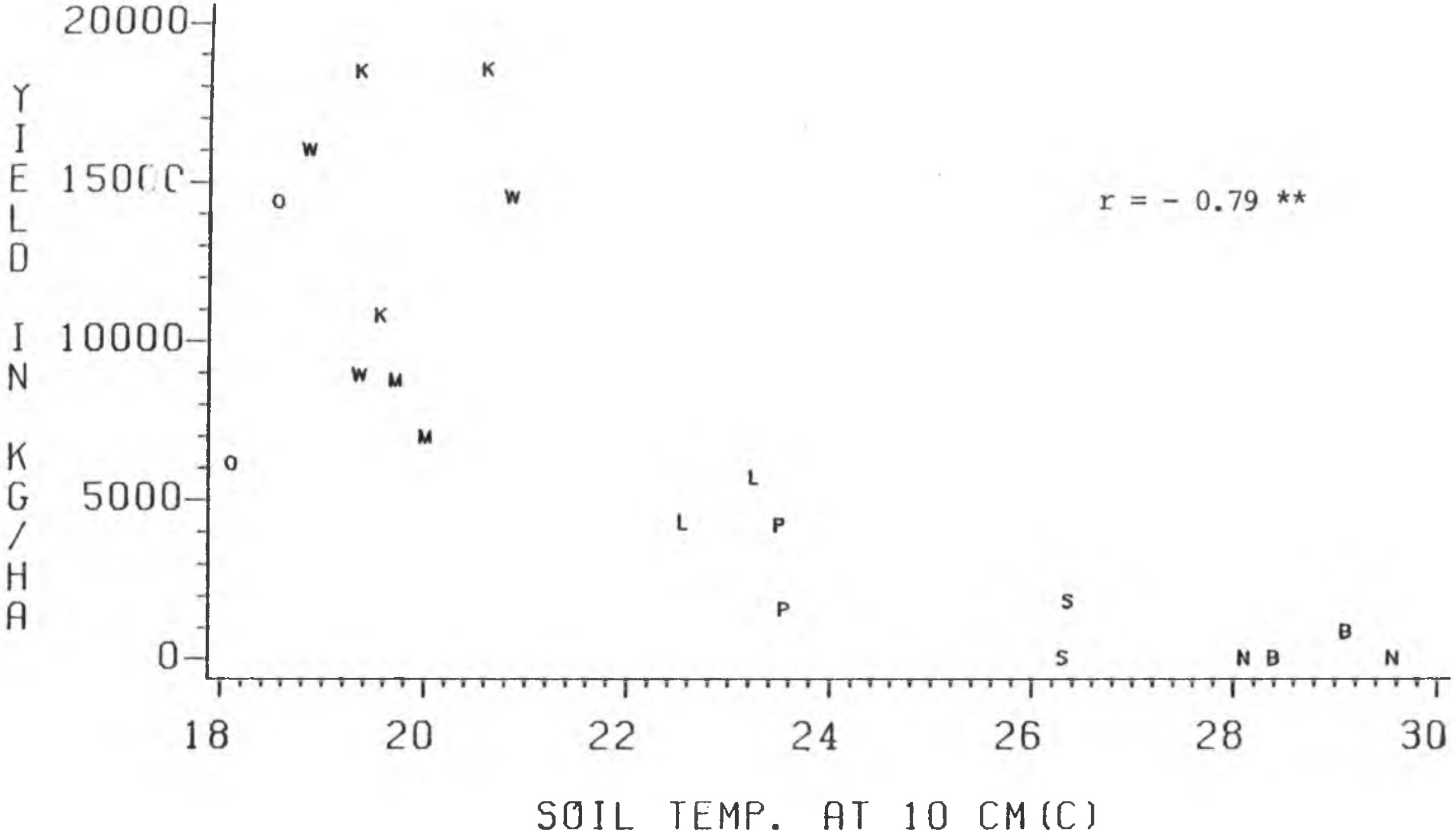


Figure 4.3 The relationship between average soil temperature and irrigated head cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

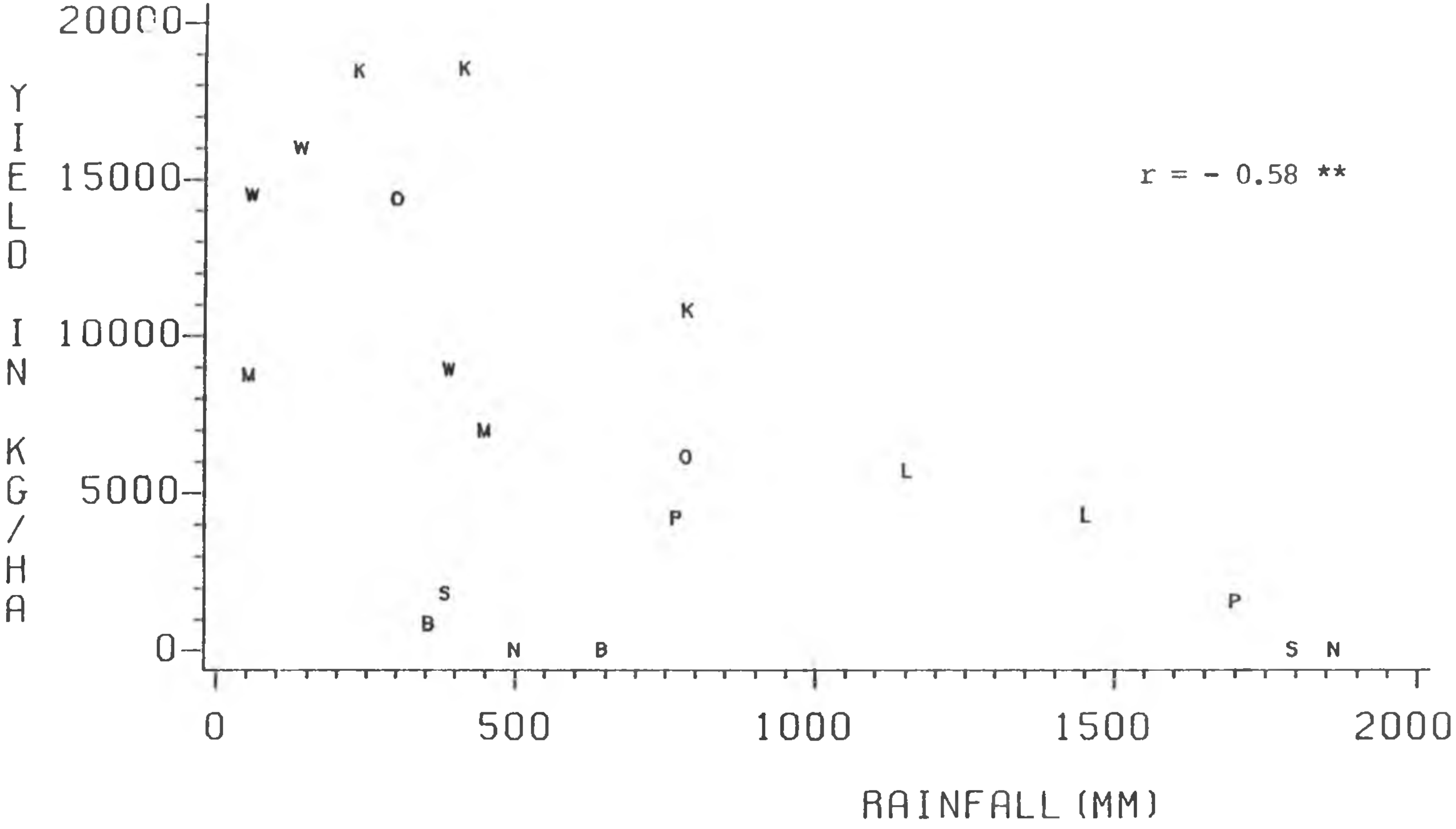


Figure 4.4. The relationship between rainfall and irrigated head cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

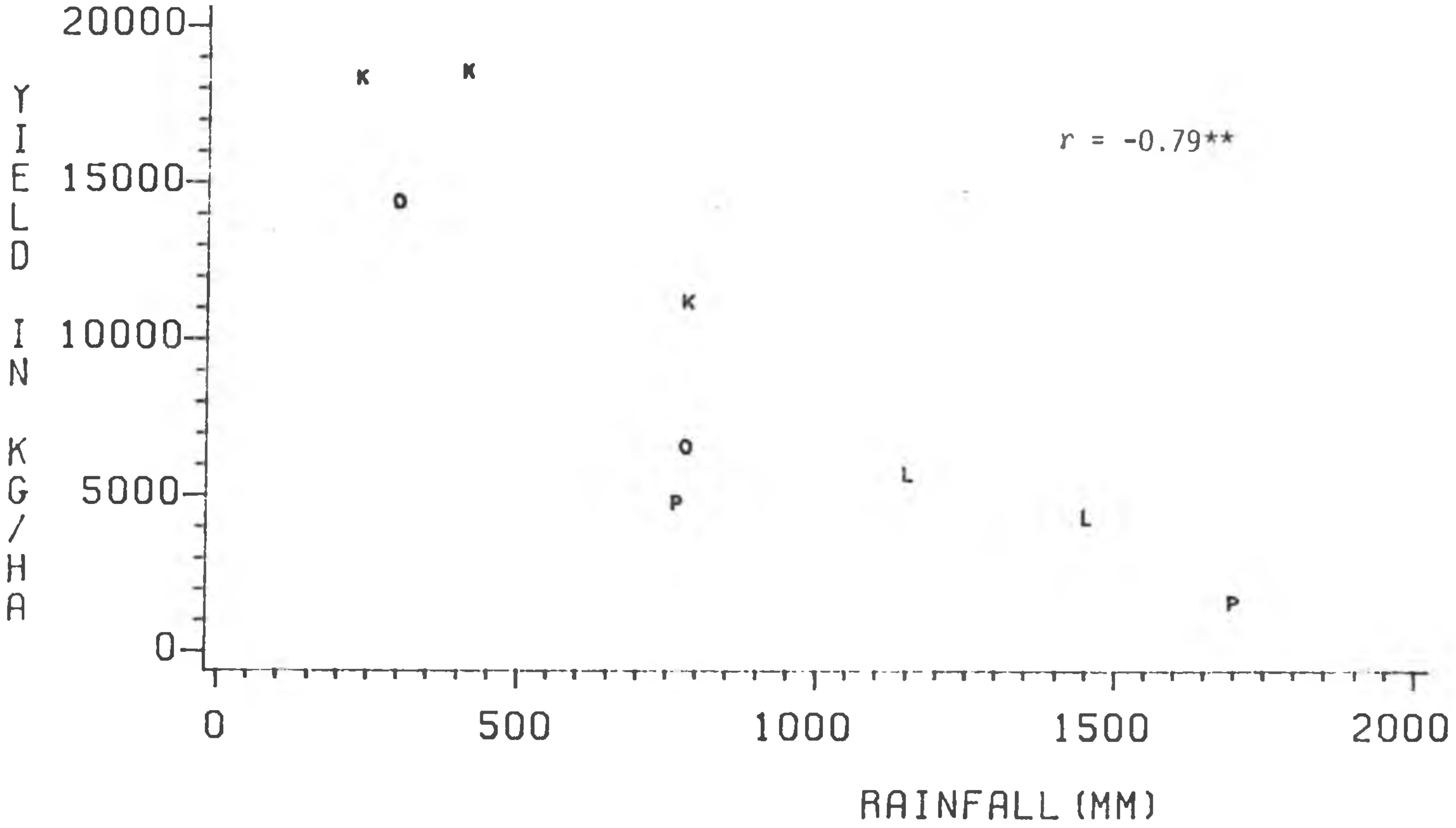


Figure 4.5 The relationship between rainfall and cabbage yield on benchmark sites of Dystrandept soils.

4.2.2 Performance of mustard cabbage

Mustard cabbage is extensively grown in a variety of climates, but it prefers a cool weather. It is reported (Knott and Deanon, 1967) that mustard cabbage tends to remain vegetative with inhibition of flowering at temperatures of about 27 to 32°C. The crop yield data and corresponding agroclimatic parameters are detailed in Table 4.4. The data show that the Hydric Dystrandepts have a high yield potential for this crop. The cool temperatures and excellent physical properties of Dystrandept sites are considered ideal for mustard cabbage production. The high yields of over 30000 kg/ha obtained in IOLE and KUK are associated with the lowest soil and air temperatures recorded during this experiment. The Dystrandept sites of LPH and PAL behave differently probably because of their higher soil and air temperatures. The poor performance of the crop on the PAL site during 1983 can be attributed to unexpectedly high maximum soil and air temperatures recorded during the period, which also might have contributed to the high worm infestation of the crop. Tropeptic Eutrustox sites appear to be next to Dystrandepts in yield performance. The soil temperatures on Eutrustox sites are close to those on Dystrandept sites of IOLE and KUK, but air temperatures are considerably higher. This could be the reason for lower yields of mustard cabbage on Eutrustox sites compared to KUK and IOLE sites. As expected, Typic Paleudults are least suited for mustard cabbage production. The low yields in Paleudults are associated with higher soil and air temperatures. Within Paleudults, the SOR site produced

Table 4.4 Mustard cabbage yields and selected agroclimatic data for benchmark sites in the second cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982	36035	437	355	383	19.8	18.9	25.0	17.1	21.0
	KUK	1982	31297	4214	610	383	21.1	19.9	23.3	16.1	19.7
	LPH	1982	14478	1233	444	310	23.8	22.4	26.9	15.2	21.0
	PAL	1982	14852	444	231	352	26.9	22.1	32.8	20.2	26.5
	PAL	1983	2936	458	3	440	31.1	23.9	35.1	19.4	27.2
Tropeptic Eutrustox	MOL	1981	8787	1488	63	600	22.1	21.8	28.6	19.1	23.8
	WAI	1982	17800	1566	43	498	22.3	21.4	30.8	18.6	24.7
Typic Paleudult	NAK	1981	3049	2246	422	436	29.4	28.9	36.7	23.4	30.0
	NAK	1982	3877	805	656	397	31.2	27.7	35.1	20.1	27.6
	BPI	1981	4357	384	457	409	26.1	26.1	33.9	22.0	28.0
	BPI	1982	4765	825	327	414	26.3	26.3	34.1	21.6	27.8
	SOR	1982	8245	799	293	379	25.8	24.4	28.1	19.8	24.0

the highest yields and also had the lowest average air temperature. During excess rainfall the comparitively poor drainage characteristic of Paleudults also might have contributed to low yields.

The negative association of mustard cabbage yields with air and soil temperatures is further illustrated in Figures 4.6, 4.7 and 4.8. The correlations of yield with maximum air temperature, minimum air temperature and mean soil temperature are highly significant with correlation coefficients of -0.83^{**}, -0.71^{**} and -0.87^{**}, respectively. High yields were obtained between maximum and minimum air temperature ranges of 22 to 26°C and 16 to 18°C, respectively. Similarly, mean soil temperatures between 18 to 21°C were conducive to high yields and a temperature of 25°C appeared to be the limit beyond which the crop failed.

4.2.3 Performance of carrot

The yield data of carrot and the recorded agroclimatic parameters for the crop periods are depicted in Table 4.5. In general, Typic Paleudult sites have given low yields (< 6100 kg/ha) compared to other sites. Both, Hydric Dystrandepts and Tropeptic Eutrustox agroenvironments appear to have comparable and high yield potentials for carrot (up to 27725 kg/ha). The overall yield data is in accordance with the fact that carrot is well adapted to cool temperature and well drained soils. Hydric Dystrandept and Tropeptic Eutrustox soils giving high carrot yields, had low air and soil temperatures. The low yield in Typic Paleudults is associated with high temperatures. The PAL site which gave the lowest carrot yield

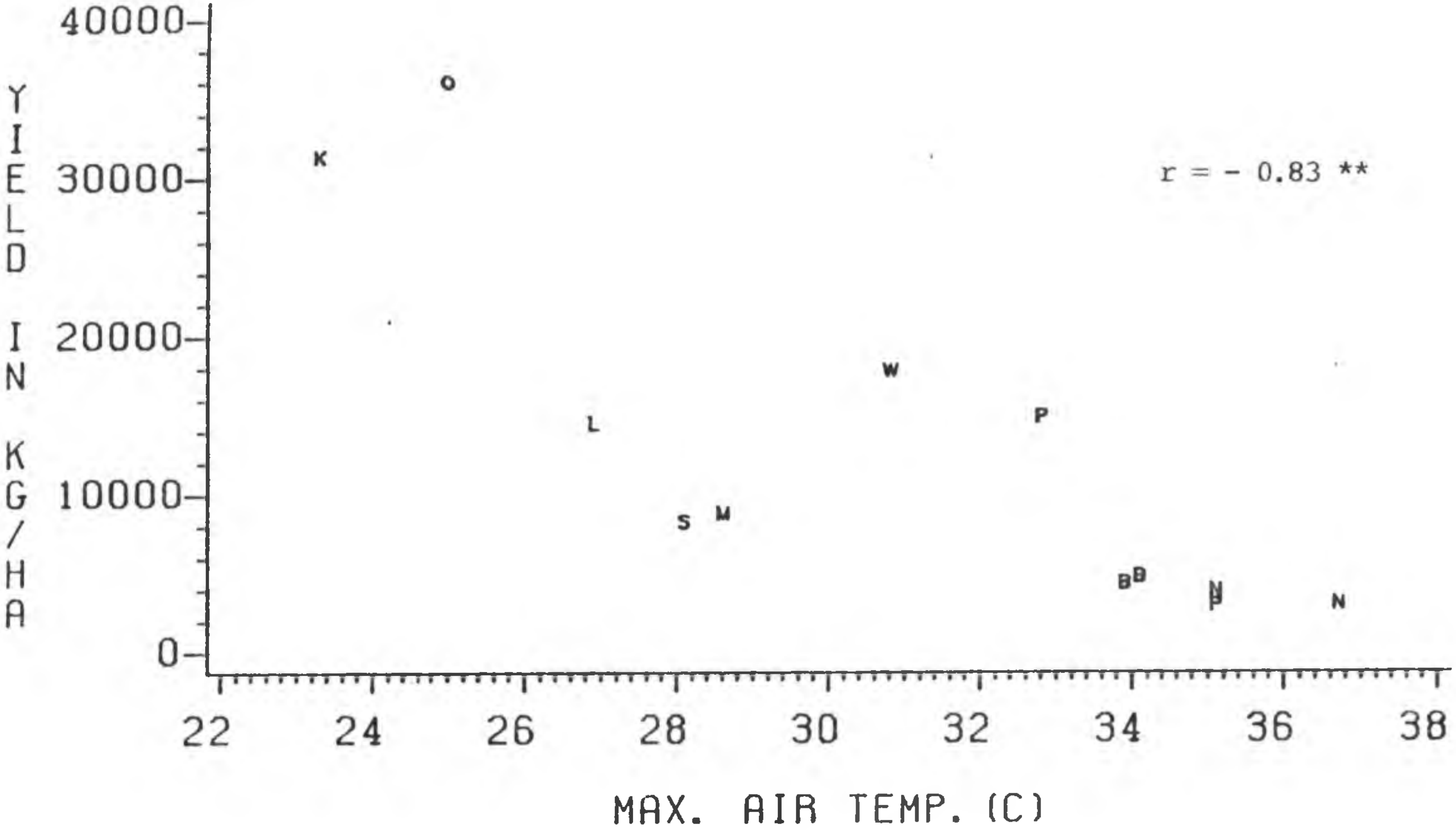


Figure 4.6. The relationship between maximum air temperature and mustard cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

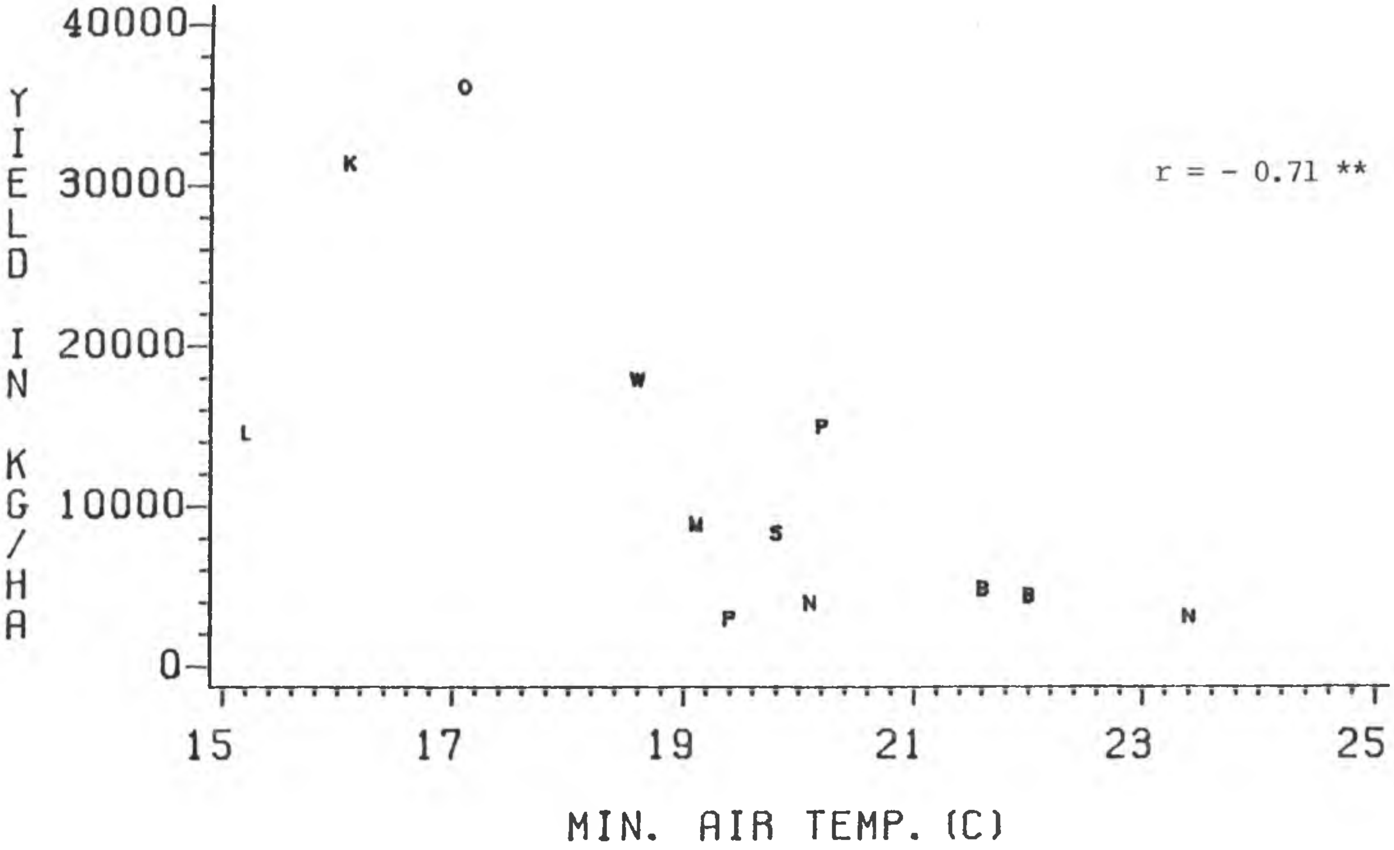


Figure 4.7. The relationship between minimum air temperature and irrigated mustard cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

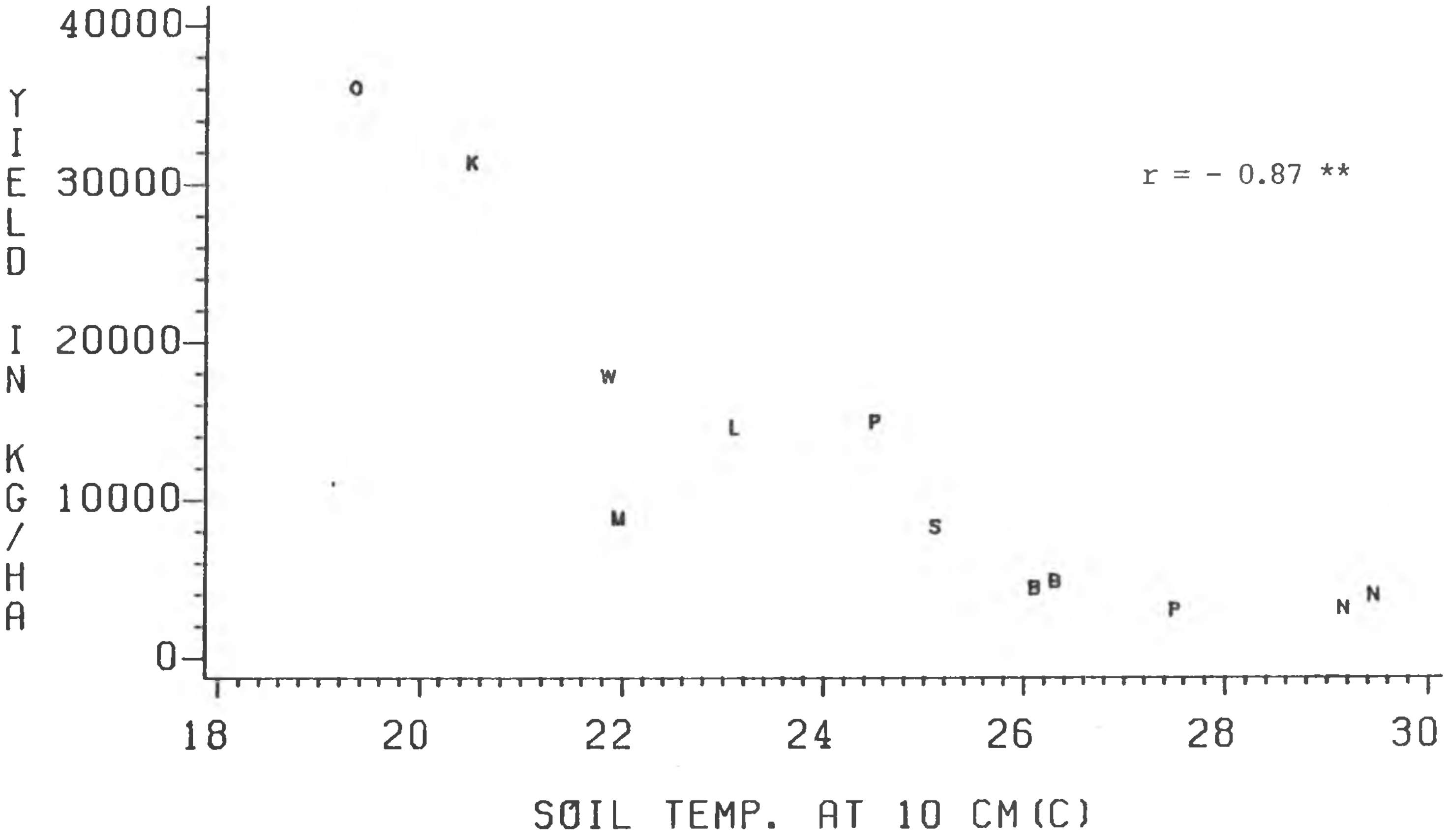


Figure 4.8 The relationship between average soil temperature and irrigated mustard cabbage yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

Table 4.5 Carrot yields and selected agroclimatic data for benchmark sites in the first cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982-83	15902	1585	430	367	18.7	18.1	22.8	13.2	18.0
	KUK	1981	9056	1460	421	437	20.2	19.0	23.8	15.3	19.6
	KUK	1982	10863	557	1193	317	20.5	19.6	23.8	15.9	19.8
	KUK	1983	20838	1082	864	382	20.4	19.5	25.4	16.6	21.0
	LPH	1981-82	11122	250	1450	245	23.1	22.0	25.4	15.8	20.6
	LPH	1982-83	9524	615	1212	379	23.9	22.6	26.3	16.1	21.2
	PAL	1982	4201	537	864	321	25.1	22.6	30.8	20.2	25.5
Tropeptic Eutrustox	MOL	1982	13630	2665	652	402	20.9	20.7	25.1	18.0	21.6
	MOL	1983	16555	1846	104	506	19.6	19.4	27.3	18.2	22.8
	WAI	1981	7470	925	218	395	19.5	19.0	28.4	18.1	23.2
	WAI	1982	17497	1719	500	313	19.4	18.7	27.1	18.5	22.8
	WAI	1983	27725	292	91	699	20.7	20.4	27.4	15.3	21.4
Typic Paleudult	NAK	1981-82	1231	193	716	405	28.7	27.4	33.0	21.6	27.3
	NAK	1982-83	2097	59	1861	438	31.7	27.2	35.7	24.5	30.1
	BPI	1981	3143	429	563	422	29.1	29.1	34.4	22.6	28.5
	BPI	1982	5751	464	643	422	28.4	28.4	33.5	22.4	28.0
	SOR	1981-82	6096	488	1634	335	26.5	25.3	28.1	21.7	24.9
	SOR	1982-83	5978	925	571	336	27.3	25.8	30.8	21.5	26.2

within the Dystrandept sites also had a maximum soil and air temperature of 25.1 and 30.8°C, respectively, which are considerably in excess of temperatures recorded on other Dystrandept sites. If the highest yields obtained are assumed to be the best yields possible, Eutrustox soils represented by WAI (1983) apparently have higher carrot yield potential then the Dystrandept soils.

Carrot yields were plotted against average soil temperature, maximum air temperature and minimum air temperature as shown in Figures 4.9, 4.10 and 4.11. The correlation coefficients for yield versus maximum air temperature and minimum air temperature were -0.63^{**} and -0.70^{**}, respectively. Soil temperature showed a slightly better relationship ($r = -0.73^{**}$) with yield.

Best yields were obtained at an average air temperature range of 17 to 23.5°C. This is close to the optimum range of temperature for carrots (15.6 - 21.1°C) reported by McCollum and Ware (1980). Temperatures above 25°C were found to be detrimental for carrot growth. It was also observed that at higher temperatures, carrot roots became shortened while at low temperatures carrot roots were long and pointed. This observation was also in accordance with the findings of workers cited above. A favorable soil temperature range for high yields of this crop (Figure 4.9) appears to be 18 to 21°C, and temperatures beyond 24°C are likely to be unsuitable.

4.2.4 Performance of Irish potato

Irish potato was chosen as one of the crops in the HD pattern as well as the TE pattern because of the cool temperatures prevailing

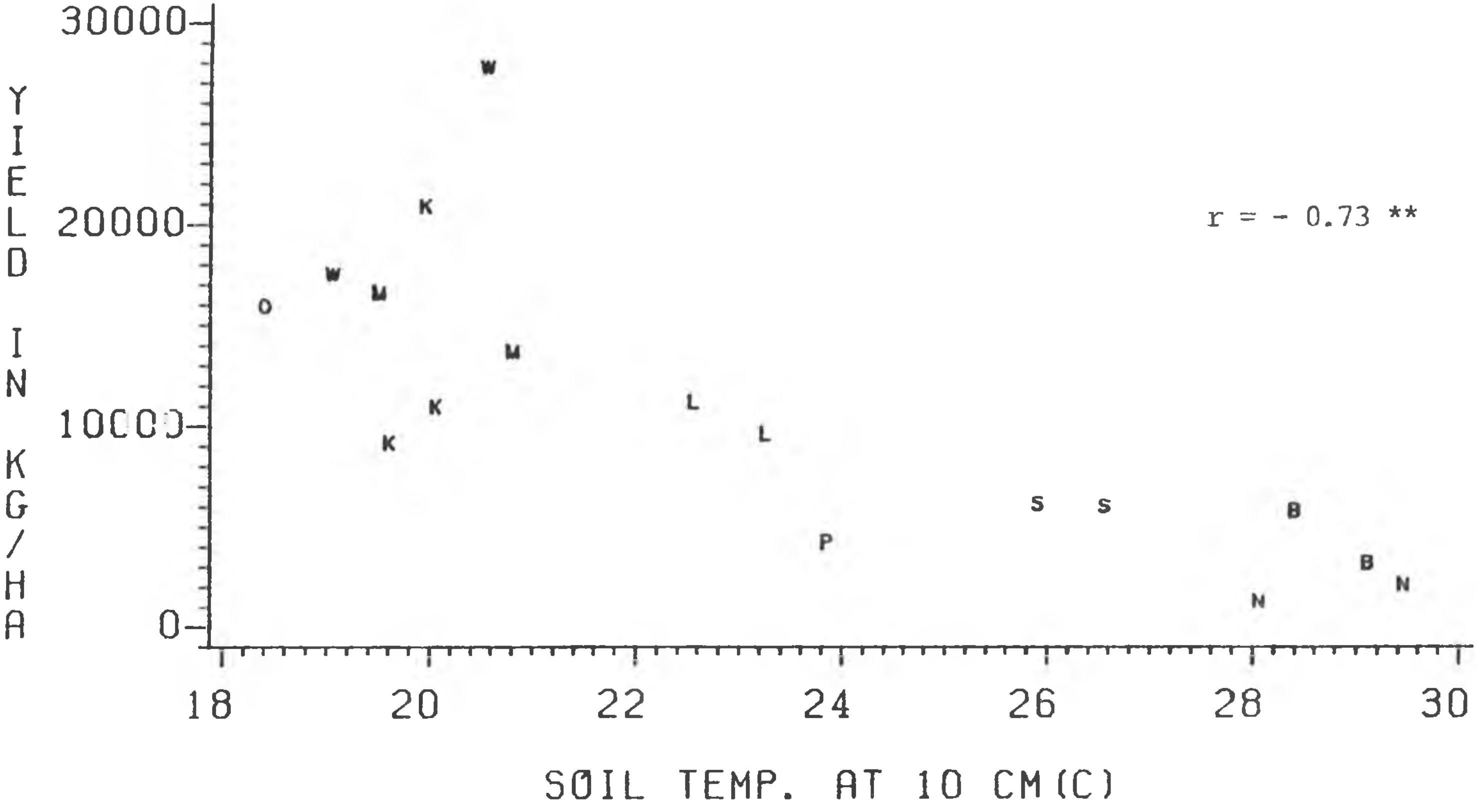


Figure 4.9 The relationship between average soil temperature and irrigated carrot yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) sites.

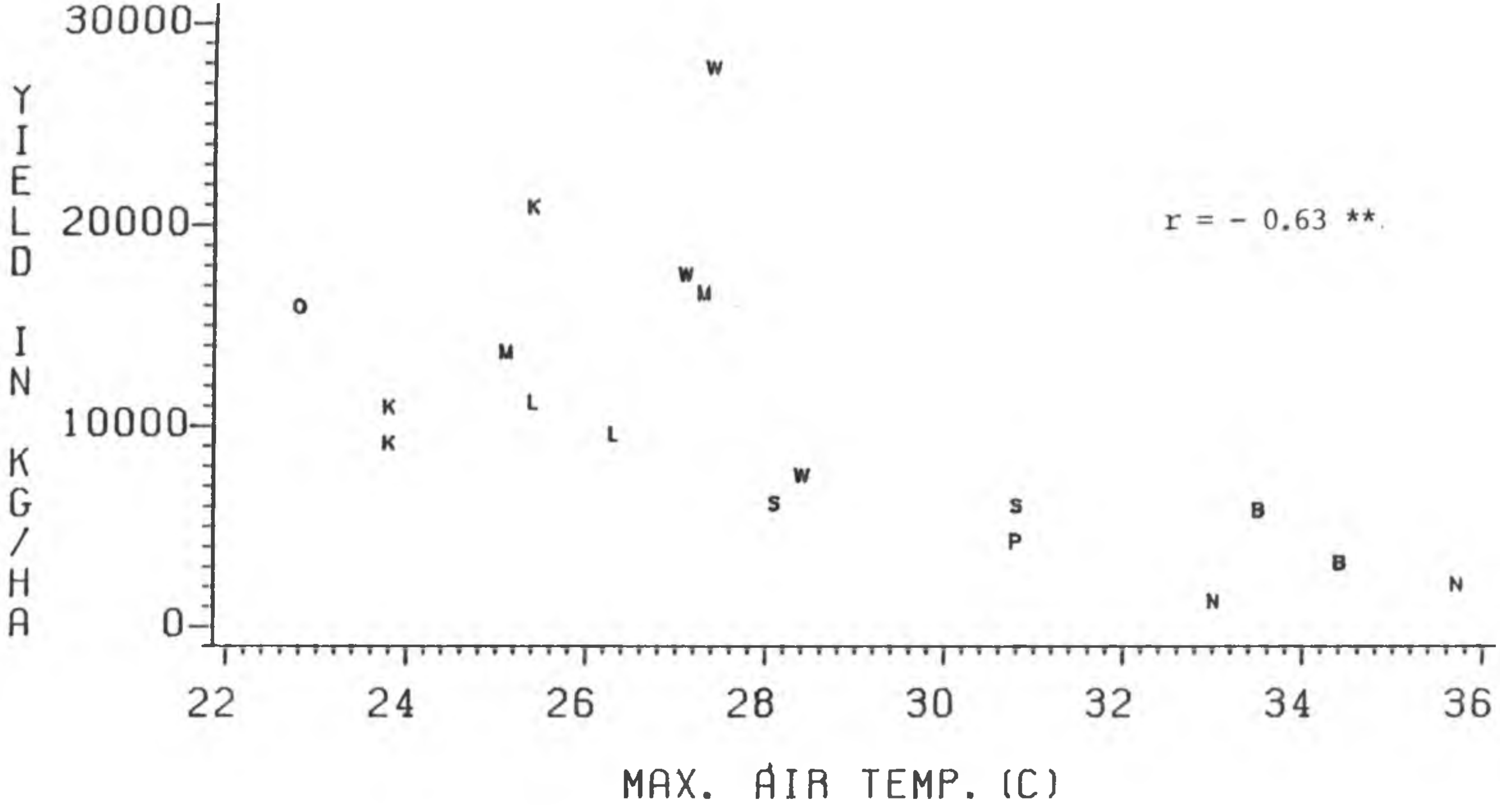


Figure 4.10. The relationship between maximum air temperature and irrigated carrot yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

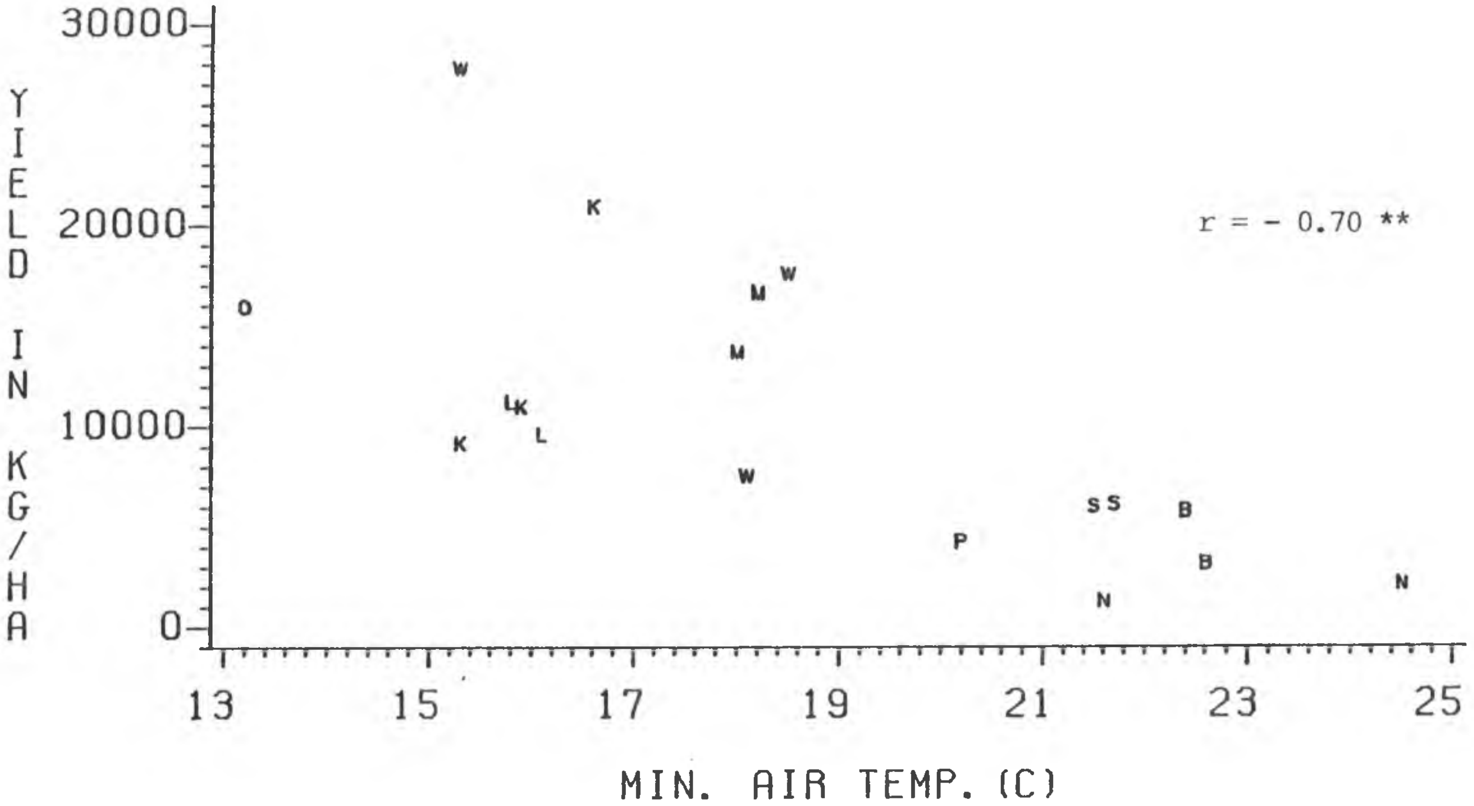


Figure 4.11. The relationship between minimum air temperature and carrot yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

throughout the year in Hydric Dystrandepts and during the rainy season in Tropeptic Eutrustox soils in Hawaii. Tropical experience, documented by Wilson (1977) has shown that 18 to 24^{o}C is the optimum range of average air temperature for growth and development of potatoes. The Tropeptic Eutrustox sites are classified as isohyperthermic, but during winter the temperatures are nearly isothermic in Hawaii and thus found suitable for potato production (Manrique, 1982).

The performance of Irish potato in the three soil families as depicted in Table 4.6, is in accordance with the expected results. The crop consistently failed in all Typic Paleudult sites (average soil and air temperature range of 24.7 to 30.2^{o}C) indicating the mismatch between the temperature requirements of Irish potato and the soil temperature regime of the soils. The results agree with another study where attempts to produce potatoes in an isohyperthermic Typic Paleudult in Peru were unsuccessful (Manrique, 1982).

The Hydric Dystrandept sites of LPH (Indonesia) amd PAL (The Philippines) also gave extremely low potato yields. Two factors appear to have caused the yield failure:

1) High rainfall during the crop period (786-2085 mm)

2) Higher soil and air temperatures compared to the Hydric Dystrandept sites in Hawaii.

The highest yield was obtained in the Eutrustox site of WAI during 1983, which is associated with high solar radiation, low temperature and very low rainfall, compared to other cropping periods (1981, 1982) at the same site. The yield potential in Eutrustox soils appears to

Table 4.6 Irish Potato yields and selected agroclimatic data for benchmark sites in the first cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1983	17852	608	380	364	18.7	18.1	22.8	13.2	18.0
	KUK	1981	13646	898	421	437	20.2	19.0	23.8	15.3	19.6
	KUK	1982	18113	1218	1683	311	19.9	19.0	23.6	15.5	19.6
	KUK	1983	23764	1946	562	389	20.4	19.5	25.4	16.6	21.0
	LPH	1981	2392	55	1237	231	22.8	21.9	25.0	15.9	20.4
	LPH	1982	4598	338	1123	376	23.9	22.6	26.3	16.1	21.2
	PAL	1981	0	0	2085	287	25.8	23.5	30.0	21.2	25.6
	PAL	1982	8718	55	786	322	25.1	22.7	31.1	20.2	25.6
Tropeptic Eutrustox	MOL	1982	13830	703	524	419	20.2	20.0	24.0	16.9	20.4
	MOL	1983	22166	1264	104	506	19.6	19.4	27.3	18.2	22.8
	WAI	1981	28532	518	212	384	19.3	19.0	28.3	18.1	23.2
	WAI	1982	16863	601	467	311	20.6	20.2	26.7	17.4	22.0
	WAI	1983	35280	777	91	699	20.7	20.4	27.4	15.3	21.4
Typic Paleudult	NAK	1981	0	0	716	405	28.7	27.4	33.0	21.6	27.3
	NAK	1982	0	0	1861	438	31.8	27.3	35.7	24.6	30.2
	BPI	1981	0	0	353	416	29.1	29.1	34.3	22.5	28.4
	BPI	1982	0	0	643	422	28.4	28.4	33.5	22.4	28.0
	SOR	1981	0	0	1498	334	26.3	25.2	27.7	21.7	24.7

be higher than on Dystrandept soils (KUK, IOLE). Besides the low rainfall, higher maximum air temperature is another factor that distinguishes Eutrustox soils from Dystrandept soils in Hawaii. It is interesting to note that high yields in Eutrustox sites (WAI 1981, 1983 and MOL 1983) were associated with slightly higher maximum air temperatures compared to the same recorded for the low yielding crop periods.

The relationship between mean soil temperature and potato yields is illustrated in Figure 4.12 ($r = -0.81^{**}$). Soil temperatures of 18 to 21°C are associated with top yields and 24 °C appears to be the limit beyond which the crop is most likely to fail. Crop yield shows a poor correlation coefficient ($r = -0.53^{**}$) with maximum air temperature (Figure 4.13) probably due to the influence of rainfall and the accompanying minimum air temperatures.

The sensitivity of the potato crop to excess moisture is apparent from Figures 4.15 and 4.16 for irrigated and non-irrigated crops respectively. The graphs show a curvilinear trend. The performance of the rainfed crop suggests that a rainfall range of 300 - 600 mm is adequate for a successful crop. Cropping periods with rainfall above 600 mm should be avoided for growing potatoes. In contrast to other cool season crops, Irish potato yields were found to be influenced significantly by the intensity of solar radiation. A correlation coefficient of 0.50^{*} was obtained between yields and solar radiation (Figure 4.14).

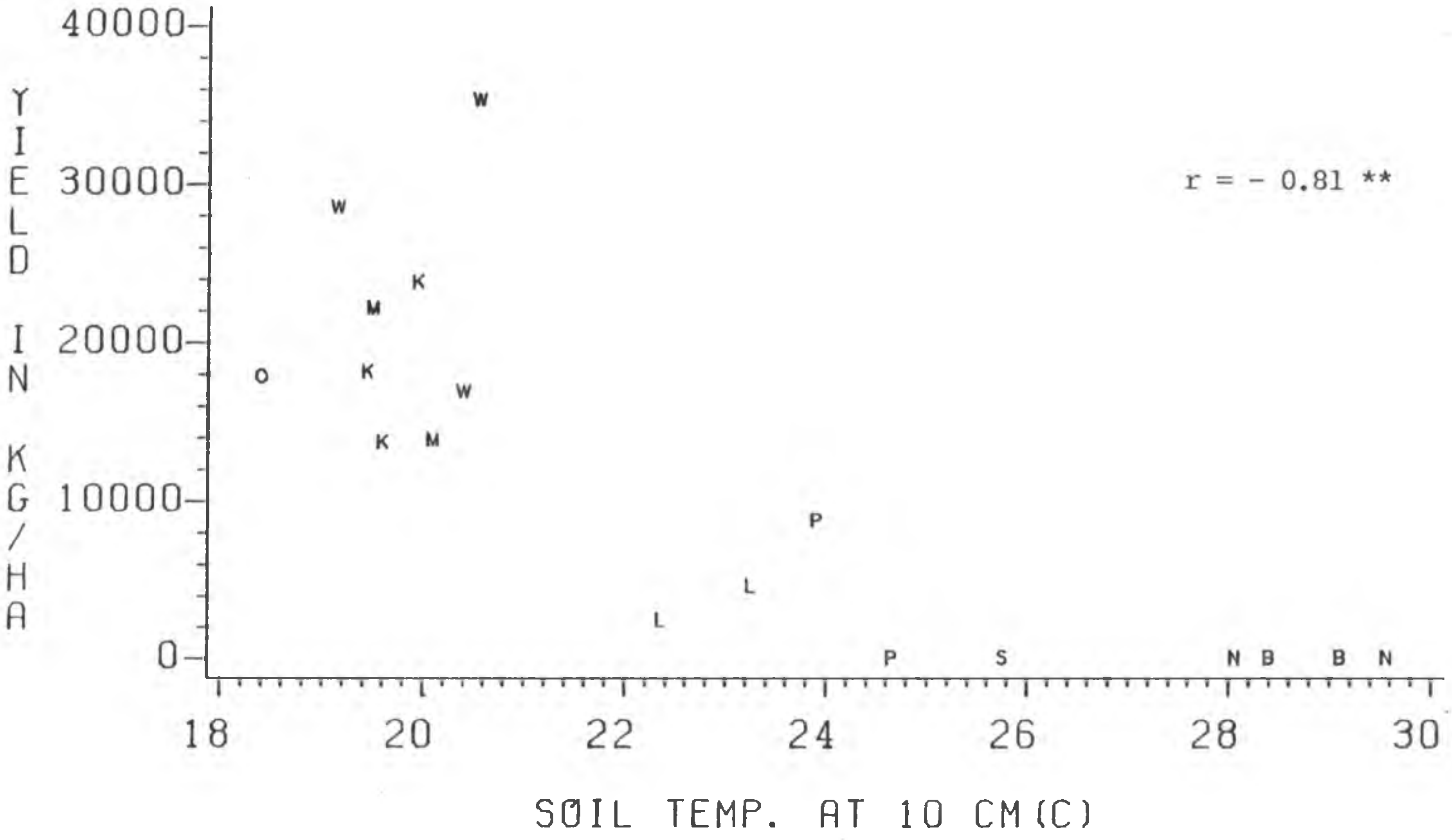


Figure 4.12 The relationship between average soil temperature and irrigated Irish Potato yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

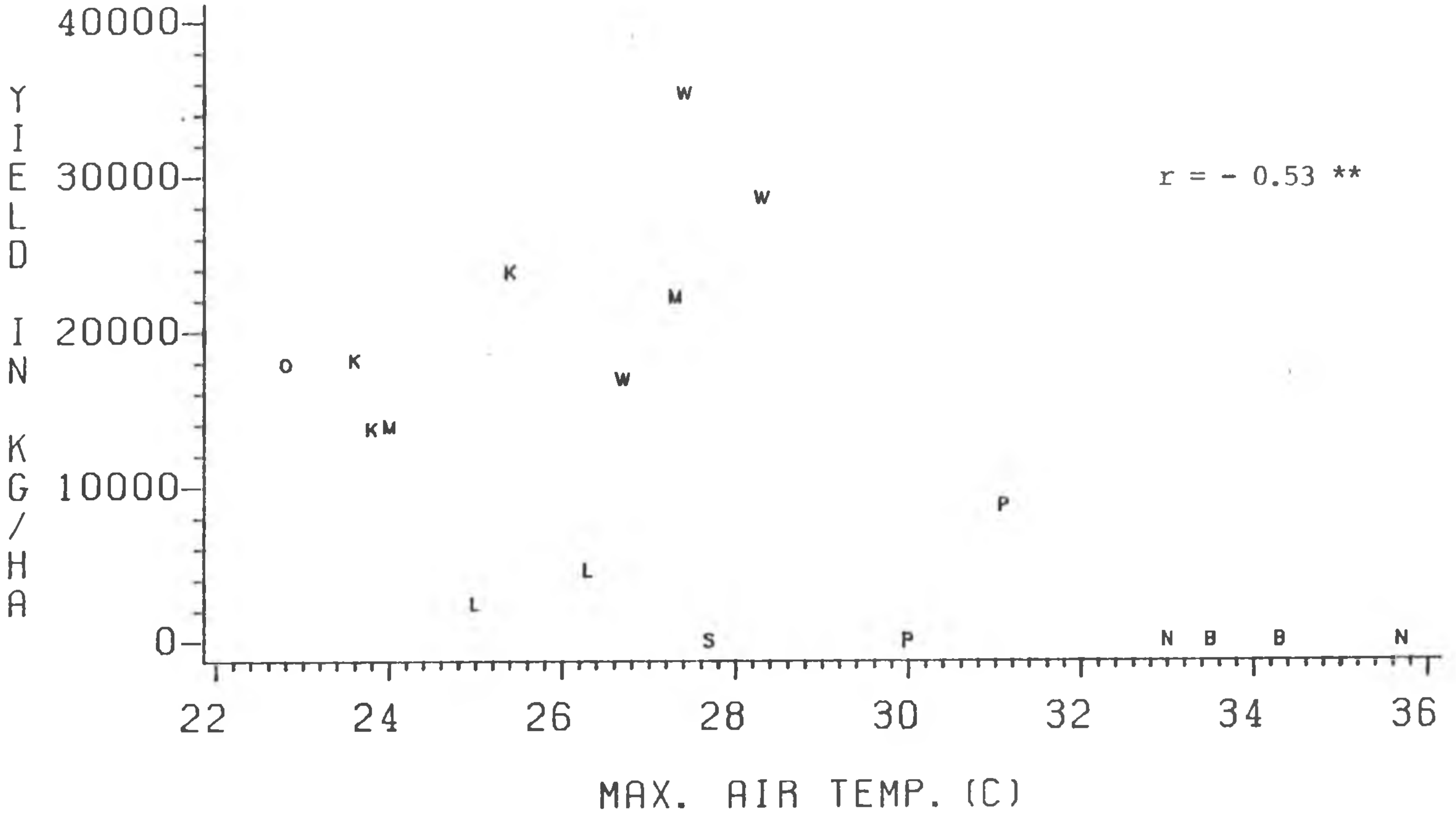


Figure 4.13. The relationship between maximum air temperature and irrigated Irish potato on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

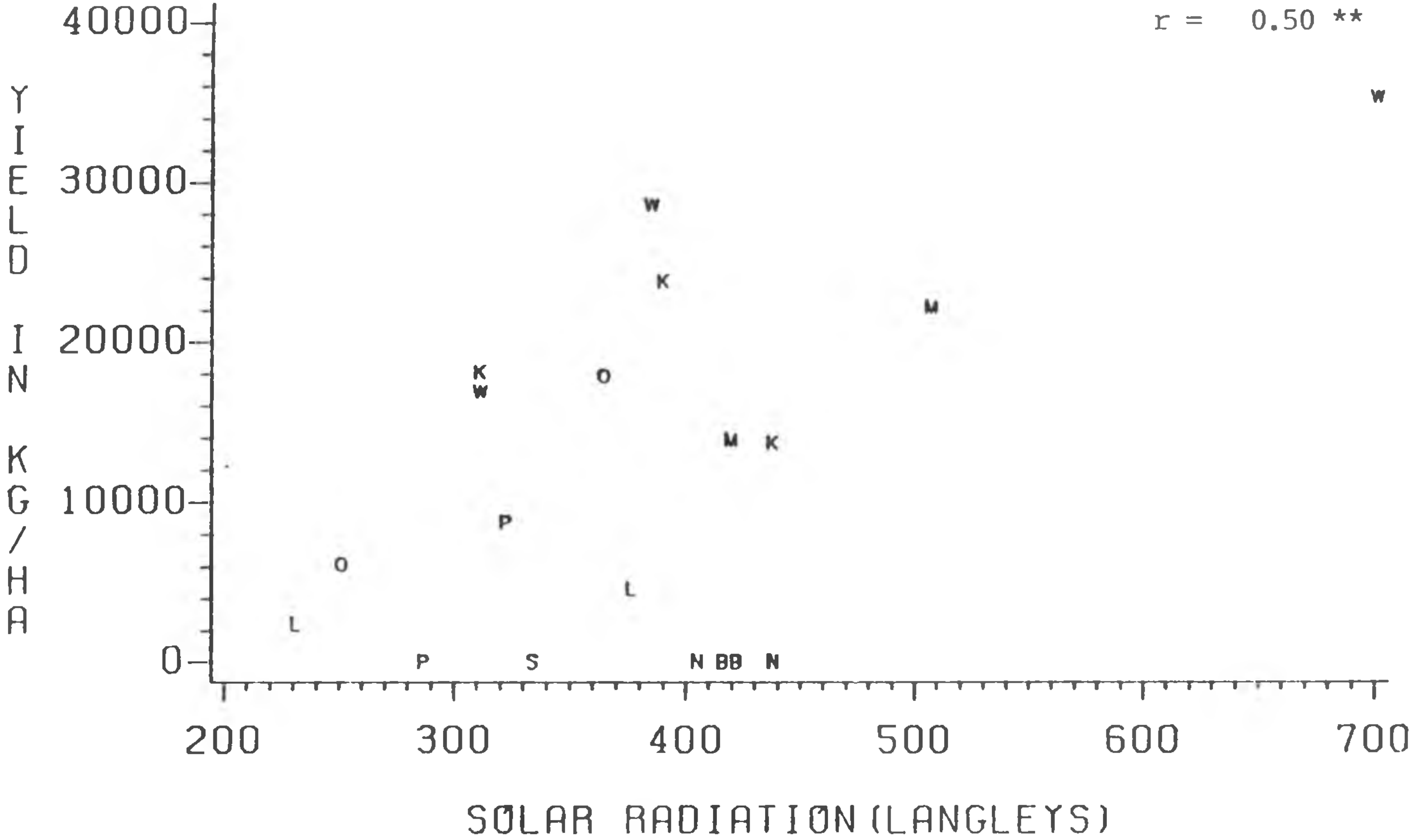


Figure 4.14. The relationship between solar radiation and irrigated Irish potato yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

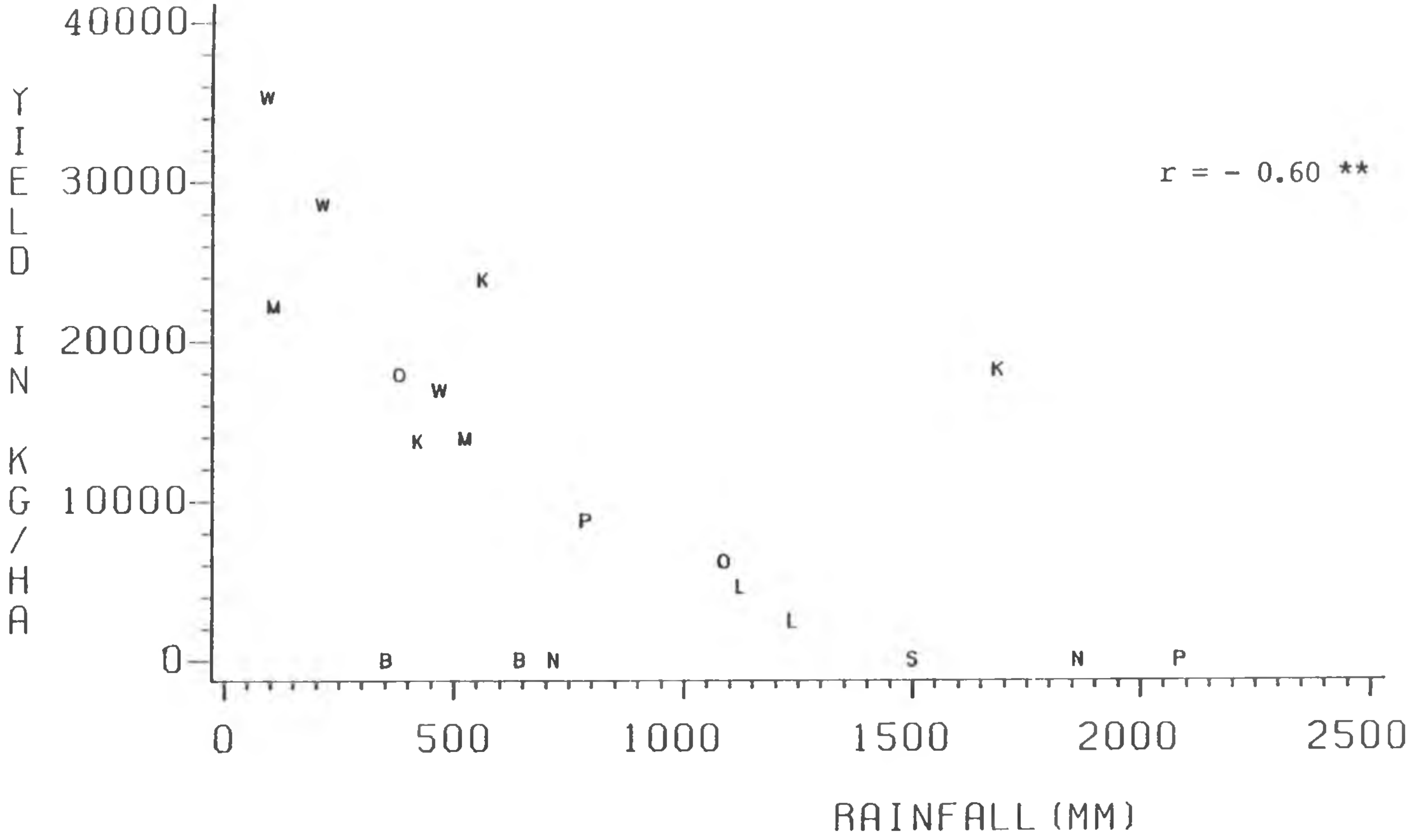


Figure 4.15. The relationship between rainfall and irrigated Irish potato yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

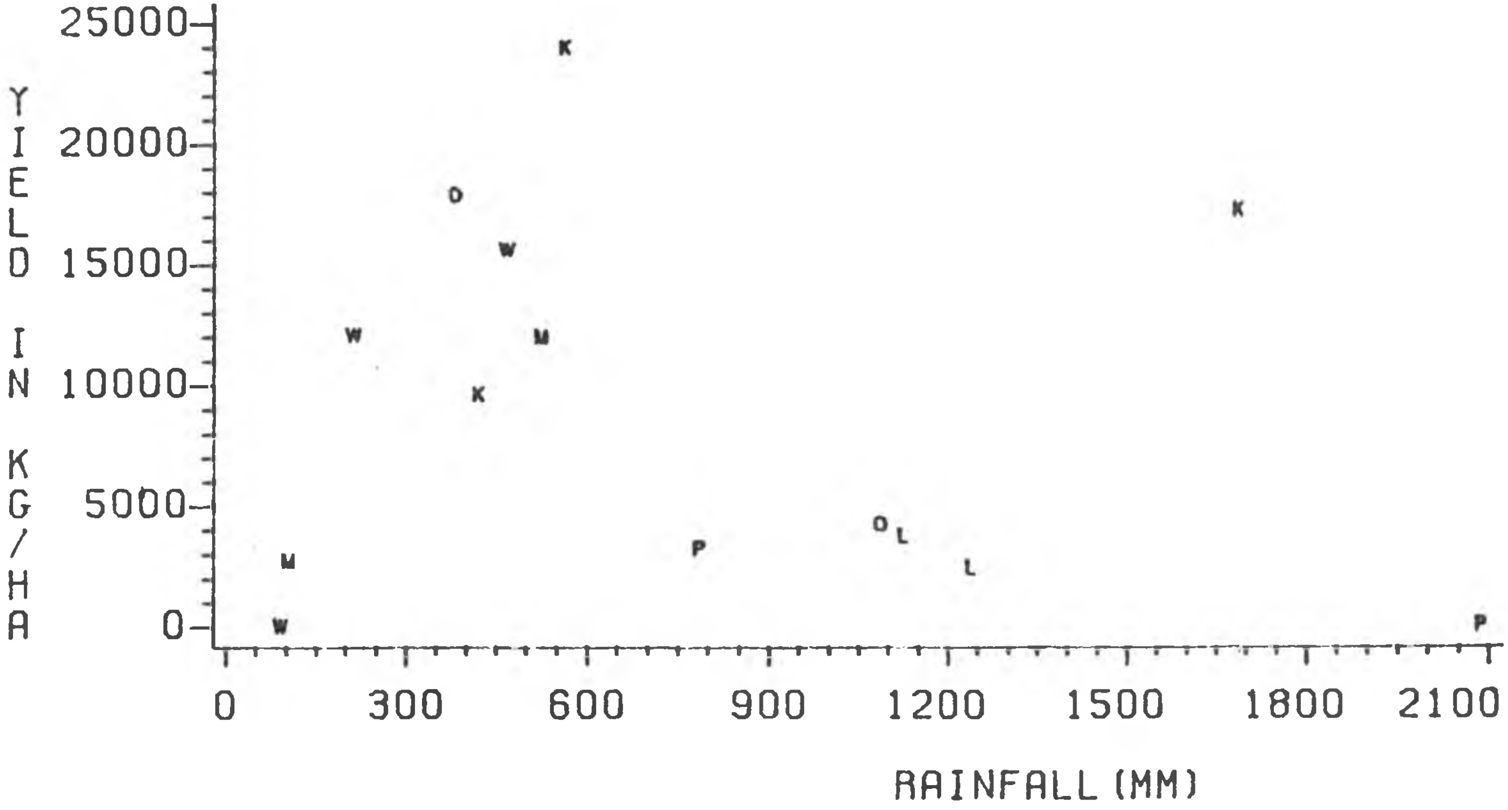


Figure 4.16. The relationship between non-irrigated Irish potato yields and total rainfall on benchmark sites of Dystrandept (O,K,P,L) and Eutrustox (M,W) soils.

4.2.5 Performance of bushbean

Bushbean (Phaseolus vulgaris L.) is the best known and most widely cultivated of all Phaseolus species. According to Rachie and Roberts (1974) it is seldom grown in the low land tropics, but is extensively cultivated at intermediate and higher altitudes. Unlike soybean it prefers a cooler climate. Bushbean yields obtained in the present study are depicted in Tables 4.7 and 4.8, for the first and second cropping seasons, respectively. The data show that the performance of bushbean was very poor in Typic Paleudults during the first (rainy) as well as second season. The poor yields are associated with high soil and air temperatures encountered in these soils. The Paleudult sites in The Philippines (SOR, BPI) during the second season, were conspicuous by the incidence of beanfly attack on the plants. This pest was not noticed on sites in Indonesia. First season crops in SOR (1981) and NAK (1982) also suffered due to heavy rainfalls.

The Dystrandept and Eutrustox soils having considerably lower soil and air temperatures compared to Paleudults, gave higher yields. Evidently, Tropeptic Eutrustox soils have the highest yield potential for bushbean as depicted by the yield levels in WAI. Low precipitation during the first (1981, 1983) and second (1981, 1982) season in WAI was presumably conducive to better crop performance. The first season crop in PAL was completely destroyed by typhoon winds and high rainfall. During the second season of 1982 unusually high soil and air temperatures were recorded in PAL, which probably led to poor yields. The poor yield performance on LPH and PAL sites as

Table 4.7 Bush bean yields and selected agroclimatic data for benchmark sites in the first cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982-83	5178	409	329	385	19.8	18.7	22.5	13.9	18.2
	KUK	1982	3617	146	743	295	20.0	19.1	23.7	15.5	19.6
	KUK	1983	2722	390	412	397	21.0	20.2	24.9	16.8	20.8
	LPH	1982-83	1547	331	1123	376	23.9	22.6	26.3	16.1	21.2
	PAL	1981-82	0	0	2085	287	25.8	23.5	30.0	21.2	25.6
Tropeptic Eutrustox	MOL	1982	2207	70	376	459	20.1	19.9	23.6	17.0	20.3
	WAI	1981	6060	223	137	346	19.1	18.7	28.1	18.4	23.2
	WAI	1982	3577	165	369	282	19.6	18.9	26.9	18.2	22.6
	WAI	1983	6323	458	56	740	21.0	20.7	28.0	15.4	21.7
Typic Paleudult	NAK	1982	637	114	1028	436	31.5	27.3	34.7	24.6	29.7
	BPI	1981	519	171	353	416	29.1	29.1	34.3	22.5	28.4
	BPI	1982	1637	197	217	439	26.4	26.4	30.6	21.7	26.2
	SOR	1981	0	0	1793	333	26.9	25.7	29.0	22.0	25.5
	SOR	1982	1204	367	369	324	27.0	25.7	30.4	21.6	26.0

Table 4.8 Bush bean yields and selected agroclimatic data for benchmark sites in the second cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1981	5313	521	101	371	21.3	20.4	25.4	17.4	21.4
	IOLE	1982	3305	248	380	386	20.0	19.2	25.3	17.2	21.2
	KUK	1981	4161	242	24	538	23.4	21.8	25.2	17.0	21.1
	KUK	1981	2883	107	544	399	21.8	20.5	23.9	16.3	20.1
	LPH	1981	1305	95	676	356	25.3	23.7	29.7	18.5	24.1
	LPH	1982	2842	103	490	312	23.6	22.2	26.9	14.7	20.8
	PAL	1981	2881	186	297	355	27.6	22.7	33.4	20.6	27.0
	PAL	1982	500	54	19	432	31.3	24.4	35.3	19.7	27.5
Tropeptic Eutrustox	MOL	1981	2597	438	65	621	22.0	21.7	28.5	19.0	23.8
	MOL	1982	3507	105	84	575	22.0	21.4	29.7	21.9	25.8
	WAI	1981	7553	975	44	496	20.8	19.8	30.6	20.6	25.6
	WAI	1982	6637	727	43	498	22.3	21.4	30.7	18.6	24.6
Typic Paleudult	NAK	1981	794	44	411	432	29.4	28.9	36.8	23.0	29.9
	BPI	1981	439	50	524	407	26.2	26.2	33.8	22.0	27.9
	BPI	1982	1027	38	444	405	26.0	26.0	33.6	21.4	27.5
	SOR	1982	3631	290	404	382	26.2	24.6	28.8	19.9	24.4

compared to Dystrandept sites in Hawaii, may also be attributed to their higher soil and air temperatures.

The apparent susceptibility of bushbean to high soil and air temperature is illustrated in Figures 4.17, 4.18, and 4.19. The yields of bushbean were highly correlated negatively ($r = -0.74^{**}$) with mean soil temperature (Figure 4.17) over all sites. However maximum air temperature showed a significant relationship ($r = -0.67^{**}$) with yield only within the Dystrandept sites (Figure 4.18). The lack of relationship between maximum air temperature and yields over all sites is because of the high air temperatures of the Eutrustox sites compared to the Dystrandept sites in Hawaii. The low soil temperatures may have neutralized the detrimental effect of high air temperatures on Eutrustox sites. This, again, suggests that soil temperature is a more stable indicator of crop performance. However, most of the climatic requirements of crops in the literature are interpreted based on air temperature without reference to soil temperature. It is therefore suggested that soil temperature requirement of the crops should be studied in more detail. In this study, the highest yields were obtained in a soil temperature range of 18 to 22°C. Soil temperatures beyond 24°C contributed to crop failure.

Performance within Hydric Dystrandept sites suggests that a maximum air temperature range of 22 to 25°C can result in good bushbean yields. Maximum air temperature beyond 30°C may not be suited to the crop. This is contrary to Ohlander's work in Ethiopia (Ohlander. 1980) which indicated that the optimum range of maximum air

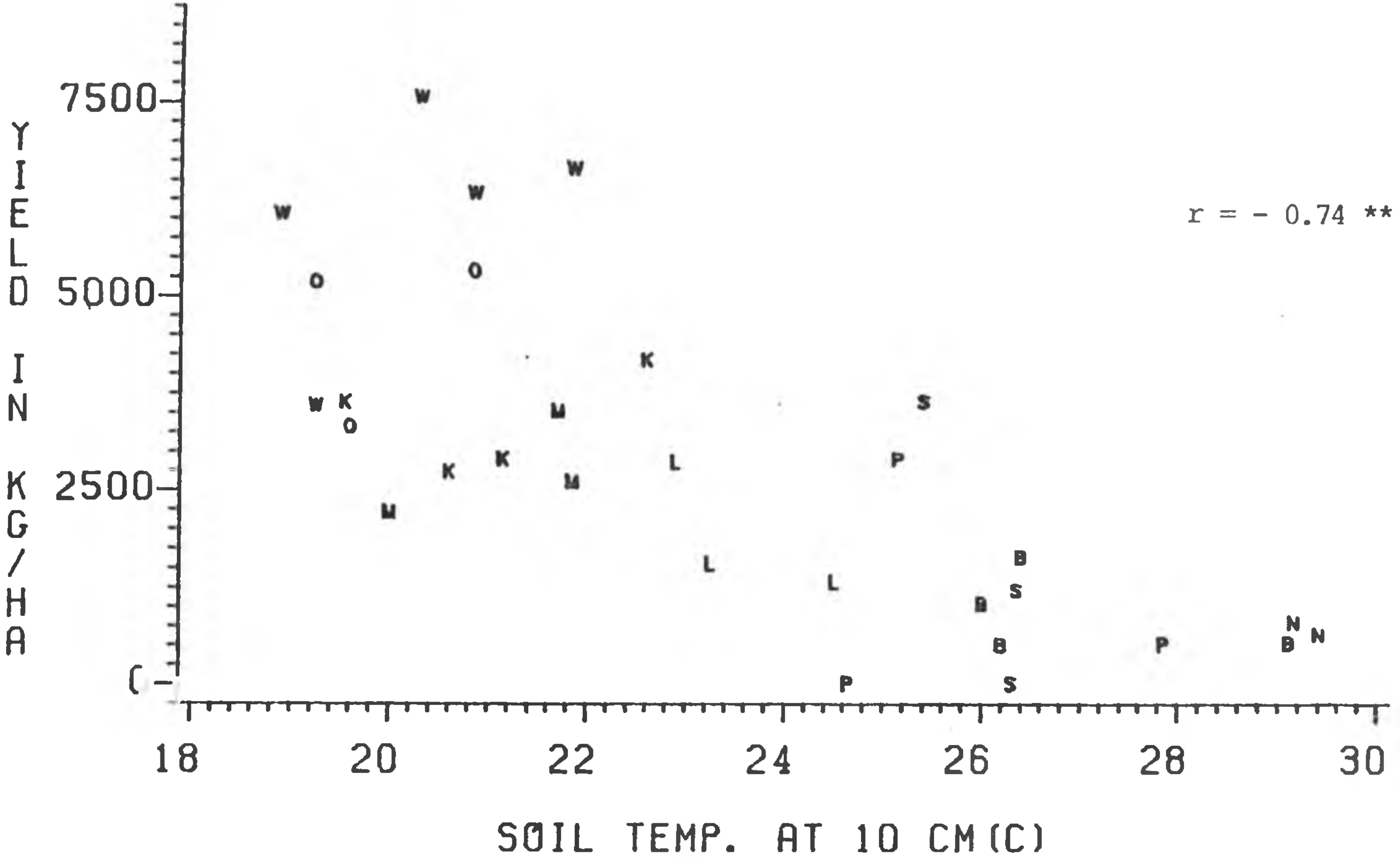


Figure 4.17 The relationship between average soil temperature and irrigated bushbean yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

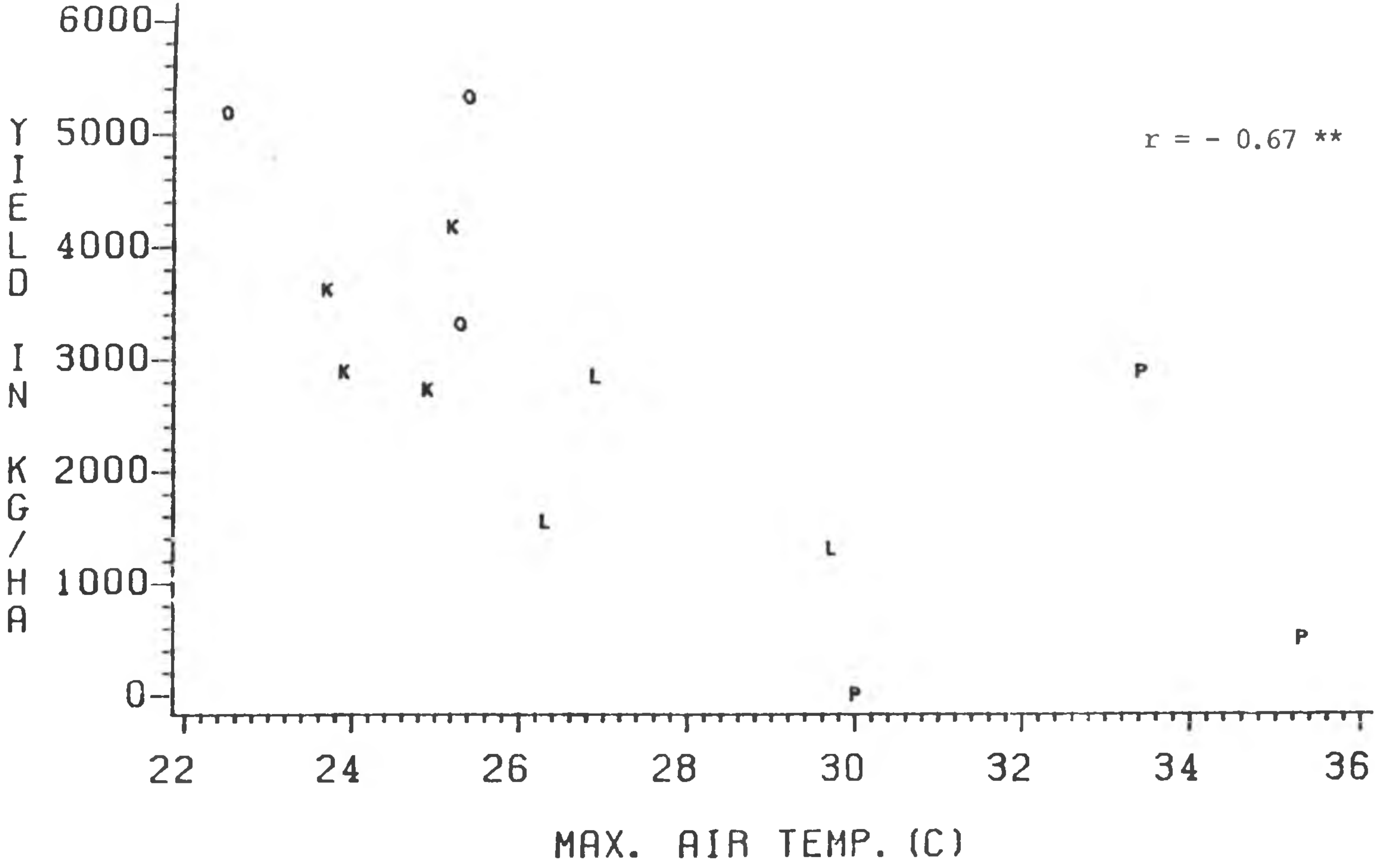


Figure 4.18. The relationship between maximum air temperature and irrigated bushbean yield on benchmark sites of Dystrandept soils.

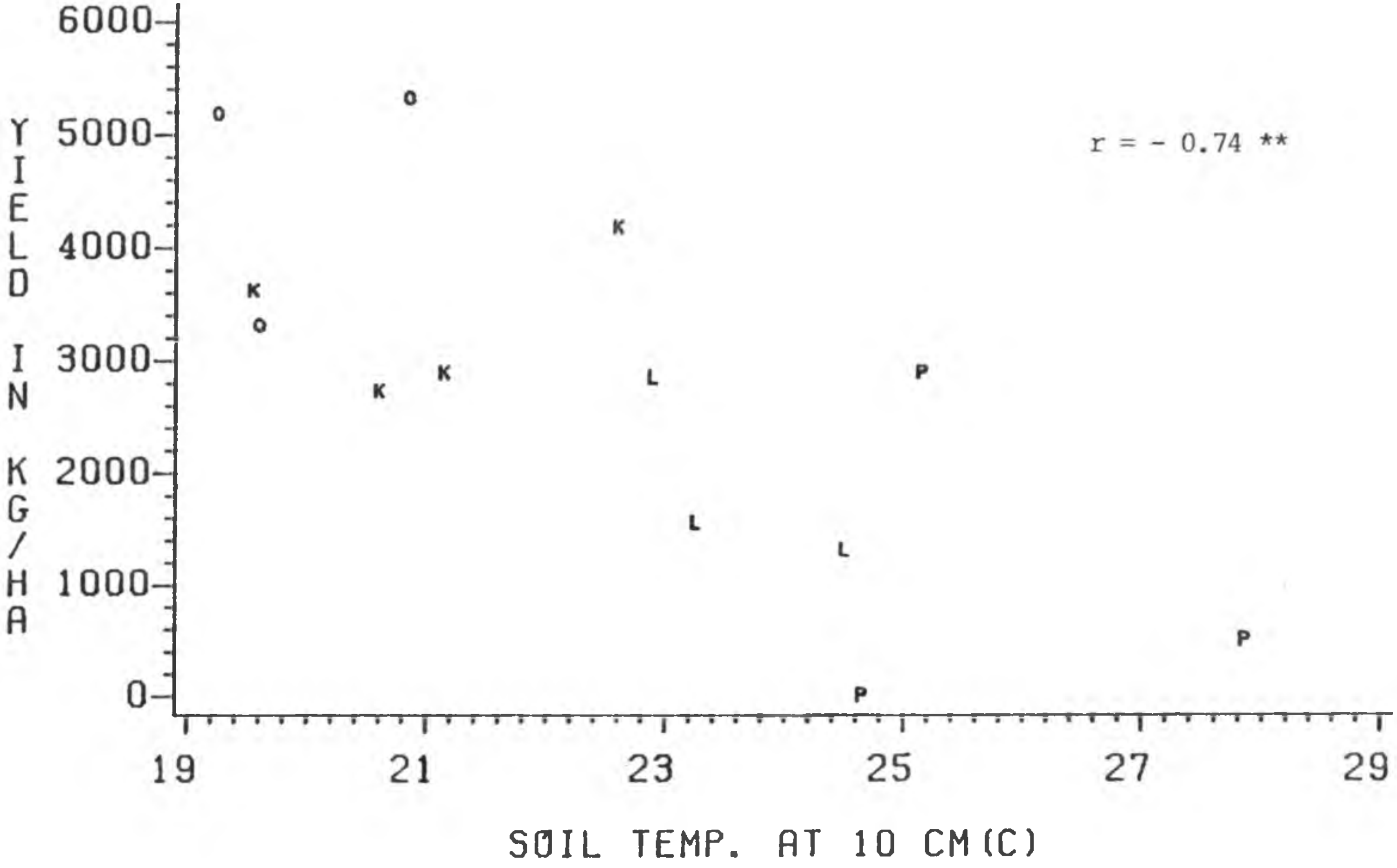


Figure 4.19 The relationship between average soil temperature and irrigated bushbean yield on benchmark sites of Dystrandept soils.

temperatures for bushbean was 30 to 32°C. Very low minimum air temperatures (10-12°C) prevailing in Ethiopia probably reverse the detrimental effects of high maximum air temperature. The effect of cultivar adaptability on temperature tolerance may also be responsible for this differential behavior. The present results are also not in agreement with those obtained by Rauseo (1974) in Puerto Rico, showing a positive correlation between bushbean yields and average air temperatures.

The decline in bushbean yields is also associated with increases in rainfall as shown in Figures 4.20 (for all sites) and 4.21 for Hydric Dystrandept sites. The yield versus rainfall relationship is better within Hydric Dystrandepts ($r = -0.80^{**}$) because of the reduction in variability, on exclusion of other soil families. Rainfall below 400 mm during the crop period was found to favor good yields of irrigated crops. With rainfall in excess of 800 mm the chances of successful bushbean cultivation were found to be low. Guazelli (1978) also observed that a precipitation level of 200-300 mm is sufficient for bushbean cultivation.

The plot of bushbean yields versus solar radiation (Figure 4.22) showed a poor ($r = 0.35^{*}$) but significant positive trend.

4.2.6 Performance of green corn

Green corn yields and related agroclimatic data for the crop period are presented in Table 4.9. As is apparent from the yield data, green corn performance is not significantly affected by any single agroclimatic variable. Corn is a warm weather crop,

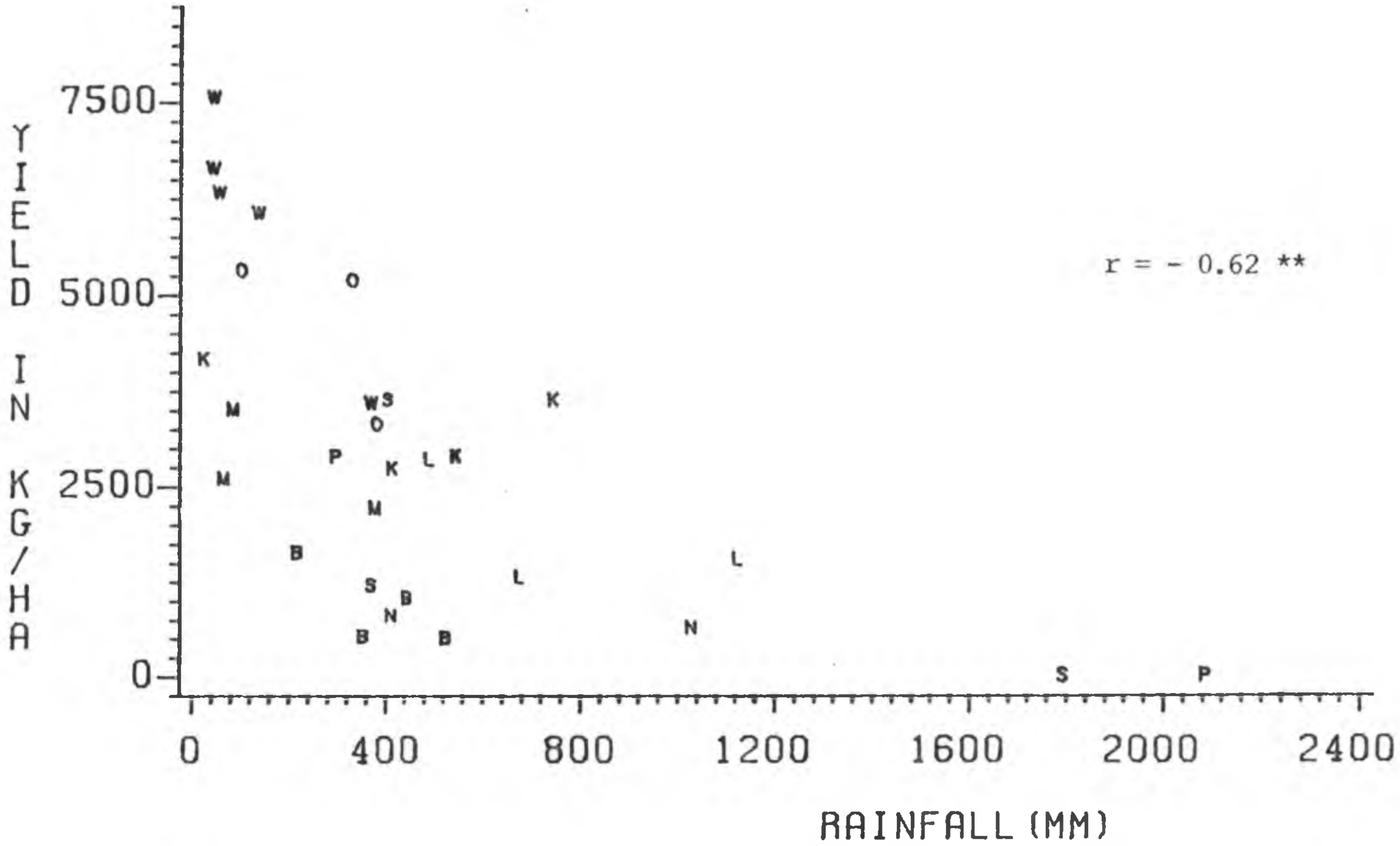


Figure 4.20. The relationship between irrigated bushbean yields and rainfall on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

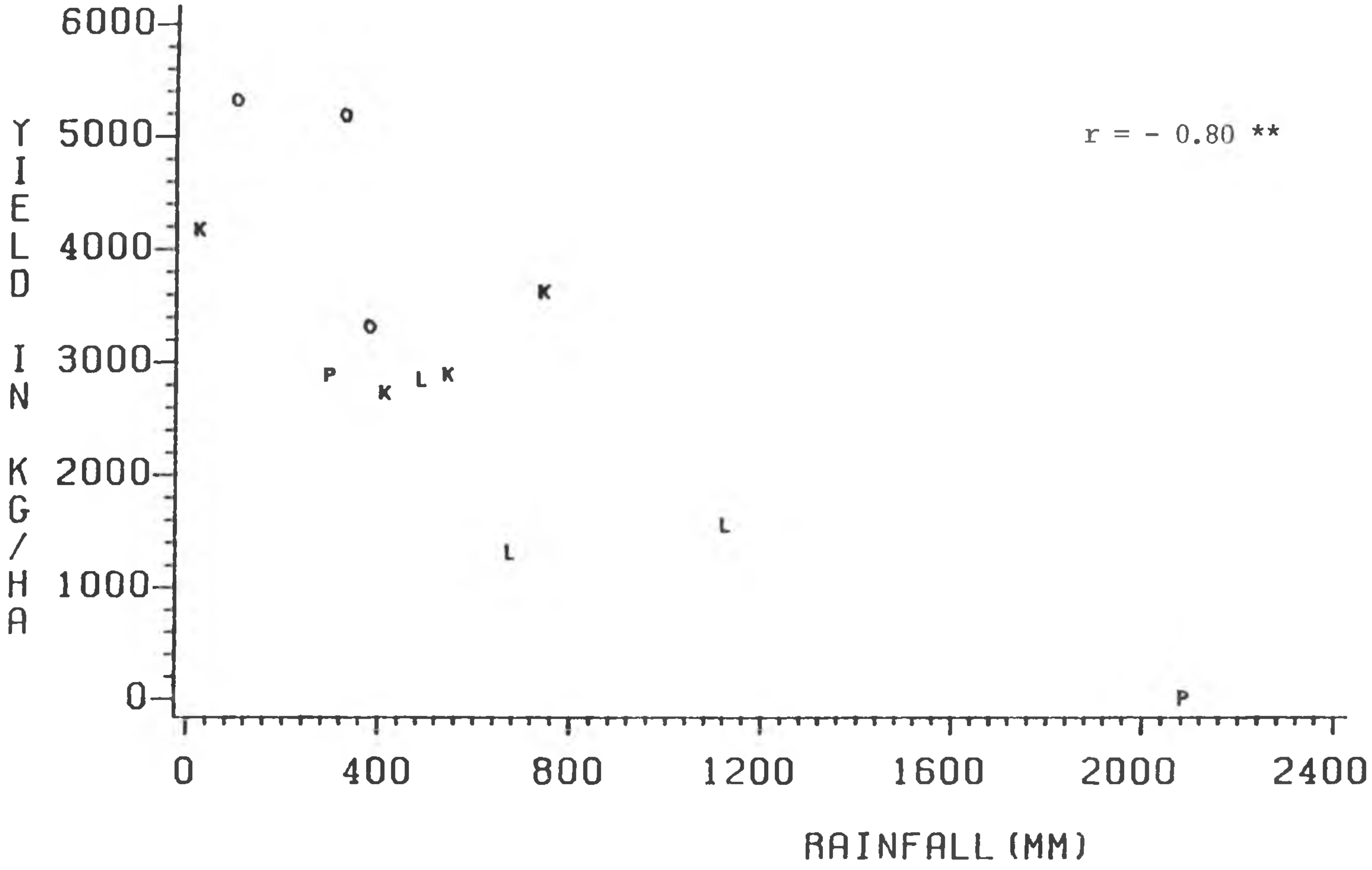


Figure 4.21. The relationship between rainfall and irrigated bushbean yield on benchmark sites of Dystrandept soils.

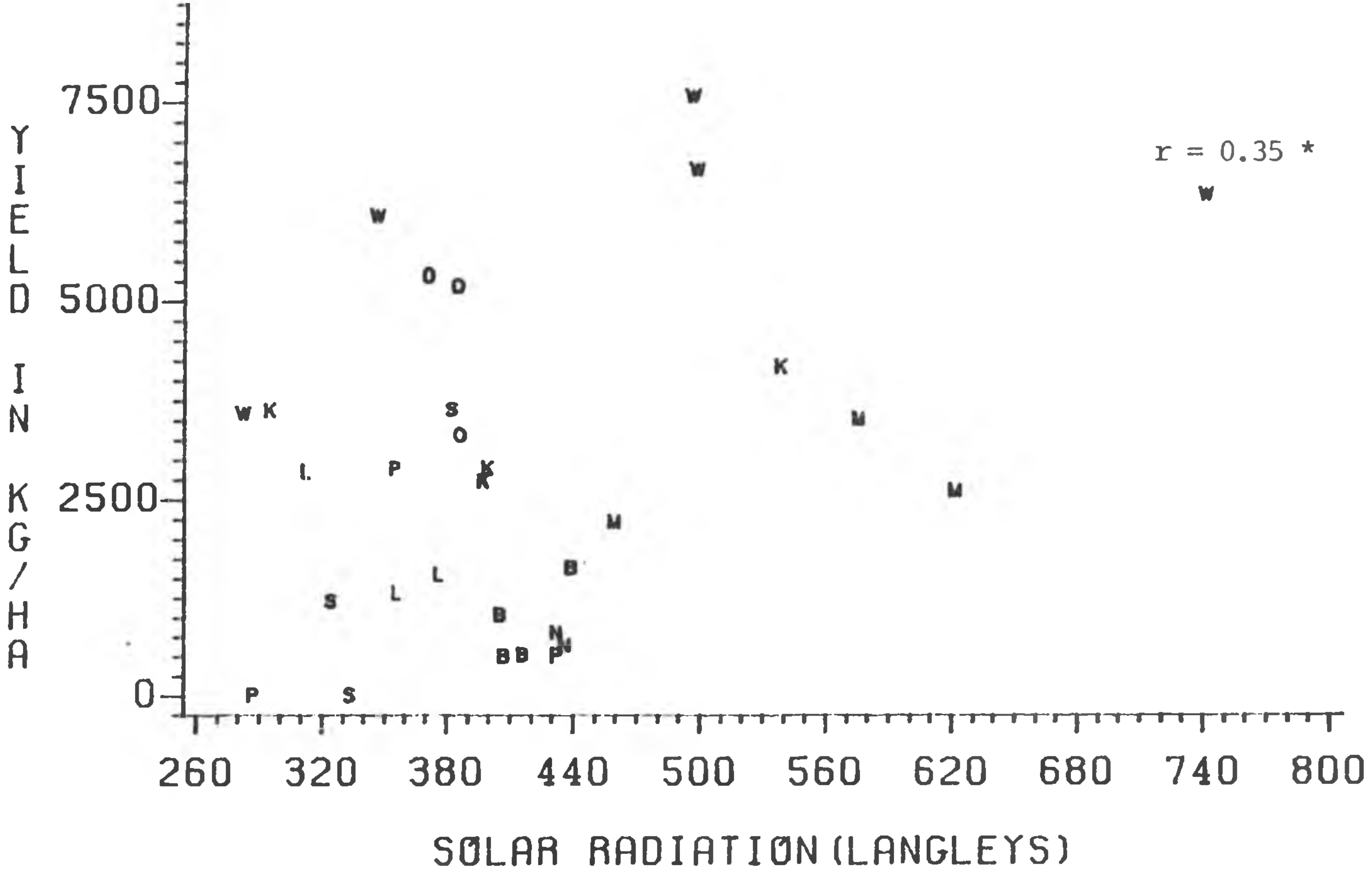


Figure 4.22. The relationship between solar radiation and irrigated bushbean yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult soils.

Table 4.9 Green corn yields and selected agroclimatic data for benchmark sites in the second cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1981	17700	1002	317	402	22.0	20.9	26.0	17.8	21.9
	IOLE	1982	7582	132	466	346	21.1	20.4	25.6	17.6	21.6
	KUK	1981	12753	457	211	514	23.7	22.2	25.1	17.4	21.2
	KUK	1982	10677	519	534	414	23.2	21.8	24.8	17.3	21.0
	ITK	1981	5579	539	315	310	23.1	23.1	26.4	15.5	21.0
	LPH	1981	5668	833	1323	325	24.8	23.2	28.6	17.5	23.0
	LPH	1982	4749	141	595	320	23.4	21.8	26.8	14.3	20.6
	PAL	1982	9625	112	643	369	27.9	23.2	34.1	21.3	27.7
	PAL	1983	9500	421	16	427	32.2	24.7	35.9	20.4	28.2
Tropeptic Eutrustox	MOL	1981	8083	777	140	560	23.2	22.7	29.1	20.2	24.6
	MOL	1982	5893	1223	149	589	22.2	21.9	30.2	22.3	26.2
	WAI	1981	12283	1634	40	493	21.6	20.4	31.2	21.3	26.2
	WAI	1982	9757	1158	82	---	23.6	22.7	31.4	19.6	25.5
Typic Paleudult	NAK	1981	5158	566	655	410	28.9	28.6	36.3	23.3	29.8
	NAK	1982	4958	188	759	374	31.0	27.5	35.4	21.2	28.3
	BPI	1981	6988	153	415	390	25.2	25.2	32.5	21.9	27.2
	BPI	1982	4514	194	238	393	25.9	25.9	33.4	21.5	27.4
	SOR	1982	9758	570	530	405	27.6	25.6	31.1	20.4	25.8

accordingly the final yield of corn grain as well as the growth of corn early in the season has been shown to increase linearly with soil temperature (Arnon, 1972). However, the results in this study suggest that the fresh weight of green ears is not limited by low temperatures (within the tropical range) if the solar radiation is adequate.

The highest yields were obtained in IOLE and KUK sites of Hydric Dystrandept soils which had the lowest soil and air temperatures. Low solar radiation could have been one of the factors contributing to low yields in Hydric Dystrandept sites of ITKA and LPH. The reason for low yields in IOLE during 1982 is not clear. However, it is interesting to note that (please refer Appendix 1) on each site, higher yields are associated with greater recorded wind velocities. The regression equation relating yield of green corn to agroclimatic variables also indicated that inclusion of wind velocity and an interaction term "wind velocity * solar radiation" as parameters in the equation, was imperative for obtaining a high regression coefficient. The latter is discussed further under the section on multiple regression models.

The Tropeptic Eutrustox soil has a great potential for green corn production as indicated by the crop performance on the WAI site during 1981. The soil temperature recorded on this site during the crop period was also the lowest within the Eutrustox experiments.

The low yields recorded in Typic Paleudult sites of NAK and BPI were presumably due to the average soil and air temperatures above 28^{O}C, accompanied by high precipitation during the crop seasons. The better performance of green corn despite high rainfall and temperature

(PAL, 1982) could be partly a reflection of the good physical structure of Dystrandept soils, that prevents the detrimental effects of excess rainfall on corn growth.

In general the present results demonstrate the difficulty of interpreting the performance of widely adapted crops on the basis of individual agroclimatic variables. The data also suggest that the beneficial and detrimental effects of high and low temperatures, respectively are not appreciably apparent when corn is harvested for green ears.

The positive trend of green corn yield at higher solar radiation is depicted in Figure 4.23.

4.2.7 Performance of soybean

Soybean yield data and the corresponding agroclimatic parameters are presented in Tables 4.10 and 4.11. Table 4.10 pertains to crop performance during the second cropping season (TE pattern) or the season immediately following the rainy season. Similarly Table 4.11 shows the yield data obtained during the third cropping season (HD pattern) or the season previous to the onset of rains. The highest yields were obtained in Hydric Dystrandept and Tropeptic Eutrustox soils during the second cropping season, which also demonstrate the good fit of this environment for soybean production.

The soil temperatures of Dystrandept sites in Hawaii (KUK, IOLE) and those of Tropeptic Eutrustox sites were similar, but air temperatures of Eutrustox sites were higher by about 3°C. Except for the possible detrimental effect of very low temperature (average air

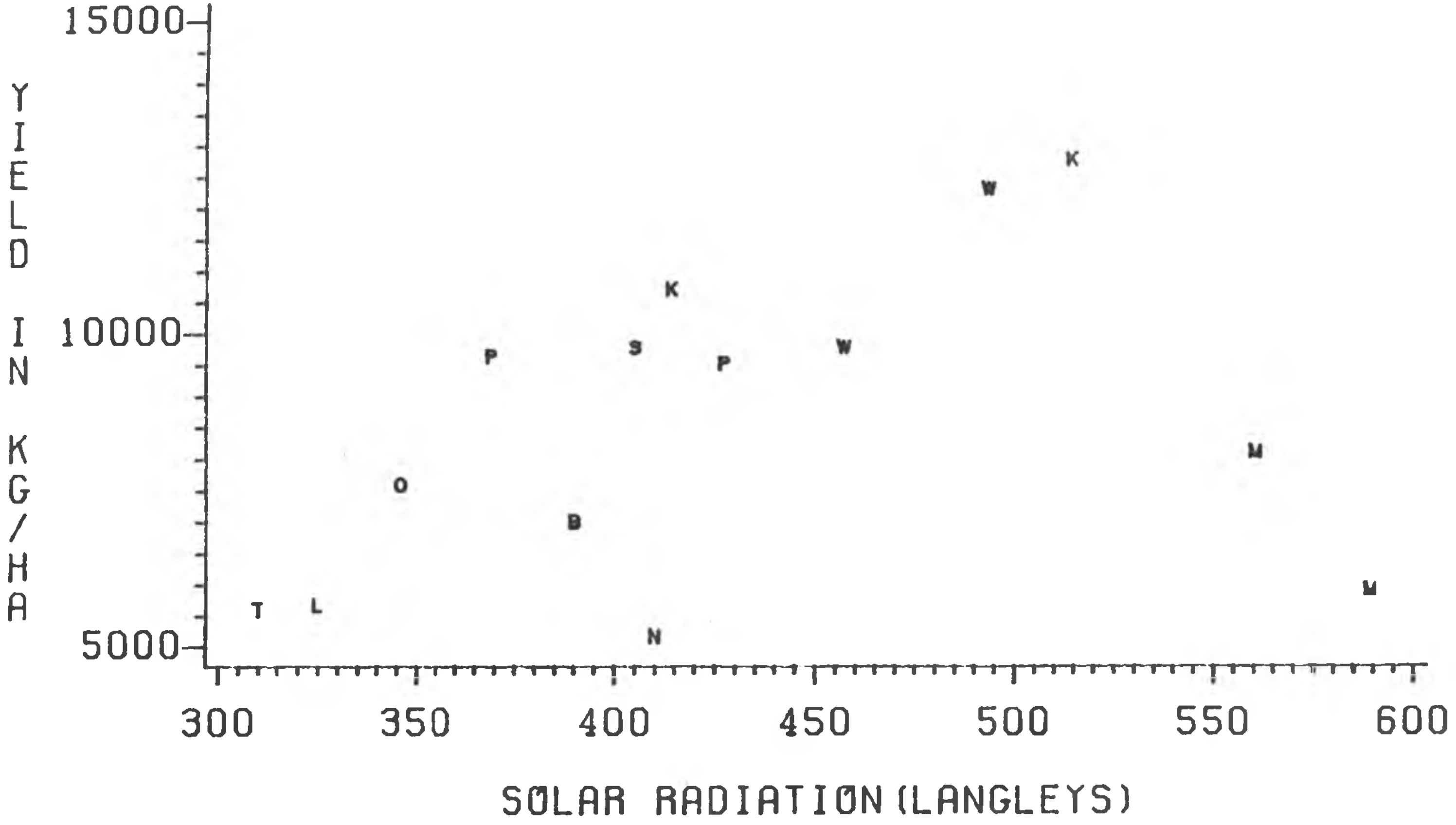


Figure 4.23. The relationship between solar radiation and irrigated green corn yield on benchmark sites of Dystrandept (O,T,K,L,P), Eutrustox (M,W) and Paleudult (B,S,N) soils.

Table 4.10 Soybean yields and selected agroclimatic data for benchmark sites in the second cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm) Max	Min	Daily avg. air temp. (°C) Max	Min	Mean
Hydric Dystrandept	IOLE	1981	3837	231	370	408	21.6	20.9	25.8	17.7	21.8
	IOLE	1982	2386	132	937	385	21.1	20.4	25.1	17.2	21.2
	KUK	1981	3299	87	247	502	23.8	22.4	25.2	17.6	21.4
	KUK	1982	2671	213	1174	404	23.0	21.6	24.9	17.6	21.2
	LPH	1981	438	42	1125	333	25.1	23.3	29.1	17.8	23.4
	LPH	1982	1683	153	344	385	23.3	21.5	26.8	13.8	20.3
	PAL	1982	2607	76	19	425	31.5	24.4	35.4	20.5	28.0
Tropeptic Eutrustox	MOL	1981	2669	98	144	571	22.8	22.4	29.0	19.7	24.4
	MOL	1982	2246	204	171	567	22.1	21.7	30.0	22.2	26.1
	WAI	1981	3538	224	91	488	21.2	20.0	30.8	20.7	5.8
	WAI	1982	3953	333	360	525	23.4	22.8	30.7	20.0	25.4
Typic Paleudult	NAK	1981	1292	25	684	413	29.0	28.7	35.9	23.3	29.6
	NAK	1982	1100	124	848	374	30.6	27.5	35.4	21.2	28.3
	BPI	1983	836	13	444	405	26.0	26.0	33.6	21.4	27.5
	SOR	1982	1867	35	404	394	26.7	24.9	29.7	19.9	24.8

Table 4.11 Soybean yields and selected agroclimatic data for benchmark sites in the third cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982	1094	72	602	287	19.1	19.0	21.7	13.1	17.4
	KUK	1981	1541	52	717	347	22.4	21.5	24.6	18.4	21.5
	KUK	1982	1504	16	701	346	22.2	20.9	26.2	18.9	22.6
	LPH	1981	1037	76	659	326	25.0	23.3	26.9	16.2	21.6
	LPH	1982	2024	10	850	486	24.2	22.4	27.2	15.2	21.2
	PAL	1981	2527	60	1146	333	30.0	25.1	32.3	23.0	27.6
	PAL	1982	1496	21	1911	302	26.3	24.0	30.4	23.1	26.8
Tropeptic Eutrustox	WAI	1981	2843	335	293	388	19.7	18.5	30.2	20.5	25.4
	WAI	1982	1297	130	439	468	23.3	22.8	28.3	18.8	23.6
Typic Paleudult	NAK	1983	497	74	86	386	29.4	27.1	37.4	23.7	30.6
	SOR	1981	1699	65	1143	405	28.6	27.0	32.5	23.5	28.0
	SOR	1982	2226	22	1070	364	27.9	26.3	30.4	22.4	26.4

temperature of 17.4°C) in IOLE during 1982 (3rd cropping season) other results suggest that an average air temperature range of 21.2 to 28.0 °C is favorable for soybean cultivation. However, the relation between yield and maximum air temperature within the Paleudult sites (Figure 4.24) indicates that maximum air temperature above 34°C associated with a minimum temperature above 21°C could be detrimental to the performance of soybean.

In Hydric Dystrandept sites of KUK and IOLE, the crop planted in May (second cropping season) gave two to three times the yields obtained for the third season crops planted in September. Lower yields obtained for the September planting are probably due to the lower solar radiation and higher precipitation recorded for the period of the crop and also due to the photoperiodic effect. The extremely poor yield in LPH during the second cropping season of 1981 was due to heavy rains received throughout the season and especially at the pod formation stage. Yields for the rest of the soybean crops in LPH were associated directly with the amount of solar radiation received. Soybean performance in PAL for both seasons is also related directly to solar radiation. Comparatively better soybean performance in PAL despite lower solar radiation (third cropping season) could be due to higher soil and air temperature of this site.

As in KUK and IOLE sites, in the Eutrustox soils of WAI, soybean yields were higher when planted in April and May (second season) as compared to crops planted in August and September (third season). Higher yields are again associated with higher solar radiation and lower rainfall. Premature flowering was also noticed in crops planted

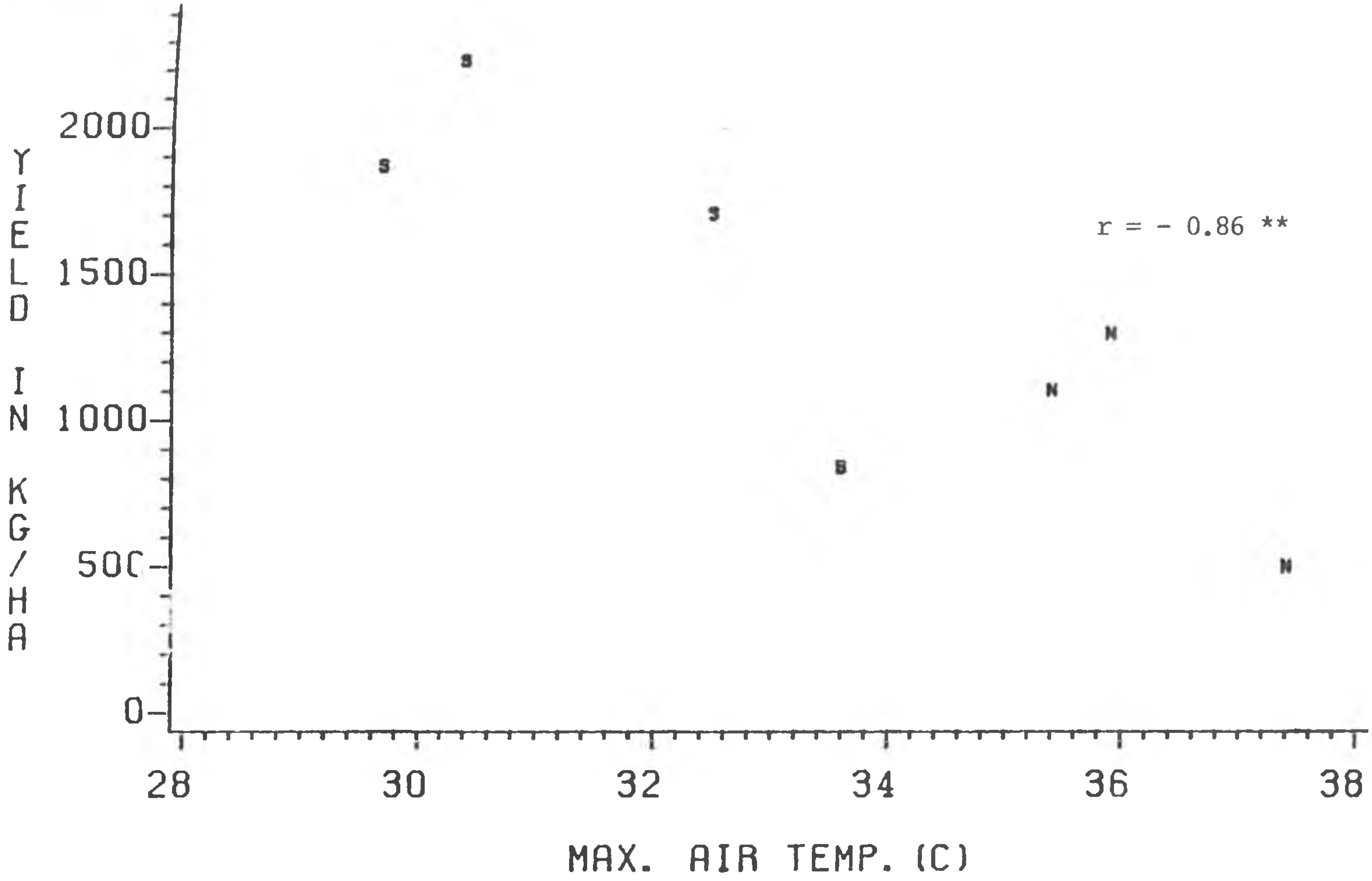


Figure 4.24. The relationship between maximum air temperature and irrigated soybean yield on benchmark sites of Paleudult soils.

during August and September due to shorter day lengths.

The positive correlation between soybean yields and solar radiation for all sites ($r = 0.53^{**}$) and for Dystrandept sites ($r = 0.66^{**}$) is illustrated in Figures 4.25 and 4.26. In contrast to other crops there was a good positive relationship between non-irrigated yields of soybean and rainfall for the crop period (Figure 4.27) over all sites. Apparently soybean responds to high precipitation, and gave the highest yield (2200 kg/ha) at a rainfall level of 1500 mm. Beyond this rainfall level the yields probably could decline as indicated by the PAL site (Figure 4.27).

4.2.8 Performance of peanut

Peanut yield data for the second and third cropping seasons are presented in Tables 4.12 and 4.13 along with the corresponding agroclimatic data.

Peanut is a widely adapted crop similar to soybean. Rachie and Silvestre (1977) observed that the optimum growing temperature for peanut is between 24 and 33°C. The results obtained in this study also attest that peanuts can grow well in a wide range of temperature. This is demonstrated by the high yields obtained in cool Dystrandepts as well as warm Paleudult soils.

The lowest yield was recorded in IOLE during the third cropping season which is associated with the lowest soil and air temperatures as well as solar radiation measured for the crop period on this site. The sites of ITKA (Indonesia) and KUK (Hawaii) were similar as far as recorded precipitation, temperature and solar radiation were

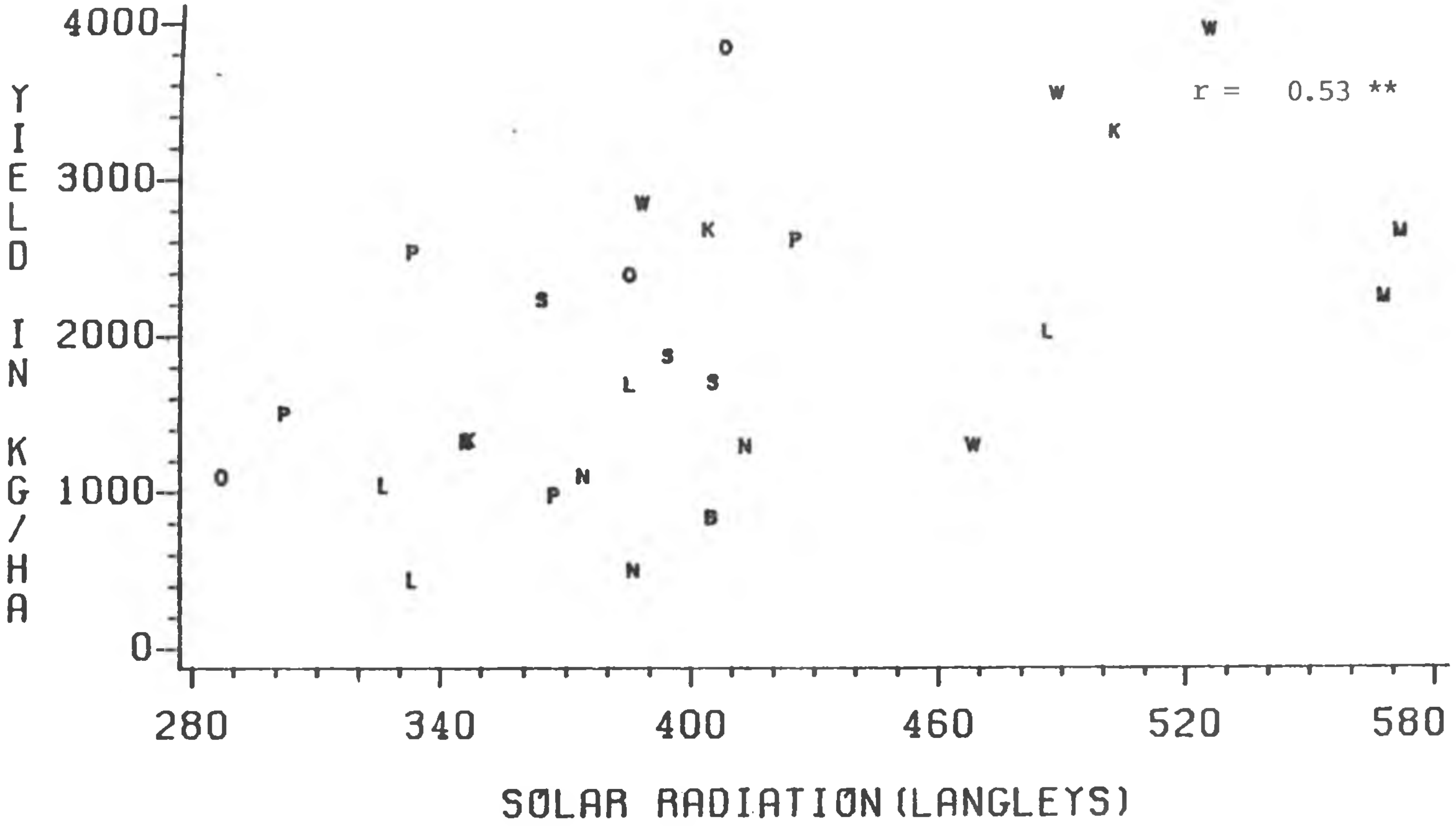


Figure 4.25. The relationship between solar radiation and irrigated soybean yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

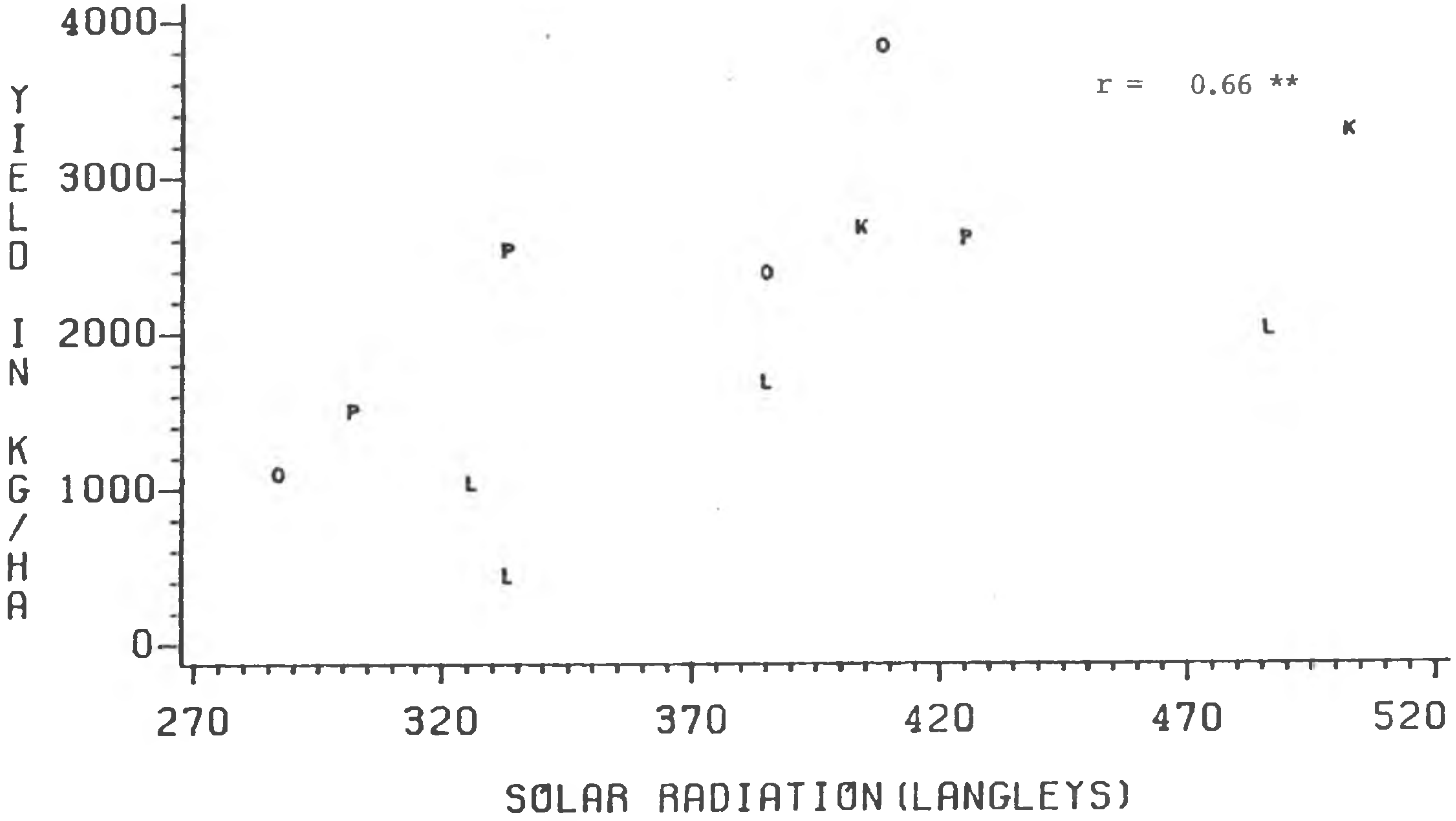


Figure 4.26. The relationship between solar radiation and irrigated soybean yield on benchmark sites of Dystrandept soils.

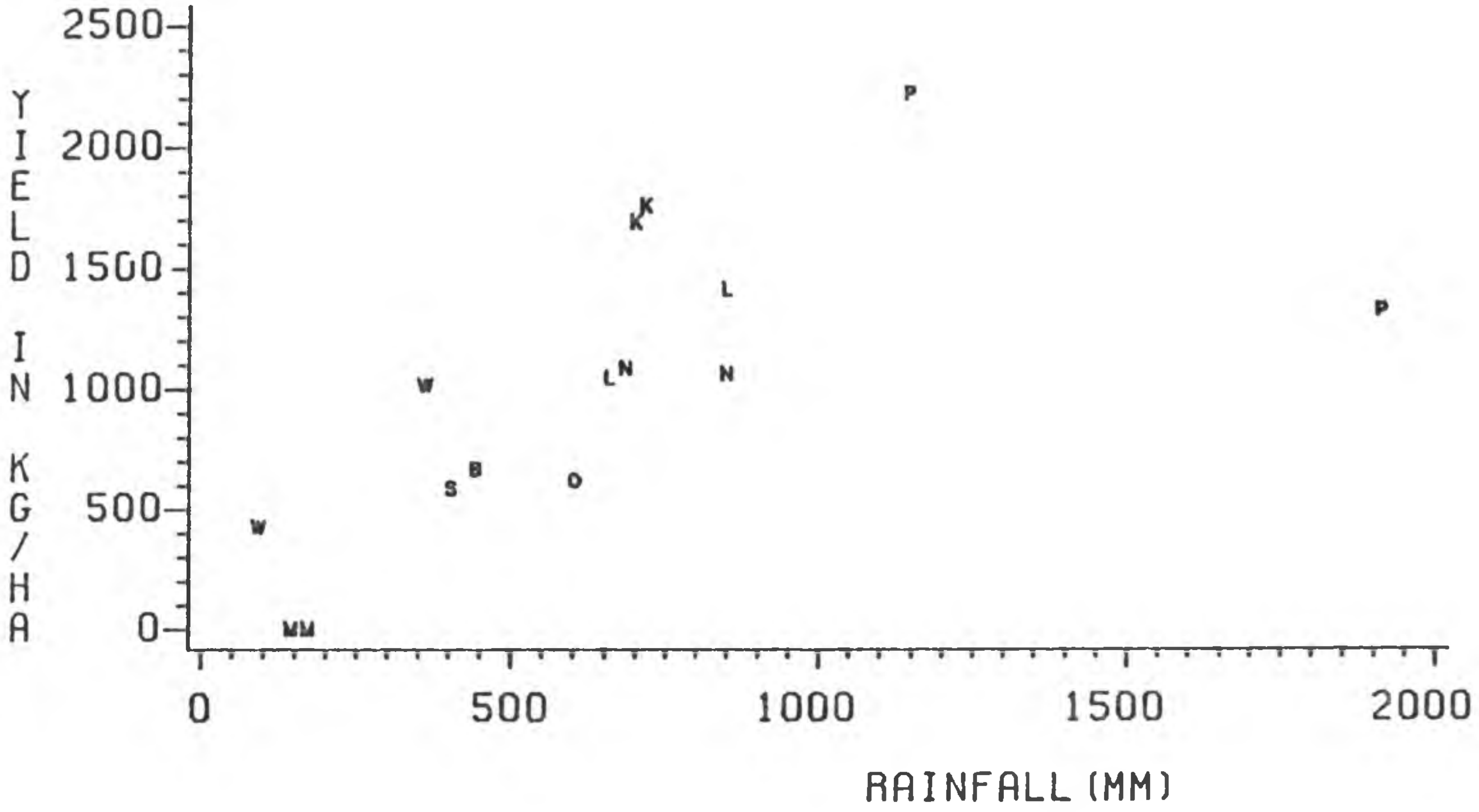


Figure 4.27. The relationship between rainfall and non-irrigated soybean yield on benchmark sites of Dystrandept (L,P,O,K), Eutrustox (M,W) and Paleudult (B,S,N) soils.

Table 4.12 Peanut yields and selected agroclimatic data for benchmark sites in the second cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	ITK	1981	3562	184	516	332	21.4	21.0	26.4	15.6	21.0
	LPH	1982	2120	262	344	385	23.3	21.5	26.8	13.8	20.3
	PAL	1982	3764	634	755	380	27.4	23.3	33.9	21.3	27.6
	PAL	1983	3137	393	19	425	31.5	24.4	35.4	20.5	28.0
Typic Paleudult	NAK	1981	747	55	684	413	29.0	28.6	35.9	23.3	29.6
	NAK	1982	422	45	848	374	30.6	27.5	35.4	21.2	28.3
	BPI	1981	3705	247	696	390	25.5	25.5	32.3	21.8	27.0
	SOR	1982	1867	148	637	402	27.4	25.3	30.5	20.3	25.4

Table 4.13 Peanut yields and selected agroclimatic data for benchmark sites in the third cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982	850	194	602	287	19.1	19.0	21.7	13.1	17.4
	KUK	1981	1933	254	718	347	22.4	21.5	24.6	18.4	21.5
	KUK	1982	1790	145	701	346	22.2	20.9	26.2	18.9	22.6
	LPH	1981	3267	325	659	326	25.0	23.3	26.9	16.2	21.6
	PAL	1981	2306	47	1226	334	30.0	25.1	32.4	23.0	27.7
	PAL	1982	2313	112	1911	302	26.2	24.0	30.4	23.1	26.8
Tropeptic Eutrustox	MOL	1982	2143	251	442	451	21.3	21.0	28.3	20.4	24.4
	WAI	1981	4250	312	352	372	19.4	18.2	30.2	20.2	25.2
	WAI	1982	2243	254	512	453	22.7	22.4	27.7	18.5	[illegible]
Typic Paleudult	BPI	1983	5179	177	186	452	29.2	29.2	33.8	22.3	[illegible]
	SOR	1981	2072	103	1143	405	28.6	27.0	32.5	23.5	28.0
	SOR	1982	2791	129	1163	364	27.9	26.3	30.4	22.4	26.4

concerned, yet peanut yield in ITKA was considerably higher. Apparently the crop in ITKA also took the longest time to mature (161 days). The only significant difference in the mean agroclimate of the two locations for the crop period, was the maximum relative humidity which was above 99 percent in ITKA compared to 87 percent and 83 percent recorded in KUK during 1981 and 1982 respectively. The preference of peanut for high relative humidity (Salter and Goode, 1967) as well as the longer maturity period of the crop, seem to be the reasons for the high yield recorded in ITKA. The overall yield data on Dystrandept sites for the two seasons show a favorable peanut response to higher temperatures. The relationships of peanut yield with maximum air temperature and average soil temperature are depicted in Figures 4.28 and 4.29, respectively.

Yields for different crops on the same site tended to be associated with higher relative humidities (Appendix 1). Tropeptic Eutrustox as well as Typic Paleudult soils show high peanut yield potential. The highest yields were obtained in BPI in 1982 (5179 kg/ha) followed by WAI in 1981 (4250 kg/ha). Consistent failure of the crop in Nakau (NAK) could be attributed to higher soil and air temperatures of this site compared to all other sites.

The general yield trend of the present study gives evidence that peanut can grow well within an average air temperature range of 21 to 28°C. The relationship of maximum air temperature and yield for all sites (Figure 4.30) indicates the possibility of yield decline beyond a maximum air temperature of 35°C. As is depicted in Figure 4.31, within the Hydric Dystrandept sites, the yields also show a positive

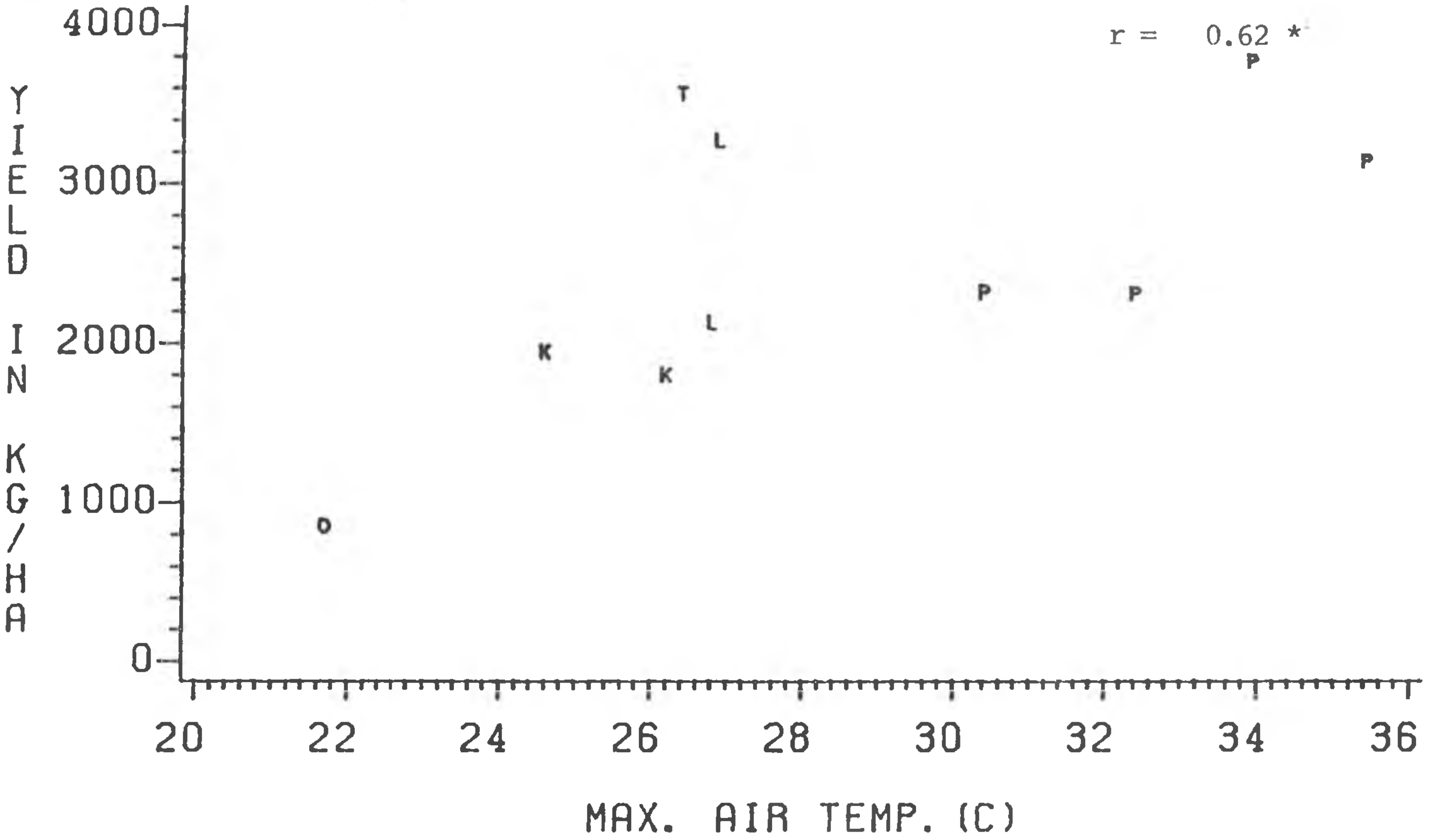


Figure 4.28. The relationship between maximum air temperature and irrigated peanut yield on benchmark sites of Dystrandept soils.

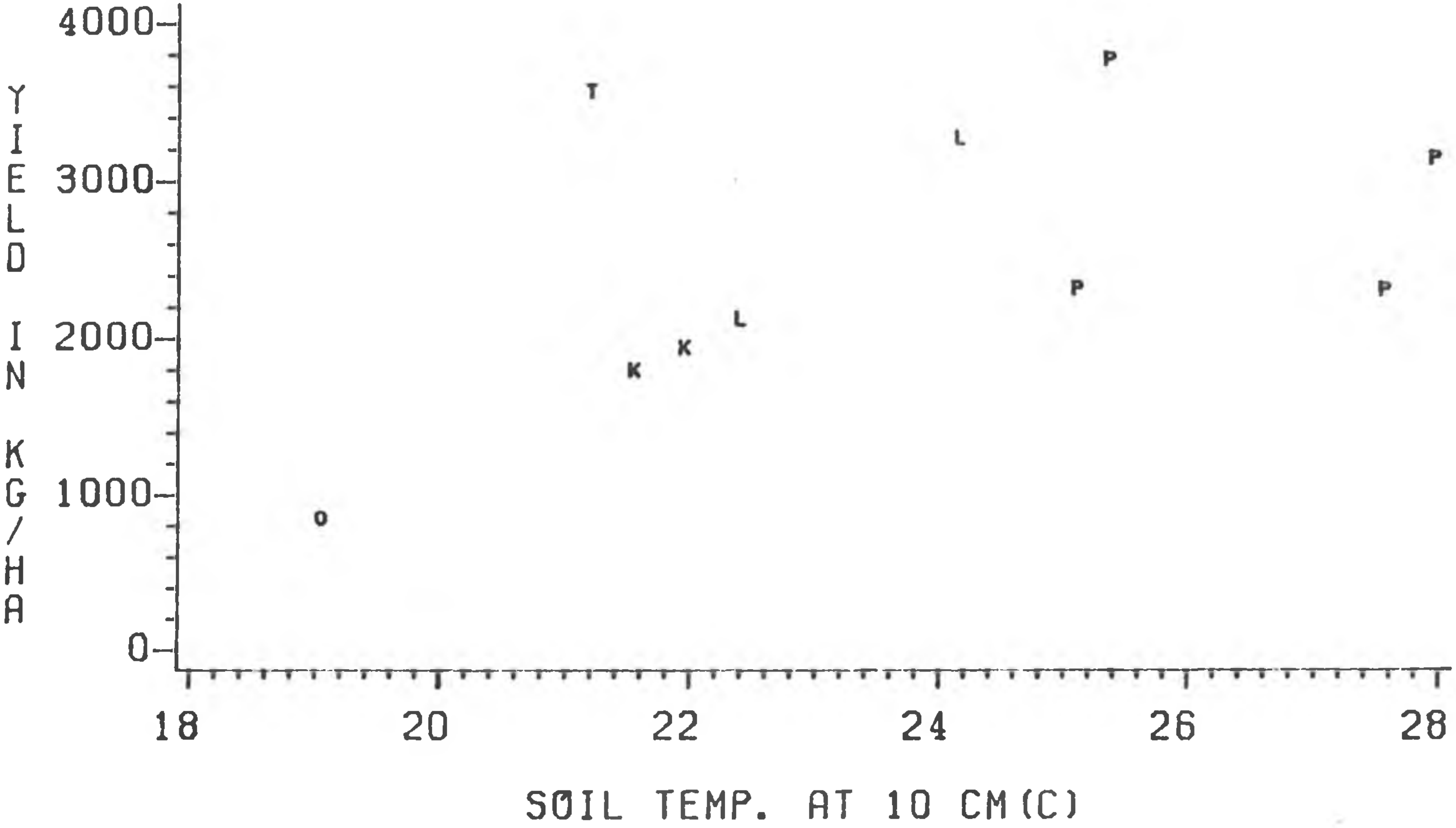


Figure 4.29 The relationship between average soil temperature and irrigated peanut yield on benchmark sites of Dystrandept soils.

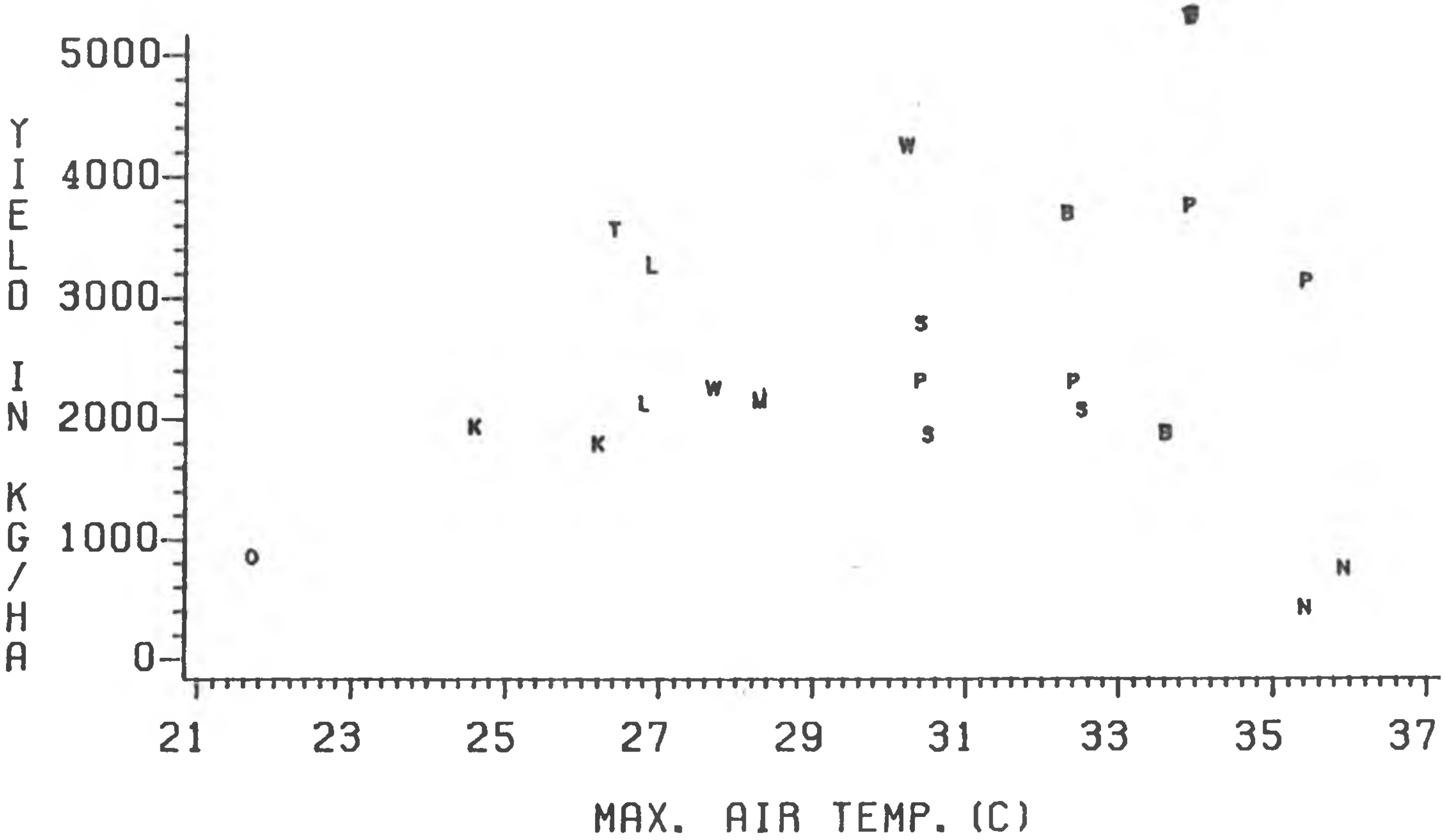


Figure 4.30. The relationship between maximum air temperature and irrigated peanut yield on benchmark sites of Dystrandept (O,T,K,L,P), Eutrustox (M,W) and Paleudult (B,S,N) soils.

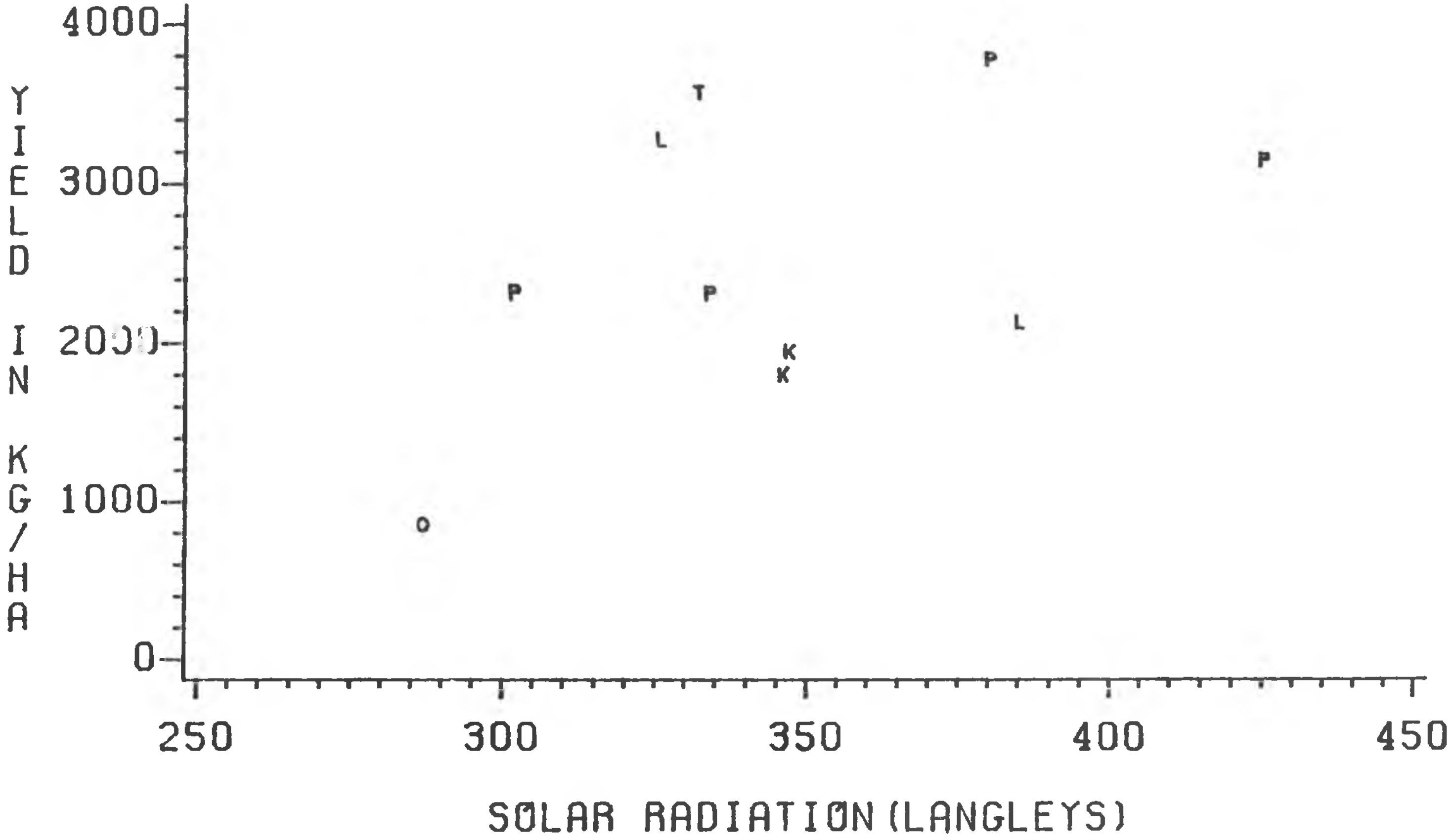


Figure 4.31. The relationship between solar radiation and irrigated peanut yield on benchmark sites of Dystrandept soils.

trend with increase in solar radiation.

4.2.9 Performance of cowpea and mungbean

Cowpea and mungbean yields are presented in Tables 4.14 and 4.15, respectively. Failure of both crops in LPH during 1981 and 1982 suggests that average soil temperature below 24°C and average air temperature less than 21.6°C is not favorable for the growth of cowpea and mungbean. This is in accordance with the fact that these crops are adapted to warm climate and were not expected to do well in the isothermic temperature regime prevalent in Dystrandept soils. However, the PAL site behaves differently because of its high soil and air temperatures, that are not quite within the isothermic range. The failure of the mungbean crop in PAL could also be attributed to early flowering and damage by heavy rains (> 1000 mm).

In NAK, maximum air temperature (> 37.4°C) beyond the upper limit of 35 °C considered adequate for cowpea (Arnon,1972) might be responsible for very low cowpea yields. Other Typic Paleudult sites show a good potential for cowpea and mungbean production as demonstrated by cowpea yields in SOR (1982) and mungbean yields in BPI (1982) and SOR (1981).

4.2.10 Performance of rice (Table 4.16)

Interpretation of rice yield data on the basis of the agroclimate is hampered by significant varietal differences as well as damage caused by typhoon, birds and incidence of blast disease. Yields were generally low, with the exception of good yields obtained in BPI

Table 4.14 Cowpea yields and selected agroclimatic data for benchmark sites in the third cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	LPH	1981	0	0	659	326	25.0	23.3	26.9	16.2	21.6
	LPH	1982	0	0	850	486	24.2	22.4	27.2	15.2	21.2
	PAL	1981	798	42	1146	333	30.0	25.1	32.3	23.0	27.6
	PAL	1982	1052	58	1411	308	26.3	24.4	31.0	23.8	27.4
Typic Paleudult	NAK	1982	125	19	20	386	29.4	27.1	37.4	23.7	30.6
	BPI	1981	513	40	614	435	----	----	34.2	22.4	28.3
	BPI	1982	790	102	25	430	----	----	34.2	22.2	28.2
	SOR	1981	949	89	931	395	28.6	26.9	32.2	23.5	27.8
	SOR	1982	1337	52	1017	356	27.8	26.2	29.8	22.3	26.0

Table 4.15 Mungbean yields and selected agroclimatic data for benchmark sites in the third cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		Mean
							Max	Min	Max	Min	
Hydric Dystrandept	LPH	1981	0	0	659	326	25.0	23.3	26.9	16.2	21.6
	LPH	1982	0	0	850	486	24.2	22.4	27.2	15.2	21.2
	PAL	1981	258	45	1080	330	30.0	25.1	32.5	23.0	27.8
	PAL	1982	80	3	1411	308	26.3	24.4	31.0	23.8	27.4
Typic Paleudult	NAK	1982	94	20	20	386	29.4	27.1	37.4	23.7	30.6
	BPI	1981	547	80	446	428	----	----	34.0	22.6	28.3
	BPI	1981	1085	54	25	430	----	----	34.0	22.2	28.1
	SOR	1981	1085	122	1143	405	28.6	27.0	32.5	23.5	28.0
	SOR	1982	668	58	1017	356	27.8	26.2	29.8	22.3	26.0

during 1981 and in PAL during 1982. Crops in PAL (1981) and SOR (1981) were damaged by typhoon. Failures at BPI (1982) and SOR (1982) were due to panicle destruction by birds, whereas the crop in NAK was affected by the blast disease.

4.2.11 Performance of field corn (Table 4.17)

Corn yields obtained in the present study were low compared to general yield levels attained in transfer experiments conducted on the same sites, by the Benchmark soils project staff (BSP, 1982). One of the reasons for the lower yields could be the period of crop growth. The transfer experiments were planted either during December-January (wet season) or June-July (dry deason), whereas the cropping systems experiment crops were planted in September-October (Appendix 1). The solar radiation obtained for the periods of corn growth in this study, are also lower than the levels obtained in the transfer experiment crop periods. However, many other agroenvironmental factors which may be responsible for differences in yield cannot be identified based on the available data.

4.3 Multiple regression models relating crop yields to agroclimatic parameters

Statistical techniques have often been used to relate climatic variables to crop production data. According to Johnson (1976) such modelling was initially developed to determine the stages of growth at which crops were susceptible to different climatic parameters. In the recent past, however, crop-climate models have been developed to

Table 4.16 Rice yields and selected agroclimatic data for benchmark sites in the first cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	LPH	1981	1360	90	2204	264	23.4	22.1	26.0	15.8	20.9
	PAL	1981	590	30	2085	287	25.8	23.5	30.0	21.2	25.6
	PAL	1982	3021	85	1039	319	25.1	22.6	30.8	20.2	25.5
Typic Paleudult	NAK	1981	1797	45	925	397	28.7	27.2	32.5	21.2	26.8
	NAK	1982	1283	31	1625	443	31.7	27.3	35.6	24.6	30.1
	BPI	1981	3821	80	839	447	----	-----	34.4	22.5	28.4
	BPI	1982	1918	131	641	419	28.7	28.6	33.5	22.2	27.8
	SOR	1981	477	142	1793	333	26.9	25.7	29.0	22.0	25.5
	SOR	1982	2544	109	571	336	27.3	25.8	30.8	21.5	26.2

Table 4.17 Corn yields and selected agroclimatic data for benchmark sites in the third cropping season.

Soil	Site	Year	Irrigated Yield (kg/ha) [mean of 3 reps]	SEM	Total Rainfall (mm)	Solar Radiation (langleys)	Daily avg. soil temp. (°C at 10cm)		Daily avg. air temp. (°C)		
							Max	Min	Max	Min	Mean
Hydric Dystrandept	IOLE	1982	2413	201	602	287	19.1	19.0	21.7	13.1	17.4
	KUK	1981	4193	176	1384	320	21.2	20.3	24.2	17.3	20.8
	KUK	1982	4037	131	721	346	21.9	20.6	26.1	18.7	22.4
Tropeptic Eutrustox	MOL	1982	3363	294	443	460	21.2	20.8	28.0	20.2	24.1
	WAI	1981	4177	83	358	352	19.0	17.7	29.6	20.0	24.8

analyse the effects of climatic fluctuation on agricultural production, and to attempt future yield predictions. The basic approach to all these models has been the "black box technique" in contrast to models based on the understanding of the different interacting physical processes. The crop-climate models developed thus far with few exceptions are mostly of the multiple regression type and use empirical relationships derived from historical crop yield and climatic data to predict potential future yields from different climatic scenarios (Biswas, 1980). The major problems of using historical crop yield data spanning a period of several years are two-fold:

(1) Difficulty of separating yield variability due to different components such as management, technology and climate.

(2) Unreliability of the climatic data due to differences in weather instruments over the years and reliance on distant weather stations, due to absence of stations on specific locations generating the crop yield data.

In the present investigation the above problems have been minimized due to uniform management practices, and standard weather equipment installed on all experimental sites. It therefore follows that the variability in yield was mainly caused by the agroclimatic parameters that were monitored. The yield data and corresponding agroclimatic variables summarized for the period of the individual crops, are detailed in Appendix 1.

Before discussing the multiple regression equations derived in this study, a brief outline of the major problems associated with such modelling techniques appears appropriate:

(1) Such models may not have realistic structure due to a lack of understanding of the interrelationships of the different physical processes involved.

(2) The coefficients of this type of model are statistical estimates and are not universal constants.

(3) The R^2 (square of multiple correlation coefficient) that is used as an indicator of the quality of the model is only an indicator of goodness of fit of the model and does not give any information on physiological accuracy of the model.

(4) The relationship between crop yields and different climatic variables is often non-linear, which is contrary to the general assumption of linearity.

(5) Multicollinearity problems are encountered due to correlation between different "independent" variables, which is especially true of meteorological variables. Due to such problems sometimes even the signs of the coefficients could be erroneous (Snee, 1973).

(6) Crops are influenced by agroclimatic factors throughout their growing season depending on development stages, hence averages of climatic variables for the total crop period may not truely represent the agroenvironmental conditions, influencing the crop.

Despite of the inherent problems cited above such modelling exercises do give a rough idea about the environmental factors likely to affect yields to a major extent. In the present investigation correlation matrices and the R SQUARE procedure (SAS) were used to screen the logical agroclimatic variables and their transformations.

The regression procedure, PROC REG (SAS) was used to estimate parameters of the selected independent variables to obtain the regression equations.

For soybean and peanut the best models incorporating as many as six agroenvironmental variables could explain less than 50 percent of the yield variability. Except for green corn, only crops that were sensitive to differences in temperature and moisture within the range of temperatures encountered in this study (head cabbage, mustard cabbage, carrot, bushbean, Irish potato) yielded prediction equations with R square values close to 0.80. A discussion of regression equations relating crop yield to selected agroclimatic parameters for individual crops follows.

4.3.1 Regression equation for irrigated bushbean yield prediction

The regression equation for bushbean yield with the related statistics is presented in Table 4.18. In accordance with Figures 4.17 and 4.20 depicting the negative relationships of bushbean yield with mean soil temperature and rainfall, these variables also give rise to negative parameter estimates.

The square root transformation of soil temperature (SQSTEMT), was included as a variable because it was found to improve the coefficient of determination, compared to the use of the untransformed variable and its other transformations. This was expected due to the curvilinear trend of the plot of soil temperature versus bushbean yield. High maximum relative humidities also indicated a detrimental effect on yield, which is reflected in the negative parameter

Table 4.18 Multiple regression model for predicting bushbean yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	26,731	3,624.6	7.37	0.0001
SQSTEMT	-3,567	655.3	-5.44	0.0001
RHMAX	-80.80	33.3	-2.42	0.02
TOTPPT	-1.25	0.47	-2.26	0.01
ATSTDM	224.7	103.7	2.17	0.04

Model $R^2 = 0.77$
Model Adj. $R^2 = 0.73$

* SQSTEMT = Square root of the average soil temperature at 10 cm for the crop period (°C)
RHMAX = Maximum relative humidity for the crop period (%)
TOTPPT = Total rainfall for the crop period (mm)
ATSTDM = Difference between average daily maximum air temperatures and mean soil temperature at 10 cm depth (°C)

estimate. O'Leary (1975) reported that higher humidity may lead to reduced bean growth due to the adverse effects of higher plant temperatures, increase in fungal activity and disturbance in hormonal balance. The parameter estimate of the variable ATSTDM shows that a greater difference between maximum air temperature and average soil temperature tends to increase yields. The WAI site (Eutrustox) giving consistently high bushbean yields was also found to differ markedly in its soil and air temperatures. The reason for the beneficial effect of such temperature differences is not clear. However higher air temperature associated with lower soil temperature may favor sugar translocation.

4.3.2 Regression equation for irrigated head cabbage yield prediction

The equation along with the relevant statistics is presented in Table 4.19. The coefficient of determination obtained for the regression indicates that the independent variables explain 79 percent of the yield variability. The adaptability of this crop to cool temperature and the consequent negative effect of high temperature is reflected by the negative parameter estimate for mean soil temperature. Figure 4.3, discussed earlier illustrates the relationship between head cabbage yields and soil temperature. Excess moisture and higher relative humidities are also detrimental to the crop and thus have negative parameter estimates. The only variable that affected the yield positively was solar radiation.

Table 4.19 Multiple regression model for predicting head cabbage yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	51,101	12,443	4.11	0.0009
TOTPPT	-2.04	1.67	-1.22	0.24
SOLRAD	9.54	8.12	1.17	0.26
AVSTEMT	-1074	233.30	-4.60	0.0003
RHMAX	-238.4	132.90	-1.79	0.093

Model $R^2 = 0.79$
Model Adj. $R^2 = 0.73$

* TOTPPT = Total rainfall for the crop period (mm)
SOLRAD = Solar radiation (avg. daily) in langleys for the crop period.
AVSTEMT = Average soil temperature at 10 cm for the crop period.
RHMAX = Maximum relative humidity for the crop period (%)

4.3.3 Regression equation for irrigated mustard cabbage yield prediction

The regrssion equation and the relevant statistics are presented in Table 4.20. This was the best model obtained in the present study with an R square of 0.97. Mustard cabbage is a cool-weather crop similar to head cabbage and as expected the coefficient for the variable soil temperature is negative. The square root transformation of soil temperature was used because of the shape of the curve illustrated in Figure 4.8. The inclusion of interaction terms " solar radiation * rainfall" and "solar radiation * air temperature minimum" was essential to obtain high R squares and their ommission resulted in considerable reduction of the R square. The interaction of solar radiation and rainfall and that of solar radiation and minimum air temperature have a positive and negative influence on yields, respectively. The agronomic significance of these terms however is far from clear. The regression equation also shows favorable consequences of greater differences between maximum and minimum air temperatures on crop yield. This is expected as higher temperature during the day favors photosynthesis and lower night temperature reduces respiration and thus favors growth of the plant.

4.3.4 Regression equation for irrigated carrot yield prediction

The regression equation is presented in Table 4.21. The R square for the multiple regression was 0.81. As in head cabbage the regression equation for this crop also showed the positive influence of solar radiation and the negative influence of higher soil

Table 4.20 Multiple regression model for predicting mustard cabbage yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	216,046	19,044	11.34	0.0001
SQSTEMT	-33,833	4,731	-7.15	0.0004
TOTPPT	-254	59.3	-4.29	0.005
SOLPPT	0.65	0.14	4.53	0.004
SOLAMIN	-5.85	1.23	-4.76	0.003
ATEMPDIF	936	536	1.74	0.132

Model $R^2 = 0.97$
Model Adj. $R^2 = 0.95$

* SQSTEMT = Square root of the average soil temperature at 10 cm, for the crop period (°C)

TOTPPT = Rainfall for the crop period (mm)

SOLAMIN = Product of solar radiation (avg. daily) in langleys and average daily minimum air tempertaure (°C) for the period of the crop

ATEMPDIF = Difference between average daily maximum and minimum air temperatures for the crop period (°C)

SOLPPT = Product of solar radiation (langleys) and rainfall (mm) for the crop period

Table 4.21 Multiple regression model for predicting carrot yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	78,040	15,144	5.15	0.0002
SOLRAD	31.0	9.4	3.30	0.006
SQSTEMT	-9,787	2,322	-4.21	0.001
RHMAX	-439.1	155.1	-2.83	0.014
RHMIN	114.5	71.9	1.59	0.135

Model $R^2 = 0.82$
Model Adj. $R^2 = 0.76$

* SOLRAD = Solar radiation (avg. daily) in langleys for the crop period
SQSTEMT = Square root of the average soil temperature at 10 cm, for the crop period (°C)
RHMAX = Maximum relative humidity for the crop period (%)
RHMIN = Minimum relative humidity for the crop period (%)

temperature and increase in maximum relative humidity. The influence of high humidity on carrot yields, observed in this study, appears to be in line with the observations of Hoffman et al. (1971) who reported that higher humidities result in increased leaf area, higher shoot:root ratio and sometimes in reduced root growth.

4.3.5 Regression equation for irrigated Irish potato yield prediction

Table 4.22 shows the regression model for Irish potato yields along with the relevant statistics. The coefficient of determination for this crop was also very high (0.97) as in the case of mustard cabbage. As expected for a cool weather crop like Irish potato, the factor of greatest influence in yield reduction is the rise in soil temperature. Higher wind velocities may reduce yields through mechanical damage and increased transpiration, which accounts for the negative parameter estimate obtained for the variable WINDVEL. The negative coefficient obtained for rainfall (SQPPT) and the positive sign of solar radiation are also illustrated in Figures 4.15 and 4.14, respectively.

4.3.6 Regression equation for irrigated green corn yield prediction

The equation is presented in Table 4.23. Contrary to the crops described earlier, the wider adaptability of green corn to temperature fluctuations is indicated by the absence of soil or air temperatures as variables in the model. Also, higher precipitation has a beneficial effect as suggested by the positive coefficient of TOTPPT. This is in contrast to head cabbage, mustard cabbage and

Table 4.22 Multiple regression model for predicting Irish potato yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	181,421	16,201	11.20	0.0001
WINDVEL	-1210.5	232.0	-5.22	0.0002
SQPPT	-107.3	82.7	-1.30	0.2188
SOLRAD	51.6	8.15	6.33	0.0001
SQSTEMT	-46,629	4870.6	09.57	0.0001
ATEMPMIN	2,404	487.6	4.93	0.0003

Model $R^2 = 0.97$
Model Adj. $R^2 = 0.95$

* WINDVEL = Average wind velocity for the crop period (km/hr)
SQPPT = Square root of total rainfall for the crop period (mm)
SOLRAD = Solar radiation (avg. daily) in langleys for the crop period
SQSTEMT = Square root of the average soil temperature at 10 cm, for the crop period (°C)
ATEMPMIN = Minimum air temperature for the crop period (°C)

Table 4.23 Multiple regression model for predicting green corn yields based on selected agroclimatic variables.

Variable*	Parameter estimate	Standard error	t	Prob > /t/
Intercept	-29,749	7833.5	-3.80	0.0022
WINDVEL	4289	706.7	6.01	0.0001
TOTPPT	2.60	2.07	1.26	0.231
SOLRAD	78.50	17.27	4.54	0.0006
SOLWIND	-8.13	1.38	-5.91	0.0001

Model R^2 = 0.77
Model Adj. R^2 = 0.70

* WINDVEL = Average wind velocity for the crop period (km/hr)
TOTPPT = Total rainfall for the crop period (mm)
SOLRAD = Solar radiation (avg. daily) in langleys for the crop period
SOLWIND = Product of SOLRAD and WINDVEL

bushbean. Higher solar radiation accompanied by greater wind velocities (SOLWIND) might lead to moisture stress (at later stages) especially for green corn due to its tall stature and abundant leaf area.

4.4 Crop performance with and without irrigation in the three tropical soil families

One of the objectives of this investigation was to evaluate the ability of each of the three agroenvironments to sustain year-round crop production without irrigation. To achieve the above purpose, specifically designed cropping patterns were tested with and without irrigation on each of the three soil families. The comparative performance of crops under irrigated and non-irrigated conditions is depicted in Tables 4.24 to 4.35.

4.4.1 Comparative productivity of the agroenvironments without irrigation

Hydric Dystrandepts: The overall crop performance on Hydric Dystrandepts (Table 4.24 to 4.30 and 4.35) clearly illustrates the fact that in these soils all the crops, with few exceptions, could do very well without irrigation. In most of the cases there was no significant difference between irrigated and non-irrigated crop yields. Except for the 1982 crop in PAL, even a long duration water loving crop like taro (Table 4.36) grown without irrigation yielded close to the irrigated crop. This indicates that in Hydric

Dystrandepts rainfall is mostly adequate and reliable throughout the year.

Typic Paleudults: With some exceptions, crops in Typic Paleudults (Tables 4.30 to 4.32 and 4.35) also performed reasonably well without irrigation. However, in many cases the non-irrigated crop yields were significantly lower than the irrigated crop yields. The rainfall data suggests that the poor performance of some crops without irrigation, was mainly a problem of rainfall distribution rather than of its shortage. In BPI the yields of the irrigated and non-irrigated cassava crop did not differ significantly.

Tropeptic Eutrustox: Yield data of corn (Table 4.34) and soybean (Table 4.35) on Tropeptic Eutrustox sites of MOL and WAI, show that irrigation is essential to sustain crop growth in this agroenvironment. Yields of non-irrigated crops of cassava (Table 4.36) were considerably lower than the irrigated crops but still quite respectable (2220 to 6210 kg/ha) indicating the drought tolerance of this crop.

The moisture regimes of the three soil families were effectively demonstrated by the performance of the soybean crop (Table 4.35). This is illustrated in Figure 4.32 where the yields of soybean are averaged for all sites within each soil family. The difference between irrigated and non-irrigated crop yields were minimal in Hydric Dystrandepts followed by Typic Paleudults reflecting their wet agroenvironment (udic moisture regime), and maximum in the dry

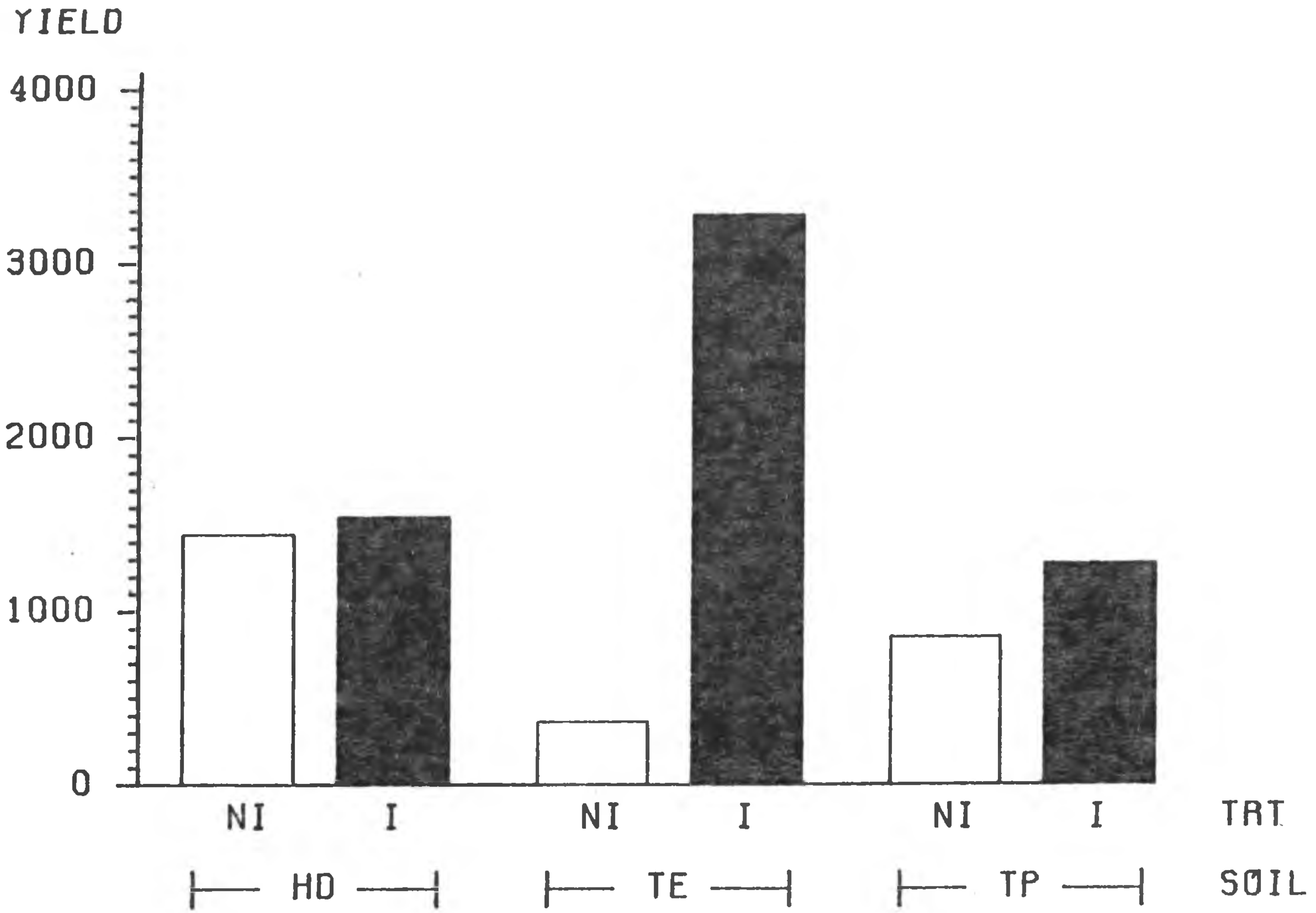


Figure 4.32. Comparative yields of irrigated (I) and non-irrigated (NI) soybean crops in Hydric Dystrandept (HD), Tropeptic Eutrustox (TE) and Typic Paleudult (TP) soils.

Tropeptic Eutrustox agroenvironment (ustic moisture regime).

4.4.2 Salient features of individual crop performance without irrigation

Bushbean (Table 4.24): The performance of non-irrigated bushbean crop (planted 5/14/81) in IOLE suggests that a properly distributed total rainfall of 101 mm during the crop period is sufficient for good bushbean yields. This is contrary to observations of Guazelli (1978) and Ohlander (1980) who indicated a rainfall requirement of at least 200 to 500 mm for bushbean cultivation in a wide range of soils in Brazil and Ethiopia, respectively. It is however important to realize that generalizations about the climatic requirements of crops such as bushbean could be misleading, due to the wide spectrum of genotypes available. Assuming that a precipitation of around 100 mm during the crop period is sufficient, the low yields obtained without irrigation in other sites despite higher rainfall could be attributed to inadequate rainfall distribution.

Head cabbage (Table 4.25): It is apparent from the data that there was no necessity for irrigation on all Dystrandept sites. A rainfall of 234 mm for the crop period was found to be sufficient for head cabbage production as indicated by the crop in KUK planted on 2/6/81. In KUK (planting date 2/25/83) and in LPH (planting date 12/19/81) surprisingly, the non-irrigated crop performed significantly better than the irrigated crop. Despite statistical significance these differences should be attributed to random error, considering

Table 4.24 Bushbean yields with and without irrigation on Hydric Dystrandept sites.

Season	Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference	Total rainfall (mm)
1	KUK	12/7/81	3617	3190	ns	743
		2/25/83	2722	3028	ns	412
	IOLE	3/1/83	5178	2190	**	329
	LPH	12/11/82	1547	864	ns	1123
2	ITKA	5/21/81	882	577	*	239
	KUK	4/13/82	2883	2370	*	544
	IOLE	5/14/81	5313	4505	ns	101
		4/15/82	3305	2635	ns[a]	380
	PAL	2/20/81	2881	2872	ns	297
	LPH	3/7/81	1305	959	*	676
		4/26/82	2842	2788	ns	490

[a] t test for unequal variances used

ns not significant

* significant ($P < 0.05$)

** highly significant ($P < 0.01$)

Table 4.25 Cabbage yields with and without irrigation on Hydric Dystrandept sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
KUK	2/6/81	18437	18300	ns	234
	12/3/81	10777	11140	ns	783
	2/25/83	16798	20185	*	412
IOLE	12/3/81	6127	6547	ns	781
	1/26/83	12692	16015	ns	298
PAL	10/22/81	1215	1864	ns	1699
	11/15/82	4187	4723	ns	766
LPH	12/19/81	2755	5814	**	1450
	12/11/82	4273	7099	ns	1151

[a]:

ns not significant
* significant ($P < 0.05$)
** highly significant ($P < 0.01$)

the fact that no irrigation was given to the plots designated for irrigation, due to adequate rainfall.

Carrot (Table 4.26): The difference between irrigated and non-irrigated crop yields was not significant on all Dystrandept sites except for the 1981 crop in KUK. The latter also appears to be a problem of inadequate rainfall distribution considering the adequacy of 430 mm of rainfall (for the crop period) for the high yields obtained in IOLE.

Irish Potato (Table 4.27): Andrew and Kassam (1976) reported that a short duration potato crop requires about 500 to 700 mm of well distributed rainfall. This is more or less in agreement with the results in this study. In Tropeptic Eutrustox and Hydric Dystrandept soils rainfall amounts of 467 mm and 380 mm (IOLE, 1/26/83 planting) respectively, appear to be adequate to produce good yields not different from those obtained under irrigation. Low yield of the non-irrigated crop in PAL could be due to inadequate rainfall distribution, whereas the poor results without irrigation in WAI (planted 1/14/81) and MOL (planted 1/26/83) suggest that rainfall amounts in the vicinity of 100 mm are insufficient for potato cultivation. The probable reasons for low yields obtained in LPH, despite irrigation have been discussed elsewhere, in this dissertation.

Table 4.26 Carrot yields with and without irrigation on Hydric Dystrandept sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
KUK	1/20/81	9057	2035	**	421
	11/3/81	10863	11283	ns	1193
	1/21/83	18678	22998	ns	864
IOLE	1/26/83	15902	12850	ns	430
PAL	10/15/82	4201	4945	ns	864
LPH	12/19/81	11122	10125	ns	1450
	12/11/82	9524	7711	ns	1212

[a]:

ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Table 4.27 Irish potato yields with and without irrigation on benchmark sites.

Soil	Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
Tropeptic Eutrustox	WAI	1/14/81	28583	12037	**	212
		12/29/81	16607	15527	ns	467
		1/14/83	35793	0	**	91
	MOL	1/5/82	12313	11930	ns	524
		1/26/83	19646	2705	**	104
Hydric Dystrandept	KUK	1/20/81	12077	9568	*	421
		12/11/81	20600	17133	*	1683
		1/21/83	26097	23957	ns	562
	IOLE	1/26/83	16078	19940	*	380
	PAL	10/15/82	8718	3198	**	786
	LPH	12/19/81	1840	2943	ns	1237
		12/11/82	4598	3703	ns	1123

[a]:

ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Mustard Cabbage (Table 4.28): The complete failure of the non-irrigated crop in PAL (planted 3/5/83) was due to extremely low rainfall. On other sites irrigation was found unnecessary. Performance of the rainfed crop planted on 2/20/82 in PAL shows that a rainfall of 231 mm was adequate for the crop. In IOLE, 355 mm of rainfall was sufficient to achieve a very high (37290 kg/ha) mustard cabbage yield.

Green Corn (Table 4.29): Performance of the 1981 crop in KUK indicates that a rainfall of 211 mm is not sufficient for corn cultivation. However the yield of green cobs (11167 kg/ha) obtained for the crop in IOLE leads to the inference that rainfall above 300 mm if properly distributed might be sufficient for decent green corn yields. Stacy et al. (1956) also reported that corn requires a rainfall of about 375 mm during the growing season.

Peanut (Table 4.30): Peanut yields obtained with and without irrigation did not differ significantly both in Hydric Dystrandept and Typic Paleudult sites. The best yields of non-irrigated crops were obtained in LPH (Hydric Dystrandept) and BPI (Typic Paleudult) sites, where the rainfall for the period of the crops was 659 and 696 mm, respectively. According to Rachie and Roberts (1974) peanut favors moderate rainfall between 500 and 600 mm for the crop period.

Cowpea and Mungbean (Tables 4.31 and 4.32): The drought tolerance of cowpea and mungbean is demonstrated by the fact that in BPI the

Table 4.28 Mustard cabbage yields with and without irrigation on Hydric Dystrandept sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
KUK	4/13/82	31300	26443	ns	610
IOLE	4/14/82	34780	37290	ns	355
PAL	2/20/82	13842	15862	ns	231
	3/15/83	2936	0	**	3
LPH	4/26/82	14478	14659	ns	444

[a]: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Table 4.29 Green corn yields with and without irrigation on Hydric Dystrandept sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
KUK	6/3/81	12755	0	**	211
	5/3/82	10676	9060	ns	534
IOLE	5/28/81	17700	11167	**	317
	5/4/82	7582	8080	ns	466
PAL	3/11/82	9625	6489	**	643
	4/4/83	9500	0	**	16
LPH	3/7/81	5667	4906	ns	1323
	4/26/82	4749	4113	*	595
ITKA	5/21/81	5579	5942	ns	315

[a]: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Table 4.30 Peanut yields with and without irrigation on benchmark sites.

	Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
Hydric Dystrandept	KUK	9/10/81	1933	2133	ns	718
		9/9/82	1790	1730	ns	701
	IOLE	9/21/82	850	447	ns	602
	PAL	5/15/81	2306	2302	ns[b]	1226
		6/28/82	2313	2206	ns	1911
	LPH	8/13/81	3267	3372	ns	659
Typic Paleudult	NAK	3/11/81	747	811	ns	684
	SOR	2/16/82	1867	1618	ns	637
	BPI	9/28/81	3705	3739	ns	696

[a]: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

[b] t test for unequal variances used

Table 4.31 Mungbean yields with and without irrigation on Typic Paleudult sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
SOR	6/3/81	1085	1130	ns	1143
	7/3/82	668	436	*	1017
BPI	2/10/81	547	436	ns	446
	2/11/82	1085	800	*	25

Table 4.32 Cowpea yields with and without irrigation on Typic Paleudult sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
SOR	6/3/81	949	1082	ns	931
	7/2/82	1337	0	**	1017
BPI	2/10/81	513	201	**	614
	2/11/82	790	431	*	25

[a]: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

rainfed crops could produce atleast 60 percent of the irrigated crop yield at a very low rainfall level of 25 mm (2/11/82 planting). The inconsistent crop performance on other sites was due to the influence of excess rains and typhoon winds experienced during the crop periods.

Rice (Table 4.33): Total failure of the non-irrigated 1981 crop in BPI was caused by drought conditions prior to flowering of the crop. In other cases the rainfall was quite adequate to produce yields comparable to the irrigated crop. It is interesting to note that the 1982 rainfed crop in SOR could perform quite well (2060 kg/ha) with a rainfall of 571 mm.

Soybean (Table 4.35): Performance of non-irrigated crops on Tropeptic Eutrustox suggests that a rainfall below 200 mm for the crop period, can be disastrous to successful rainfed cultivation of soybean in these soils. The high yields obtained with rainfall amounting to 1146 mm show that this crop is quite tolerant to excess moisture conditions. Compared to other leguminous crops, soybean is known to be tolerant of waterlogging (Heatherly and Russell, 1979).

4.5 Comparison of bushbean yields in two intercropping systems

In the second cropping season of the HD pattern (cropping pattern designed for Hydric Dystrandepts), two alternate intercropping systems were tested. In one case bushbean was intercropped with green corn in the same row [Figure 3.8 (B)] and in another case bushbean was intercropped with mustard cabbage in alternate rows (Figure 3.9). The

Table 4.33 Rice yields with and without irrigation on Typic Paleudult sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
BPI	5/4/81	3821	44	**	839
	5/24/82	1918	1822	ns	641
SOR	9/24/81	477	323	ns	1793
	10/11/82	2544	2060	*	571
NAK	10/27/81	1591	2002	ns	925
	12/15/82	1283	972	ns	1625

Table 4.34 Corn yields with and without irrigation on Tropeptic Eutrustox sites.

Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
WAI	9/16/81	4180	0	**	358
	9/22/82	750	0	**	512
MOL	9/17/82	3360	0	**	443

a: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Table 4.35 Soybean yields with and without irrigation on benchmark sites.

Soil	Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]	Total rainfall (mm)
Tropeptic Eutrustox	WAI	5/1/81	3538	425	**	91
		4/27/82	4539	1013	**	360
	MOL	5/12/81	2669	0	**	144
		5/6/82	2246	0	**	171
Hydric Dystrandept	KUK	9/10/81	1327	1755	*	718
		9/9/82	1319	1688	ns	701
	IOLE	9/22/82	1094	681	*	602
	PAL	5/15/81	2527	2213	ns	1146
		6/28/82	1496	1319	ns	1911
	LPH	8/12/81	1037	1045	ns	659
		9/16/82	2024	1412	**	850
Typic Paleudult	NAK	3/11/81	1292	1086	**	684
		3/9/82	1100	1059	ns	848
	SOR	2/16/82	1867	585	**	404
	BPI	11/5/82	836	665	**	444

a: ns = not significant
* = significant ($P < 0.05$)
** = highly significant ($P < 0.01$)

Table 4.36 Taro and cassava yields with and without irrigation on benchmark sites.

Crop	Soil	Site	Planting date	Mean yield with irrigation (kg/ha)	Mean yield without irrigation (kg/ha)	Significance of difference[a]
Taro	Tropeptic Eutrustox	WAI	4/6/81	1150	0	**
	Hydric Dystrandept	KUK	1/21/81	3090	1580	*
			4/13/82	2908	2180	ns
		LPH	3/7/81	7937	6980	ns
		PAL	3/14/82	2824	862	**
		IOLE	4/14/82	8800	5860	**
Cassava	Tropeptic Eutrustox	WAI	4/6/81	7545	2220	**
			2/17/82	7820	6210	**
		MOL	2/22/82	4112	2430	ns
	Typic Paleudult	BPI	7/13/82	6112	6120	ns

[a]: ns = not significant
* = significant
** = highly significant

planting patterns for each combination are detailed in Chapter II. The yield data for bushbean along with corresponding yields of the associated crops are presented in Table 4.37.

Bushbean performance was superior in "bushbean + mustard cabbage" combination compared to the same in "bushbean + green corn" combination. Except for the sites of MOL and SOR, in other sites the total yield of component crops in the "bushbean + mustard cabbage" intercrop was at least 1.6 and up to 3.8 times that of the "bushbean + green corn" combination. Apparently, the bushbean performance was not adversely affected even by the high yields of the associated mustard cabbage crops in IOLE and KUK sites.

The present results suggest that mustard cabbage is a poor competitor for nutrients and light compared to green corn. Mustard cabbage is a short statured crop and hence unlike green corn, does not lead to shading of the companion crop. Being a deep rooted crop compared to mustard cabbage, green corn possibly competes for the same soil volume as bushbean. Also as mentioned earlier, green corn was planted in the same row as bushbean whereas mustard cabbage was planted in alternate rows. The latter also may contribute to reduced competition.

4.6 Response of soybean to N application and Rhizobium inoculation in the three soil families

The results of experimentation on nitrogen application and Rhizobium inoculation as reflected by soybean yields on Hydric Dystrandepts, Tropeptic Eutrustox and Typic Paleudult sites are

Table 4.37 Bushbean yields in "bushbean + mustard cabbage" and "bushbean + green corn" intercrop combinations.

Soil	Site	Year	Mean yield[b] with mustard cabbage (kg/ha)	Mean yield[b] with green corn (kg/ha)	Significance of difference[a]
Tropeptic Eutrustox	MOL	1981 (irrigated)	2823 (8787)	2370 (8083)	ns
	WAI	1982 (irrigated)	7433 (17800)	5840 (9757)	ns
Hydric Dystrandept	IOLE	1982 (irrigated)	3777 (34780)	2833 (7582)	ns
		1982 (non-irrig.)	2850 (37290)	2420 (8080)	ns
	KUK	1982 (irrigated)	3127 (31297)	2720 (10677)	*
		1982 (non-irrig.)	3083 (26443)	1657 (9060)	*
	PAL	1981 (irrigated)	4055 (13842)	1706 (9625)	**
		1981 (non-irrig.)	3884 (15862)	1861 (6489)	*
Typic Paleudult	SOR	1982 (irrigated)	4838 (8245)	2425 (9758)	*

[a] ns = not significant
* = significant
** = highly significant

[b] Yield of the associated crop in brackets

presented in Tables 4.38, 4.39, and 4.40 respectively.

The data for all Eutrustox sites show that Rhizobium inoculation tended to increase the average yields. Except for the crop in WAI planted on 5/1/81, nitrogen application also resulted in higher average yields. However the positive response to Rhizobium inoculation was significant in WAI for August, 81 and April, 82 plantings and in MOL for May, 82 planting. The M_4 treatment consisting of 20 kg N application along with the Rhizobium seed treatment, did not cause further significant increase in yield, as indicated by the crops planted in April and May at MOL and WAI. This is in agreement with the view that externally applied N generally inhibits nitrogen fixation in well nodulated legume systems (Gibson, 1976; Lawn and Brun, 1974). Johnson et al. (1975) also reported that added nitrate appears to substitute for. rather than augment, fixed N and does not increase yields above the level obtained with adequately symbiotic plants.

The fact that different plots on the same experimental site respond differently to Rhizobium inoculation, stresses the high specificity of response to inoculation which depends on local microclimate, and biological factors. It is interesting to note that the N alone treatment (100 kg N/ha) did not differ significantly from the control in all soybean crop trials on Eutrustox sites. This suggests that the Eutrustox soils of WAI and MOL, have sufficient inherent N supply or effective Rhizobium strain to match the resultant N supply on addition of nitrogen at the rate of 100 kg N/ha.

Soybean yields in Hydric Dystrandept soils also did not show any

Table 4.38 Yield response of soybean to nitrogen application and rhizobium innoculation on Hydric Dystrandept sites *

Site	Planting Date	Treatment[a]	Mean[b] Yield (kg/ha)
IOLE	9/27/82	M_1	1003 A
		M_2	1053 A
		M_3	1217 A
KUK	9/10/81	M_1	1443 A
		M_2	1233 A
		M_3	1303 A
IOLE	5/13/81	M_1	3185 B
		M_2	3577 AB
		M_3	4033 A
		M_4	3900 A
KUK	5/27/81	M_1	3045 AB
		M_2	2788 B
		M_3	3512 A
		M_4	3340 A
LPH	8/12/81	M_1	1000 AB
		M_2	1152 A
		M_3	958 B
PAL	5/15/81	M_1	2187 A
		M_2	2477 A
		M_3	2919 A
	3/14/83	M_1	2348 A
		M_2	2803 A
		M_3	2669 A

* Note: Different crops on the same site were planted on separate plot locations

[a] M_1 No inoculum, no nitrogen
M_2 No inoculum, 100 kg N/ha
M_3 With inoculum, no nitrogen
M_4 With inoculum and 20 kg N/ha

[b] For each site means followed by the same letter are not significantly different at 5% level, based on Waller Duncan test.

Table 4.39 Yield response of soybean to nitrogen application and rhizobium irnoculation on Tropeptic Eutrustox sites. *

Site	Planting Date	Treatment[a]	Mean[b] Yield (kg/ha)
MOL	9/15/82	M_1	687 A
		M_2	793 A
		M_3	1057 A
WAI	8/27/81	M_1	2067 B
		M_2	2843 AB
		M_3	3250 A
MOL	5/12/81	M_1	2330 A
		M_2	2630 A
		M_3	2610 A
		M_4	3107 A
MOL	5/6/82	M_1	1745 C
		M_2	1910 BC
		M_3	2550 AB
		M_4	2780 A
WAI	5/1/81	M_1	3310 A
		M_2	2993 A
		M_3	4293 A
		M_4	3557 A
WAI	4/27/82	M_1	3677 B
		M_2	4230 AB
		M_3	5363 A
		M_4	4890 AB

* Note: Different crops on the same site were planted on separate plot locations.

[a] M_1 No inoculum, no nitrogen
M_2 No inoculum, 100 kg N/ha
M_3 With inoculum, no nitrogen
M_4 With inoculum and 20 kg N/ha

[b] For each site means followed by the same letter are not significantly different at 5% level, based on Waller Duncan test.

Table 4.40 Yield response of soybean to nitrogen application and rhizobium innoculation on Typic Paleudult sites.

Site	Planting Date	Treatment[a]	Mean[b] Yield (kg/ha)
NAK	3/11/81	M_1	1411 A
		M_2	1206 A
		M_3	1260 A
SOR *	6/3/81	M_1	1626 B
		M_2	1772 B
		M_3	2939 A
SOR *	7/6/82	M_1	2165 A
		M_2	2169 A
		M_3	2344 A
SOR **	2/16/82	M_1	1813 A
		M_2	1946 A
		M_3	1841 A

* Same plot location
** Different plot location

[a]
M_1 No inoculum, no nitrogen
M_2 No inoculum, 100 kg N/ha
M_3 With inoculum, no nitrogen
M_4 With inoculum, 20 kg N/ha

[b]
For each site means followed by the same letter are not significantly different at 5% level, based on Waller Duncan test.

response to 'N alone' (M_2) treatment over control. apparently for the same reason cited above. Significant response to Rhizobium inoculation was apparent only in IOLE for the 1981 crop. The better response to Rhizobium inoculation shown by the crop planted in May compared to that planted in September at IOLE and KUK suggests that Rhizobium is effective only when the other yield limiting factors are not dominant in influencing the yield. Premature flowering due to photoperiod sensitivity resulted in poor performance of the crops planted in September.

Comparative evaluation of treatment responses in Tropeptic Eutrustox and Hydric Dystrandept sites indicates a higher probability of response to Rhizobium inoculum in Tropeptic Eutrustox soils. This is illustrated in Figure 4.33, where yields for each treatment are averaged over all sites in each soil family. Poor response to Rhizobium inoculation can generally be expected in Hydric Dystrandepts for the following probable reasons:

1) High organic carbon content of these soils (> 6 %) shown in Table 3.2.

2) Better survivability of existing or previously introduced Rhizobium strains in the absence of the host plant, due to the prevailing moist and cool soil environment.

The low organic carbon contents (Table 3.2) as well as the ustic moisture regime of Eutrustox soils are factors that probably could contribute to better response for Rhizobium inoculation in these soils. Ustic soils having an isohyperthermic temperature regime are dry in some or all parts for 90 or more cumulative days. According to

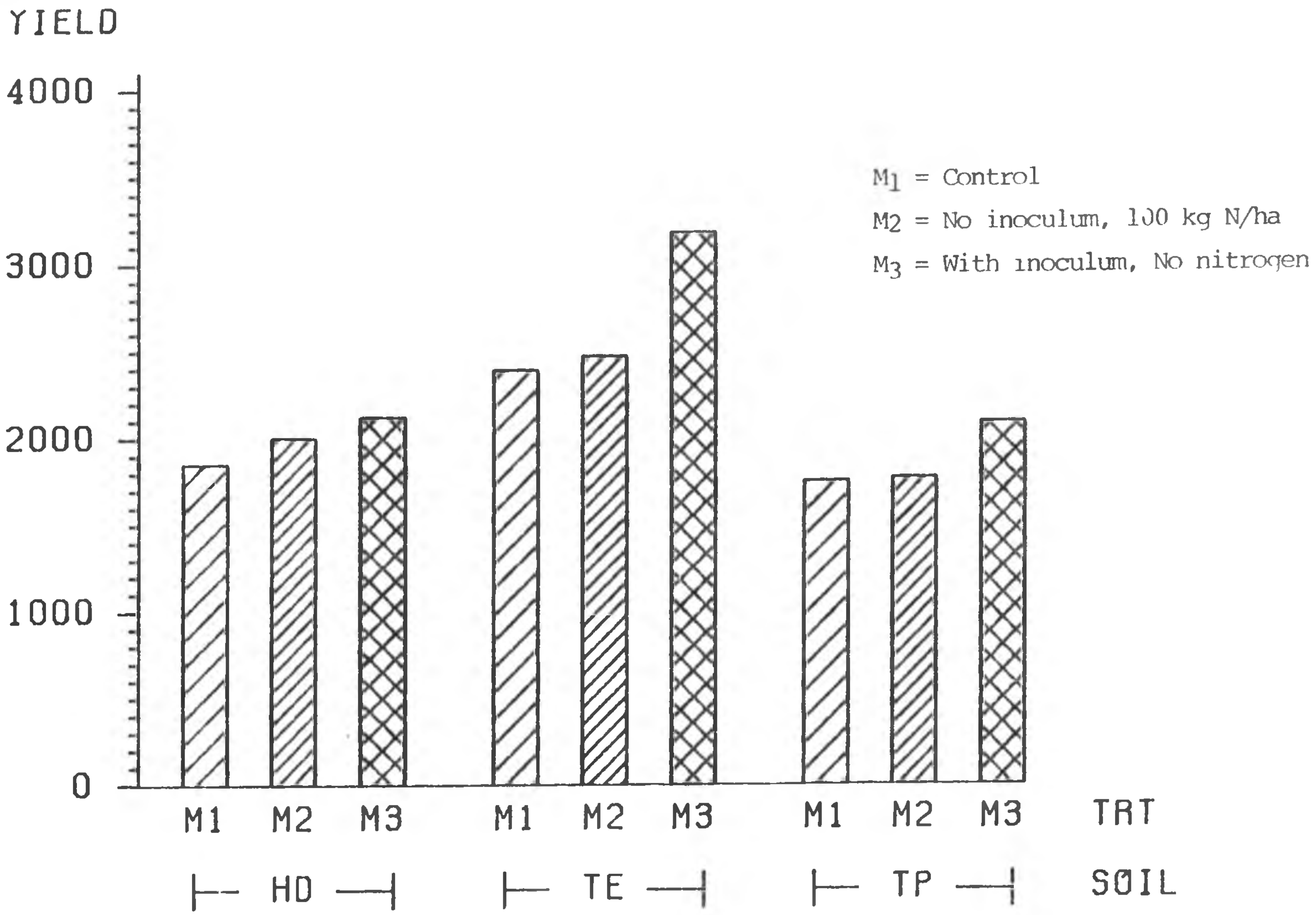


Figure 4.33. Effect of N application and rhizobium inoculation on soybean yields in Hydric Dystrandept (HD), Tropeptic Eutrustox (TE) and Typic Paleudult (TP) soils.

Graham et al. (1963) Rhizobia are susceptible to desiccation in natural soils. Osa-afiana and Alexander (1982) also found that drying is one of the factors affecting Rhizobium survival in tropical soils.

In Typic Paleudults, the NAK site did not show any response to N application as well as Rhizobium inoculation. It appears that high temperature (maximum air temperature > 36°C) restricts soybean performance in NAK. The results in the SOR site for the June 81 planting show a very significant response to Rhizobium inoculum. This particular block was recently cleared and not previously planted to soybean, hence possibly the lack of effective strains of Rhizobia in the soil, resulted in the response to the inoculum. In the following year (July, 82 planting) the same plots did not respond to Rhizobium inoculation indicating the possible persistence and dispersal of previously inoculated Rhizobia. The udic moisture regime of the soil is likely to assure the survivability of Rhizobia. The crop planted on 2/16/82 on the same site, but on a different set of plots also did not respond to N application and Rhizobium inoculation. This is probably due to the dispersal of the soil from previously inoculated adjacent plots, during land preparation.

4.6.1 Inference based on nodulation data

Nodulation data was available for the March, 83 crop in PAL (Table 4.41) and June, 81 crop in SOR (Table 4.42). In SOR the effectiveness of Rhizobia reflected in soybean yields was also vividly apparent from the number of nodules. Only the inoculated plants were nodulated, with no sign of nodulation in the M_1 (control) and

Table 4.41 Nodulation data and plant dry weight for soybean experiment at PAL site (planted March 14, 1983)

Treatment	Mean Yield (kg/ha)[b]	Number of nodules[a]	Nodule fresh weight (g)[a]	Dry weight of plants (g)[a]
M_1	2348 A	157	2.2	35.3
M_2	2803 A	91	1.1	37.0
M_3	2669 A	213	2.2	35.8

Table 4.42 Nodulation data and plant dry weight for soybean experiment at SOR site (planted June 3, 1981)

Treatment	Mean Yield (kg/ha)[b]	Number of nodules[a]	Nodule fresh weight (g)[a]	Dry weight of plants (g)[a]
M_1	1626 B	0	0	87.2
M_2	1772 B	0	0	80.8
M_3	2939 A	163	4.57	88.9

[a] Based on average of ten randomly selected plants in each replication seven weeks after planting.

[b] Means followed by the same letter are not significantly different at 5% level, based on Waller Duncan test.

M_2 (N application) treatments. Hence, it can be inferred that the M_1 and M_2 treated plants obtained their N requirement from soil supply alone. The dry weights of the sampled plants did not show any relationship with nodulation or yield.

In the Dystrandept site of PAL (Table 4.41) there was no significant response to inoculum, and nodules were found in all treatments. As expected, the Rhizobium alone (M_3) treatment resulted in plants with the maximum number of nodules, and the nitrogen treated plants had the minimum number of nodules. Probably the added nitrogen fertilizer in the M_2 treatment inhibits profuse nodulation. Adequate nodulation in the control treatment (M_1) demonstrates that the soil at the PAL site was not devoid of suitable Rhizobial strains. The dry weights of the sampled plants were proportional to the final yields.

Comparison of soybean yields, nodule number and nodule fresh weights recorded in the two sites, points out that the effectiveness of nodules in increasing plant yield is not a simple function of nodule number or weight.

4.7 Effect of side crop on yield of the main crop

In multiple cropping systems the assessment of the effect of a side crop on the border rows of the main crop is important for attempting efficient design of cropping patterns. In the present investigation, for the HD cropping pattern taro was cultivated as the long term side crop (please refer to Chapter III for layout and planting procedures) bordering the plots of the main crop. Data indicating the effect of the taro crop on the adjacent border rows of soybean and peanut plots were available for PAL and SOR sites. The comparative performance of the two central rows (not affected by taro) and two outer rows adjacent to taro is depicted in Table 4.43. The final yields of taro are presented in Table 4.44.

In SOR and PAL the outer rows of soybean as well as peanut were adversely affected due to competition with the adjacent taro rows. The border effect is more pronounced in PAL compared to the same in SOR. This is expected due to the better growth of taro in PAL as indicated by the yield data in Table 4.43. It is interesting to note that the detrimental border effect is greater for the peanut crop.

Being a short statured crop compared to soybean, peanut is shaded by the tall taro leaves. One of the other factors contributing to this may be the fact that the penetration of pegs (gynophores) and subsequent underground development of peanuts is hampered by the physical as well as nutritional interference of taro.

The present observations indicate that crops can differ substantially in their competitive ability and whenever there is a choice, the better competing crop can be chosen for an intercrop combination.

4.8 Relationship of crop duration with temperature and yield

Perusal of correlation matrices of crop yields, duration and agroclimatic variables indicated some interesting relationships between crop duration (number of days from planting to maturity) and soil as well as air temperatures. Simple correlation coefficients for relationships of temperature and yield with crop duration are

Table 4.43 Effect of adjacent border rows of taro on yield of soybean and peanut under irrigation.

Crop	Site	Average yield of 2 central rows (g)	Average yield of 2 outer rows bordering taro (g)	Planting date
Peanut	PAL	2075	1246	5/15/81
	SOR	1864	1338	6/3/81
Soybean	PAL	2527	1927	5/15/81
	SOR	1948	1853	6/3/81

Table 4.44 Taro yield data

Site	Yield of taro kg/ha	Planting date
PAL	3251	5/15/81
SOR	1715	7/1/81

presented in Table 4.45.

The site temperatures (soil and air) had significant negative correlations with duration (the number of days from planting to maturity) of Irish potato, head cabbage, soybean and peanut. Duration of green corn was, however, related only to average air temperature. This trend is expected due to the fact that high temperature leads to hastening of flowering as well as maturity of many crops. Compared to other crops, the maturity period of Irish potato appears to be highly sensitive to air and soil temperatures as indicated by large correlation coefficients.

Crop yields also showed a significant positive relationship with durations of Irish potato and soybean. This may be the result of longer time period available for production and translocation of photosynthate to the yield producing organs such as seeds and tubers. Lack of relationship between duration and yield of cabbage as well as green corn could be attributed to the nature of harvested products. In cabbage the whole above ground portion is harvested and recorded as yield, and hence the question of photosynthate translocation does not arise. Similarly the green corn yield includes the weight of tender corn grains as well as that of cobs.

Table 4.45 Simple correlation coefficients of air and soil temperature on day to maturity, and days to maturity on yield for selected crops.

Crop	Mean air temp. versus no. of days to maturity	Mean soil temp. versus no. of days to maturity	Yield versus no. of days to maturity	No. of observations
Irish Potato	-0.88**	-0.96**	0.74**	16
Cabbage	-0.68**	-0.60**	0.30 ns	19
Soybean	-0.44*	-0.57**	0.47**	30
Peanut	-0.57**	-0.55**	--	22
Green corn	-0.70**	-0.30 ns	-0.20 ns	18

CHAPTER V

SUMMARY AND CONCLUSIONS

Tropical regions provide an unique opportunity for boosting food production in the time dimension because of the favorable temperature and solar radiation prevailing throughout the year. A majority of the small farmers in the tropics do take advantage of such conditions through sequential cropping. It is therefore more relevant to evaluate the crop production potential of tropical agroenvironments through year-round cropping. In the present study, year-round cropping systems were used to evaluate a network of ten Benchmark soil sites representing the following tropical soil families :

(i) Thixotropic, isothermic soil family of Hydric Dystrandepts, with sites in Kukaiau (KUK) and Niulii (IOLE) in Hawaii, Palestina (PAL) in The Philippines and ITKA, and Segunung (LPH) in Indonesia.

(ii) Clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, with sites in Molokai (MOL) and Waipio (WAI) in Hawaii.

(iii) Clayey, kaolinitic, isohyperthermic family of Typic Paleudults with sites in Sorsogon (SOR), and Davao (BPI) in The Philippines and Nakau (NAK) in Indonesia.

Information about the agroenvironments inferred from the soil family name and the available weather data were utilized to select a set of crops and subsequently design cropping patterns for the three soil families. The seasonal variation of rainfall and temperature were considered for fitting crop sequences in the cropping patterns.

The cropping pattern for Hydric Dystrandepts consisted of vegetable crop combination of head cabbage, carrot and bushbean with Irish potato as an alternate crop followed by alternative vegetable crop combinations of bushbean and mustard cabbage or bushbean and green corn, then followed by soybean and peanut as alternate crops. Cassava was planted as a long term side crop. For Typic Paleudults the first season crops were upland rice (main crop) with green corn planted in wide rows followed by soybean and peanut as alternate crops, which were succeded by cowpea and mungbean as the alternatives. The long term side crops were cassava and taro. The cropping sequence designed for Tropeptic Eutrustox was Irish potato followed by soybean and then by corn. Intercrop combination of pigeon pea with taro, and cassava were grown as side crops.

All experimental sites were thoroughly characterized for soil and climate and continuously monitored for weather variables such as rainfall, air and soil temperature, relative humidity, wind speed and direction, and solar radiation.

Each soil family site was tested with a specifically designed cropping pattern and an alternate cropping pattern designed for another soil family, to rate crop performances under different environments. The specifically designed cropping pattern was tested with and without irrigation to judge the necessity of irrigation in udic and ustic moisture regimes. The alternate pattern was grown with irrigation. The crops of the first season were planted at the start of the rainy season.

As the main emphasis was on monitoring the effect of agroclimatic parameters on various crops and sequences of crops, the soil nutrients were optimized on all sites by following standardized procedures.

A Rhizobium inoculation and nitrogen application trial was superimposed on soybean crop in the above patterns to investigate the response to Rhizobium inoculation and N application in the three soil families.

The results in brief were as follows :

1) Protein and calorie production of completely irrigated crop sequences indicated that in Tropeptic Eutrustox soils the specifically designed TE pattern (Irish potato - soybean - corn) resulted in the highest yields. In the KUK site (Hydric Dystrandepts) contrary to expectation, the TE pattern resulted in higher calorie and protein yields than the specifically designed HD pattern (Irish potato, vegetables - vegetables - soybean, peanut). This was mainly due to the high soybean yields obtained during April to August (TE pattern) compared to that in the September to January period (HD pattern). The HD pattern had similar production potential on Eutrustox (MOL, WAI) and Dystrandept (KUK) sites with Eutrustox sites having a slight yield advantage. The excellent agricultural potential of Eutrustox soils was demonstrated by the record calorie (46,581 k cal/ha) and protein (2101 kg/ha) yields obtained in the WAI site. Except for the PAL and KUK sites the cropping pattern designed for a particular agroenvironment (e.g. HD pattern for Hydric Dystrandepts) performed better than the alternate pattern. The NAK site (Typic Paleudult) was found to be the least productive, evidently due to the high soil and air temperatures (> 27°C) compared to all other sites. The PAL site

(Dystrandepts) performed better when planted to the TP pattern (designed for Typic Paleudults) as temperatures here were comparable to those recorded for Paleudults (24 - 27°C).

2) Performance of individual irrigated crops depicted the sensitivity of crops such as head cabbage, mustard cabbage, Irish potato, carrot and bushbean, to high temperature and excess moisture. Their yield variability was effectively accounted for by soil and air temperature fluctuations, and rainfall intensities. On the other hand, soybean and peanut were found to possess a wide range of adaptability to temperature and moisture levels. Table 5.1 shows a tentative compilation of some agroclimatic requirements for different crops, deduced from the present study.

3) Irish potatoes, mustard cabbage, head cabbage and carrot are cool weather crops and their performance as expected was negatively correlated to soil temperature ($r > -0.70^{**}$). Highest yields of these crops were obtained within a soil temperature range of 18 to 22°C. The crops performed badly at mean soil temperatures above 24°C. Typic Paleudults had soil temperature beyond 24°C and hence could be separated effectively from other soil families based on the performance of the above crops. Temperature-wise the Dystrandept site of PAL was found to be isohyperthermic similar to Paleudult sites. Head cabbage and Irish potato crops failed completely when the rainfall for the crop period exceeded 1000 mm.

4) A negative relationship was found between bushbean yields and soil temperature ($r = -0.74^{**}$). Highest bushbean yields were obtained in a soil temperature range of 18 to 22°C. The low yielding Dystrandept

Figure 5.1 A tentative approximation of agroclimatic requirements for several crops, based on the present study.

Crop	Air Temperature (°C)			Soil Temperature (°C)		Rainfall (mm)	
	Min.	Max.	Mean	Mean			
	Favorable Range			Favorable Range	Unfavorable	Favorable	Unfavorable
Head Cabbage	13.0-19.0	23.0-28.0	18.0-23.5	18-22	> 26	230-300	> 800
Mustard Cabbage	16.0-18.0	22.0-26.0	-	18-21	> 25	230-350	-
Carrot	13.0-19.0	23.0-28.0	18.0-23.5	19-23	> 24	400-450	-
Irish potato	13.0-20.0	23.0-28.0	18.0-23.0	18-22	> 24	350-470	>650
Bushbean	-	22.0-26.0	18.0-25.8	18-22	> 24	100-200	-
Green corn	-	-	-	-	-	300-350	-
Soybean	17.0-23.0	25.0-35.0	21.2-28.0	-	-	800-1250	-
Peanut	14.0-23.5	25.0-35.0	21.0-28.0	21-28	-	650-700	-

sites of PAL and LPH had soil temperatures beyond 24°C, comparable to Paleudult sites. The decline of bushbean yield was also associated with an increase in rainfall ($r = -0.80^{**}$). The crop failed when the rainfall for the crop period exceeded 600 mm.

5) Soybean performance was good in an average air temperature range of 21.2 to 28.0°C. In KUK and IOLE (Dystrandepts) as well as in the Eutrustox site of WAI, soybean planted in April-May gave higher yields compared to the crop planted in August-September. The higher yields were associated with higher solar radiation, low rainfall and longer day lengths. Soybean yields were correlated positively with solar radiation.

6) Peanut also showed wide adaptability. High yields were obtained in cool Dystrandepts as well as in warm Paleudults. The highest yield was recorded in the Paleudult site of BPI (5179 kg/ha). The poor performance in NAK suggested a possible yield decline above a maximum air temperature of 35°C.

7) In contrast to other crops, there was a high positive correlation between non-irrigated yields of soybean and rainfall for the crop period over all sites. The highest yield (2200 kg/ha) was obtained at a rainfall of 1300 mm.

8) Regression equations using agroclimatic parameters as independent variables were derived to predict yields of different crops. Except for green corn, only crops that were sensitive to differences in temperature and excess moisture (mustard cabbage, head cabbage, carrot, bushbean, and Irish potato) yielded prediction equations with coefficients of determination close to 0.80. For soybean and peanut

the best models incorporating as many as six environmental parameters explained less than 50 percent of the yield variability. Soil temperature or its square root transformation was one of the independent variables in the regression equations for all crops except green corn, which is widely adapted to temperature fluctuation. Other agroclimatic variables used in the regression equations were rainfall, air temperature, relative humidity, solar radiation and wind velocity. Interaction terms such as "solar radiation * rainfall", "solar radiation * minimum air temperature" and "solar radiation * wind velocity" were also utilized as independent variables in regression equations for mustard cabbage, Irish potato and green corn yields. Good yield prediction equations with R squares of 0.97 and 0.96 were obtained for mustard cabbage and Irish potato.

9) On Hydric Dystrandept and Typic Paleudult sites, most crops did very well without irrigation. This reflects the udic moisture regime of these soils and also suggests that the matching of crop requirements to seasonal rainfall variation was adequate. Very poor performance of non-irrigated crops on Tropeptic Eutrustox sites confirmed the absolute necessity of supplemental irrigation for year-round crop production on these soils. The comparative moisture regimes of the three soil families was effectively demonstrated by the performance of the soybean crop with and without irrigation. The difference in yields with and without irrigation was minimal in Hydric Dystrandepts and maximum in Tropeptic Eutrustox soils.

10) In Eutrustox soils Rhizobium inoculation resulted in superior performance compared to the control. in most cases. However, N

application (100 kg/ha) did not result in significant yield increase over the control. There was a slight response to N application in Dystrandepts and significant response to Rhizobium was apparent only in IOLE. Overall results indicate a higher probability of response to Rhizobium inoculation in the Tropeptic Eutrustox than in Hydric Dystrandepts. In the Typic Paleudults, only one site (SOR) which was planted to soybean for the first time, showed a significant response to Rhizobium. The nodulation data collected in SOR showed profuse nodulation on inoculated plants that responded and no nodules in other treatments. In PAL where there was no response, almost equal number of nodules were present on plants representing the three treatments (control. Rhizobium inoculated, N applied).

11) Bushbean yields were higher in the "bushbean + mustard cabbage" combination compared to those of the "bushbean + green corn" combination.

12) Compared to other crops the maturity period of Irish potato was found to be highly sensitive to temperature. The duration of the Irish potato crop was negatively correlated with soil and air temperature ($r = -0.88^{**}$ and -0.96^{**}, respectively). The delay in maturity was found conducive to better yields.

13) The reduction of yield due to competition posed by the side crop of taro was greater in peanut than in soybean.

14) The efficacy of Soil Taxonomy to stratify agroenvironments for predicting crop yield potential

The distinctive feature of this study was the use of a taxonomically characterized and fully weather monitored network of widely separated tropical experimental sites. The agroclimatic information inferred from the soil family nomenclature was employed to select crops for the design of cropping patterns. Each of the three soil families were represented at least by two widely separated sites. Plant nutrients were optimized and all the management practices followed were standardized to be uniform on all sites. In effect the experimental set up was an attempt to verify three assumptions:

a) Two widely separated sites belonging to the same soil family have similar potential for crop production.

b) The soil family level of Soil Taxonomy stratifies temperature and moisture regimes effectively for predicting the behavior of different crops.

c) Features of agronomic significance that are not explicitely used to identify soil taxa such as solar radiation, precipitation, pests and diseases, wind speed etc. under normal conditions should be similar within a soil family.

The three assumptions are related to each other but stated separately for the convenience of discussion.

A drawback of this study was the availability of less than three years of crop data. To give allowance for the effects of abnormal weather and possible management errors, several years of data are desirable. But considering the cost and logistical problems involved, in such studies it is practical to extract the maximum information within a short experimental period. Because of the daily recording of weather data, it was possible to carefully screen out crops that were affected by random stresses such as typhoon winds, excessive rains, and also severe pest damage.

Making the critical assumption central to the present investigation of "identical varietal behavior", the analysis underscores the non feasibility of making precise yield estimates of crops at the same management level, based on the soil family. There was substantial year to year variation in crop yields on the same site during corresponding seasons. This is expected due to the marked influence of locational factors such as yearly variation in soil and air temperatures, precipitation, humidity, pest incidence etc., that respond to uniqueness of a particular season at a particular site.

Only the performance of crops that are sensitive to temperature and excess rainfall (head cabbage, Irish potato, carrot, mustard cabbage, bushbean) could segregate the soil families to a reasonable extent. The agroclimatic parameters most influential in affecting crop performance under conditions of uniform crop and soil management, were soil and air temperatures. Within a soil family, sites with similar soil and air temperatures performed differently mainly due to variations of rainfall, solar radiation and possibly wind speed.

The Typic Paleudult sites could be separated easily from other soil families due to poor performance of the above crops. The distinct behavior of this soil was apparently due to its higher soil and air temperatures (> 26°C) although soil physical conditions also may have played some role. However, the better performance of mustard cabbage, head cabbage and carrot in the Typic Paleudult site of SOR which has comparatively cooler temperatures (< 25°C), clearly indicates the necessity of creating an isomegathermic temperature regime for better prediction of crop behavior in tropical soils. This is especially true of the NAK site which recorded the highest soil and air temperatures (> 27°C) and had the lowest crop productivity even for the specifically designed TP pattern. The proximity of this site to the equator and the resultant influence of photoperiod also may have contributed to the site's low crop productivity.

Tropeptic Eutrustox sites which are classified as isohyperthermic, had soil temperatures (at 10 cm depth) equal to or below 22°C throughout the period of this study. Tropeptic Eutrustox soils differed from Hydric Dystrandepts in air temperature which was at least 4°C higher in the former. The Hydric Dystrandept sites of KUK and IOLE and Eutrustox site of WAI, were comparable in overall yield potential. However the sites of LPH and PAL (Dystrandepts) and MOL (Eutrustox) gave considerably lower yields compared to their counterparts.

The LPH and PAL sites had higher soil and air temperatures compared to the Dystrandept sites in Hawaii. In fact the average air and soil temperature (at 10 cms) in PAL were above 23°C, which is in the isohyperthermic range. The maximum air temperature also was at least 4°C above the same for all other Dystrandept sites. The performance of carrot, head cabbage, Irish potato and mustard cabbage indicated the possible reductions in yield potential of these crops due to higher temperatures within the Dystrandept sites. The results of this study clearly indicate the need to reassess the designation of isothermic temperature regime at least for the PAL site.

Despite the close similarity of MOL and WAI sites as far as rainfall, temperature and solar radiation were concerned, the yield performance of most crops was comparatively poor at the MOL site. This could be attributed to high wind velocity (> 15 km/hr) recorded routinely at MOL.

The general implications of the study are the following:

i) Classification at the soil family level of Soil Taxonomy is useful to select crops having a high probability of success in a given agroenvironment. However, actual crop yields will be determined by the uniqueness of weather in a particular season at a particular site.

ii) Performance of crops sensitive to high temperature within the tropical range, suggests the need to add a new temperature class which covers mean soil temperature at 50 cm greater than 28°C.

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
BSB	HD	1	AND	H	IOL	2	1	5565	1365	64	12.7	329	385	19.8	18.7	22.5	13.9	90	59	03/01/83
BSB	HD	1	AND	H	IOL	2	2	5610	2220	64	12.7	329	385	19.8	18.7	22.5	13.9	90	59	
BSB	HD	1	AND	H	IOL	2	3	4360	2985	64	12.7	329	385	19.8	18.7	22.5	13.9	90	59	
BSB	HD	2	AND	H	IOL	1	1	4540	4775	62	13.5	101	371	21.3	20.4	25.4	17.4	96	49	05/14/81
BSB	HD	2	AND	H	IOL	1	2	5095	4600	62	13.5	101	371	21.3	20.4	25.4	17.4	96	48	
BSB	HD	2	AND	H	IOL	1	3	6305	4140	62	13.5	101	371	21.3	20.4	25.4	17.4	96	48	
BSB	HD	2	AND	H	IOL	2	1	2820	2615	64	8.5	380	386	20.0	19.2	25.3	17.2	92	61	04/15/82
BSB	HD	2	AND	H	IOL	2	2	3460	2685	64	8.5	380	386	20.0	19.2	25.3	17.2	92	61	
BSB	HD	2	AND	H	IOL	2	3	3635	2605	64	8.5	380	386	20.0	19.2	25.3	17.2	92	61	
BSB	HD	1	AND	H	KUK	2	1	3570	3280	66	6.6	743	295	20.0	19.1	23.7	15.5	88	61	12/07/81
BSB	HD	1	AND	H	KUK	2	2	3390	2800	66	6.6	743	295	20.0	19.1	23.7	15.5	88	61	
BSB	HD	1	AND	H	KUK	2	3	3890	3490	66	6.6	743	295	20.0	19.1	23.7	15.5	88	61	
BSB	HD	1	AND	H	KUK	3	1	3280	4100	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	02/25/83
BSB	HD	1	AND	H	KUK	3	2	2915	2560	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	
BSB	HD	1	AND	H	KUK	3	3	1970	2425	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	
BSB	HD	2	AND	H	KUK	1	1	2532	4497	63	11.2	24	538	23.4	21.8	25.2	17.0	86	57	05/21/81
BSB	HD	2	AND	H	KUK	1	2	2212	5067	63	11.2	24	538	23.4	21.8	25.2	17.0	86	57	
BSB	HD	2	AND	H	KUK	1	3	3625	7032	63	11.2	24	538	23.4	21.8	25.2	17.0	86	57	
BSB	HD	2	AND	H	KUK	2	1	3095	2675	63	7.8	544	399	21.8	20.5	23.9	16.3	87	65	04/13/82
BSB	HD	2	AND	H	KUK	2	2	2755	2285	63	7.8	544	399	21.8	20.5	23.9	16.3	87	65	
BSB	HD	2	AND	H	KUK	2	3	2800	2150	63	7.8	544	399	21.8	20.5	23.9	16.3	87	65	
BSB	HD	1	AND	I	LPH	2	1	2208	832	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	12/11/82
BSB	HD	1	AND	I	LPH	2	2	1180	1322	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	
BSB	HD	1	AND	I	LPH	2	3	1253	437	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	
BSB	HD	2	AND	I	LPH	1	1	1288	1093	59	3.7	676	356	25.3	23.7	29.7	18.5	98	73	03/07/81
BSB	HD	2	AND	I	LPH	1	2	1150	977	59	3.7	676	356	25.3	23.7	29.7	18.5	98	73	
BSB	HD	2	AND	I	LPH	1	3	1478	806	59	3.7	676	356	25.3	23.7	29.7	18.5	98	73	
BSB	HD	2	AND	I	LPH	2	1	2727	2663	85	3.8	490	312	23.6	22.2	26.9	14.7	98	68	04/26/82
BSB	HD	2	AND	I	LPH	2	2	2752	3006	85	3.8	490	312	23.6	22.2	26.9	14.7	98	68	
BSB	HD	2	AND	I	LPH	2	3	3048	2694	85	3.8	490	312	23.6	22.2	26.9	14.7	98	68	
BSB	HD	1	AND	P	PAL	1	1	0	0	0	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	10/22/81
BSB	HD	1	AND	P	PAL	1	2	0	0	0	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
BSB	HD	1	AND	P	PAL	1	3	0	0	0	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
BSB	HD	2	AND	P	PAL	1	1	3126	2962	70	5.7	297	355	27.6	22.7	33.4	20.6	99	62	12/20/82
BSB	HD	2	AND	P	PAL	1	2	3001	2804	70	5.7	297	355	27.6	22.7	33.4	20.6	99	62	
BSB	HD	2	AND	P	PAL	1	3	2516	2851	70	5.7	297	355	27.6	22.7	33.4	20.6	99	62	
BSB	HD	2	AND	P	PAL	2	1	288	815	64	6.1	19	432	31.3	24.4	35.3	19.7	99	35	03/15/83
BSB	HD	2	AND	P	PAL	2	2	360	426	64	6.1	19	432	31.3	24.4	35.3	19.7	99	35	
BSB	HD	2	AND	P	PAL	2	3	408	704	64	6.1	19	432	31.3	24.4	35.3	19.7	99	35	
BSB	HD	1	OXI	H	MUL	1	1	2180	.	64	15.7	376	459	20.1	19.9	23.6	17.0	96	74	01/05/82
BSB	HD	1	OXI	H	MUL	1	2	2100	.	64	15.7	376	459	20.1	19.9	23.6	17.0	96	74	
BSB	HD	1	OXI	H	MUL	1	3	2340	.	64	15.7	376	459	20.1	19.9	23.6	17.0	96	74	
BSB	HD	2	OXI	H	MUL	1	1	3225	.	62	21.7	65	621	22.0	21.7	28.5	19.0	96	51	05/14/81
BSB	HD	2	OXI	H	MUL	1	2	2810	.	62	21.7	65	621	22.0	21.7	28.5	19.0	96	51	
BSB	HD	2	OXI	H	MUL	1	3	1755	.	62	21.7	65	621	22.0	21.7	28.5	19.0	96	51	
BSB	HD	2	OXI	H	MUL	2	1	3580	.	61	15.9	84	575	22.0	21.4	29.7	21.9	97	65	05/06/82
BSB	HD	2	OXI	H	MUL	2	2	3300	.	61	15.9	84	575	22.0	21.4	29.7	21.9	97	65	
BSB	HD	2	OXI	H	MUL	2	3	3640	.	61	15.9	84	575	22.0	21.4	29.7	21.9	97	65	
BSB	HD	1	OXI	H	WAI	1	1	6030	.	57	10.0	137	346	19.1	18.7	28.1	18.4	91	49	01/15/81
BSB	HD	1	OXI	H	WAI	1	2	6460	.	57	10.0	137	346	19.1	18.7	28.1	18.4	91	49	
BSB	HD	1	OXI	H	WAI	1	3	5690	.	57	10.0	137	346	19.1	18.7	28.1	18.4	91	49	
BSB	HD	1	OXI	H	WAI	2	1	3610	.	67	7.2	369	282	19.6	18.9	26.9	19.2	88	58	12/08/81
BSB	HD	1	OXI	H	WAI	2	2	3275	.	67	7.2	369	282	19.6	18.9	26.9	19.2	88	58	
BSB	HD	1	OXI	H	WAI	2	3	3845	.	67	7.2	369	282	19.6	18.9	26.9	18.2	88	58	
BSB	HD	1	OXI	H	WAI	3	1	7130	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	02/11/83

APPENDIX I CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
BSB	HD	1	OXI	H	WAI	3	2	6295	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	
BSB	HD	1	OXI	H	WAI	3	3	5545	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	
BSB	HD	2	OXI	H	WAI	1	1	9502	.	62	8.1	44	496	20.8	19.8	30.6	20.6	88	48	05/12/81
BSB	HD	2	OXI	H	WAI	1	2	6647	.	62	8.1	44	496	20.8	19.8	30.6	20.6	88	48	
BSB	HD	2	OXI	H	WAI	1	3	6510	.	62	8.1	44	496	20.8	19.8	30.6	20.6	88	48	
BSB	HD	2	OXI	H	WAI	2	1	5245	.	52	6.6	43	498	22.3	21.4	30.7	18.6	87	49	05/02/82
BSB	HD	2	OXI	H	WAI	2	2	6965	.	52	6.6	43	498	22.3	21.4	30.7	18.6	87	49	
BSB	HD	2	OXI	H	WAI	2	3	7700	.	52	6.6	43	498	22.3	21.4	30.7	18.6	87	49	
BSB	HD	1	ULT	I	NAK	2	1	458	.	74	3.9	1028	436	31.5	27.3	34.7	24.6	99	50	12/15/82
BSB	HD	1	ULT	I	NAK	2	2	606	.	74	3.9	1028	436	31.5	27.3	34.7	24.6	99	50	
BSB	HD	1	ULT	I	NAK	2	3	848	.	74	3.9	1028	436	31.5	27.3	34.7	24.6	99	50	
BSB	HD	2	ULT	I	NAK	1	1	750	.	43	3.2	411	432	29.4	28.9	36.8	23.0	99	41	03/11/81
BSB	HD	2	ULT	I	NAK	1	2	882	.	43	3.2	411	432	29.4	28.9	36.8	23.0	99	41	
BSB	HD	2	ULT	I	NAK	1	3	749	.	43	3.2	411	432	29.4	28.9	36.8	23.0	99	41	
BSB	HD	1	ULT	P	BPI	1	1	248	.	81	3.5	353	416	29.1	29.1	34.3	22.5	97	55	05/26/81
BSB	HD	1	ULT	P	BPI	1	2	835	.	81	3.5	353	416	29.1	29.1	34.3	22.5	97	55	
BSB	HD	1	ULT	P	BPI	1	3	475	.	81	3.5	353	416	29.1	29.1	34.3	22.5	97	55	
BSB	HD	2	ULT	P	BPI	1	1	588	.	68	4.7	524	407	26.2	26.2	33.8	22.0	98	57	09/28/81
BSB	HD	2	ULT	P	BPI	1	2	475	.	68	4.7	524	407	26.2	26.2	33.8	22.0	98	57	
BSB	HD	2	ULT	P	BPI	1	3	417	.	68	4.7	524	407	26.2	26.2	33.8	22.0	98	57	
BSB	HD	1	ULT	P	BPI	2	1	1317	.	87	4.9	217	439	26.4	26.4	30.6	21.7	84	46	07/09/82
BSB	HD	1	ULT	P	BPI	2	2	1996	.	87	4.9	217	439	26.4	26.4	30.6	21.7	84	46	
BSB	HD	1	ULT	P	BPI	2	3	1588	.	87	4.9	217	439	26.4	26.4	30.6	21.7	84	46	
BSB	HD	2	ULT	P	BPI	2	1	1087	.	103	5.6	444	405	26.0	26.0	33.6	21.4	89	39	11/05/82
BSB	HD	2	ULT	P	BPI	2	2	1036	.	103	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
BSB	HD	2	ULT	P	BPI	2	3	957	.	103	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
BSB	HD	1	ULT	P	SOR	1	1	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	10/29/81
BSB	HD	1	ULT	P	SOR	1	2	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
BSB	HD	1	ULT	P	SOR	1	.	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
BSB	HD	2	ULT	P	SOR	1	1	4126	.	63	9.1	404	382	26.2	24.6	28.8	19.9	76	66	02/16/82
BSB	HD	2	ULT	P	SOR	1	2	3647	.	63	9.1	404	382	26.2	24.6	28.8	19.9	76	66	
BSB	HD	2	ULT	P	SOR	1	3	3121	.	63	9.1	404	382	26.2	24.6	28.8	19.9	76	66	
BSB	HD	1	ULT	P	SOR	2	1	1307	.	65	8.0	369	324	27.0	25.7	30.4	21.6	90	79	11/16/82
BSB	HD	1	ULT	P	SOR	2	2	522	.	65	8.0	369	324	27.0	25.7	30.4	21.6	90	79	
BSB	HD	1	ULT	P	SOR	2	3	1782	.	65	8.0	369	324	27.0	25.7	30.4	21.6	90	79	
CAB	HD	1	AND	H	IOL	1	1	6160	5250	86	10.3	781	280	18.2	18.0	24.4	15.7	91	59	12/03/81
CAB	HD	1	AND	H	IOL	1	2	5080	7980	86	10.3	781	280	18.2	18.0	24.4	15.7	91	59	
CAB	HD	1	AND	H	IOL	1	3	7140	6410	86	10.3	781	280	18.2	18.0	24.4	15.7	91	59	
CAB	HD	1	AND	H	IOL	3	1	15250	14770	92	10.6	298	364	18.9	18.2	23.0	13.1	90	54	01/26/83
CAB	HD	1	AND	H	IOL	3	2	10795	17350	92	10.6	298	364	18.9	18.2	23.0	13.1	90	54	
CAB	HD	1	AND	H	IOL	3	3	12030	15925	92	10.6	298	364	18.9	18.2	23.0	13.1	90	54	
CAB	HD	1	AND	H	KUK	1	1	21690	12880	66	11.8	234	440	19.8	18.9	23.3	15.2	88	56	02/06/81
CAB	HD	1	AND	H	KUK	1	2	18420	21270	66	11.8	234	440	19.8	18.9	23.3	15.2	88	56	
CAB	HD	1	AND	H	KUK	1	3	15200	20740	66	11.8	234	440	19.8	18.9	23.3	15.2	88	56	
CAB	HD	1	AND	H	KUK	2	1	10700	11550	82	6.5	783	306	20.0	19.1	24.0	15.6	85	61	12/03/81
CAB	HD	1	AND	H	KUK	2	2	9300	12290	82	6.5	783	306	20.0	19.1	24.0	15.6	85	61	
CAB	HD	1	AND	H	KUK	2	3	12330	9580	82	6.5	783	306	20.0	19.1	24.0	15.6	85	61	
CAB	HD	1	AND	H	KUK	3	1	16735	22110	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	02/25/83
CAB	HD	1	AND	H	KUK	3	2	16410	19995	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	
CAB	HD	1	AND	H	KUK	3	3	17250	18450	61	8.2	412	397	21.0	20.2	24.9	16.8	81	58	
CAB	HD	1	AND	I	LPH	1	1	2313	6684	115	3.9	1450	245	23.1	22.0	25.4	15.8	90	71	12/10/81
CAB	HD	1	AND	I	LPH	1	2	3304	6226	115	3.9	1450	245	23.1	22.0	25.4	15.9	90	71	
CAB	HD	1	AND	I	LPH	1	3	2648	4532	115	3.9	1450	245	23.1	22.0	25.4	15.8	90	71	
CAB	HD	1	AND	I	LPH	2	1	6283	6552	89	3.5	1151	376	23.9	22.6	26.3	16.1	99	89	12/11/82
CAB	HD	1	AND	I	LPH	2	2	3233	8429	89	3.5	1151	376	23.9	22.6	26.3	16.1	99	89	

APPENDIX I CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
CAB	HD	1	AND	I	LPH	2	3	3304	6317	89	3.5	1151	376	23.9	22.6	26.3	16.1	99	89	
CAB	HD	1	AND	P	PAL	1	1	1481	1012	93	8.4	1699	302	24.6	22.5	29.1	20.6	97	68	10/22/81
CAB	HD	1	AND	P	PAL	1	2	608	1225	93	8.4	1699	302	24.6	22.5	29.1	20.6	97	69	
CAB	HD	1	AND	P	PAL	1	3	1556	3354	93	8.4	1699	302	24.6	22.5	29.1	20.6	97	68	
CAB	HD	1	AND	P	PAL	2	1	4651	2536	76	5.6	766	293	24.5	22.5	30.5	20.2	99	69	11/15/82
CAB	HD	1	AND	P	PAL	2	2	3432	4806	76	5.6	766	293	24.5	22.5	30.5	20.2	99	69	
CAB	HD	1	AND	P	PAL	2	3	4479	6828	76	5.6	766	293	24.5	22.5	30.5	20.2	99	69	
CAB	HD	1	OXI	H	MOL	1	1	7150	.	80	15.8	445	454	20.1	19.9	23.9	17.0	96	73	01/04/82
CAB	HD	1	OXI	H	MOL	1	2	7950	.	80	15.8	445	454	20.1	19.9	23.9	17.0	96	73	
CAB	HD	1	OXI	H	MOL	1	3	5800	.	80	15.8	445	454	20.1	19.9	23.9	17.0	96	73	
CAB	HD	1	OXI	H	MOL	2	1	10925	.	61	15.8	52	521	19.8	19.6	27.8	18.2	99	75	02/23/83
CAB	HD	1	OXI	H	MOL	2	2	7985	.	61	15.8	52	521	19.8	19.6	27.8	18.2	99	75	
CAB	HD	1	OXI	H	MOL	2	3	7310	.	61	15.8	52	521	19.8	19.6	27.8	18.2	99	75	
CAB	HD	1	OXI	H	WAI	1	1	16590	.	67	9.9	137	356	18.9	18.8	28.1	18.2	91	48	01/15/81
CAB	HD	1	OXI	H	WAI	1	2	14690	.	67	9.9	137	356	18.9	18.8	28.1	18.2	91	48	
CAB	HD	1	OXI	H	WAI	1	3	16690	.	67	9.9	137	356	18.9	18.8	28.1	18.2	91	48	
CAB	HD	1	OXI	H	WAI	2	1	9120	.	76	7.3	386	289	19.7	19.0	27.1	18.2	88	57	12/07/81
CAB	HD	1	OXI	H	WAI	2	2	8730	.	76	7.3	386	289	19.7	19.0	27.1	18.2	88	57	
CAB	HD	1	OXI	H	WAI	2	3	8850	.	76	7.3	386	289	19.7	19.0	27.1	18.2	88	57	
CAB	HD	1	OXI	H	WAI	3	1	14285	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	02/11/83
CAB	HD	1	OXI	H	WAI	3	2	15160	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	
CAB	HD	1	OXI	H	WAI	3	3	13995	.	60	6.8	56	740	21.0	20.7	28.0	15.4	79	44	
CAB	HD	1	ULT	I	NAK	1	1	0	.	.	3.6	497	400	28.6	27.6	33.2	22.0	96	38	10/27/81
CAB	HD	1	ULT	I	NAK	1	2	0	.	0	3.6	497	400	28.6	27.6	33.2	22.0	96	38	
CAB	HD	1	ULT	I	NAK	1	3	0	.	0	3.6	497	400	28.6	27.6	33.2	22.0	96	38	
CAB	HD	1	ULT	I	NAK	2	1	0	.	0	3.4	1861	438	31.8	27.3	35.7	24.6	99	50	12/15/82
CAB	HD	1	ULT	I	NAK	2	2	0	.	0	3.4	1861	438	31.8	27.3	35.7	24.6	99	50	
CAB	HD	1	ULT	I	NAK	2	3	0	.	0	3.4	1861	438	31.8	27.3	35.7	24.6	99	50	
CAB	HD	1	ULT	P	BPI	1	1	777	.	74	3.5	353	418	29.1	29.1	34.4	22.5	97	56	05/26/81
CAB	HD	1	ULT	P	BPI	1	2	1140	.	74	3.5	353	418	29.1	29.1	34.4	22.5	97	56	
CAB	HD	1	ULT	P	BPI	1	3	625	.	74	3.5	353	418	29.1	29.1	34.4	22.5	97	56	
CAB	HD	1	ULT	P	BPI	2	1	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	06/02/82
CAB	HD	1	ULT	P	BPI	2	2	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
CAB	HD	1	ULT	P	BPI	2	3	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
CAB	HD	1	ULT	P	SOR	1	1	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	10/29/81
CAB	HD	1	ULT	P	SOR	1	2	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
CAB	HD	1	ULT	P	SOR	1	3	0	.	.	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
CAB	HD	1	ULT	P	SOR	2	1	1100	.	72	8.0	381	322	27.0	25.7	30.4	21.6	90	79	11/17/82
CAB	HD	1	ULT	P	SOR	2	2	1636	.	72	8.0	381	322	27.0	25.7	30.4	21.6	90	79	
CAB	HD	1	ULT	P	SOR	2	3	2688	.	72	8.0	381	322	27.0	25.7	30.4	21.6	90	79	
CRT	HD	1	AND	H	IOL	2	1	15965	9850	112	11.1	430	367	18.7	18.1	22.8	13.2	90	56	01/26/83
CRT	HD	1	AND	H	IOL	2	2	13125	16380	112	11.1	430	367	18.7	18.1	22.8	13.2	90	56	
CRT	HD	1	AND	H	IOL	2	3	18615	12320	112	11.1	430	367	18.7	18.1	22.8	13.2	90	56	
CRT	HD	1	AND	H	KUK	1	1	10830	4920	108	11.2	421	437	20.2	19.0	23.8	15.3	88	55	01/20/81
CRT	HD	1	AND	H	KUK	1	2	6160	300	108	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
CRT	HD	1	AND	H	KUK	1	3	10180	885	108	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
CRT	HD	1	AND	H	KUK	2	1	11830	12720	123	7.0	1193	317	20.5	19.6	23.8	15.9	85	62	11/03/81
CRT	HD	1	AND	H	KUK	2	2	9900	10870	123	7.0	1193	317	20.5	19.6	23.8	15.9	85	62	
CRT	HD	1	AND	H	KUK	2	3	10860	10260	123	7.0	1193	317	20.5	19.6	23.8	15.9	85	62	
CRT	HD	1	AND	H	KUK	3	1	20175	25640	116	8.1	864	382	20.4	19.5	25.4	16.6	81	54	01/21/83
CRT	HD	1	AND	H	KUK	3	2	19340	21365	116	8.1	864	382	20.4	19.5	25.4	16.6	81	54	
CRT	HD	1	AND	H	KUK	3	3	16520	21990	116	8.1	864	382	20.4	19.5	25.4	16.6	81	54	
CRT	HD	1	AND	I	LPH	1	1	11108	10734	115	3.9	1450	245	23.1	22.0	25.4	15.8	90	71	12/19/81
CRT	HD	1	AND	I	LPH	1	2	11562	9229	115	3.9	1450	245	23.1	22.0	25.4	15.8	90	71	
CRT	HD	1	AND	I	LPH	1	3	10695	10414	115	3.9	1450	245	23.1	22.0	25.4	15.9	90	71	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
CRT	HD	1	AND	I	LPH	2	1	10287	6198	99	3.5	1212	379	23.9	22.6	26.3	16.1	99	89	12/11/82
CRT	HD	1	AND	I	LPH	2	2	8306	7883	99	3.5	1212	379	23.9	22.6	26.3	16.1	99	89	
CRT	HD	1	AND	I	LPH	2	3	9979	9054	99	3.5	1212	379	23.9	22.6	26.3	16.1	99	89	
CRT	HD	1	AND	P	PAL	2	1	3314	3886	115	5.4	864	321	25.1	22.6	30.8	20.2	99	66	10/15/82
CRT	HD	1	AND	P	PAL	2	2	5170	6814	115	5.4	864	321	25.1	22.6	30.8	20.2	99	66	
CRT	HD	1	AND	P	PAL	2	3	4118	4134	115	5.4	864	321	25.1	22.6	30.8	20.2	99	66	
CRT	HD	1	OXI	H	MUL	1	1	18650	.	118	16.6	652	402	20.9	20.7	25.1	18.0	95	71	11/06/81
CRT	HD	1	OXI	H	MUL	1	2	12670	.	118	16.6	652	402	20.9	20.7	25.1	18.0	95	71	
CRT	HD	1	OXI	H	MUL	1	3	9570	.	118	16.6	652	402	20.9	20.7	25.1	18.0	95	71	
CRT	HD	1	OXI	H	MUL	2	1	18275	.	100	16.0	104	506	19.6	19.4	27.3	18.2	99	76	01/27/83
CRT	HD	1	OXI	H	MUL	2	2	18525	.	100	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
CRT	HD	1	OXI	H	MUL	2	3	12865	.	100	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
CRT	HD	1	OXI	H	WAI	1	1	9320	.	112	9.4	218	395	19.5	19.0	28.4	18.1	91	48	01/15/81
CRT	HD	1	OXI	H	WAI	1	2	6520	.	112	9.4	218	395	19.5	19.0	28.4	18.1	91	48	
CRT	HD	1	OXI	H	WAI	1	3	6570	.	112	9.4	218	395	19.5	19.0	28.4	18.1	91	48	
CRT	HD	1	OXI	H	WAI	2	1	17870	.	125	7.6	500	313	19.4	18.7	27.1	18.5	88	57	11/06/81
CRT	HD	1	OXI	H	WAI	2	2	20270	.	125	7.6	500	313	19.4	18.7	27.1	18.5	88	57	
CRT	HD	1	OXI	H	WAI	2	3	14350	.	125	7.6	500	313	19.4	18.7	27.1	18.5	88	57	
CRT	HD	1	OXI	H	WAI	3	1	28270	.	103	7.0	91	699	20.7	20.4	27.4	15.3	79	45	01/14/83
CRT	HD	1	OXI	H	WAI	3	2	27270	.	103	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
CRT	HD	1	OXI	H	WAI	3	3	27635	.	103	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
CRT	HD	1	ULT	I	NAK	1	1	1152	.	81	3.8	716	405	28.7	27.4	33.0	21.6	96	40	10/27/81
CRT	HD	1	ULT	I	NAK	1	2	944	.	81	3.8	716	405	28.7	27.4	33.0	21.6	96	40	
CRT	HD	1	ULT	I	NAK	1	3	1597	.	81	3.8	716	405	28.7	27.4	33.0	21.6	96	40	
CRT	HD	1	ULT	I	NAK	2	1	2022	.	134	3.4	1861	438	31.7	27.2	35.7	24.5	99	48	12/15/82
CRT	HD	1	ULT	I	NAK	2	2	2214	.	134	3.4	1861	438	31.7	27.2	35.7	24.5	99	48	
CRT	HD	1	ULT	I	NAK	2	3	2056	.	134	3.4	1861	438	31.7	27.2	35.7	24.5	99	48	
CRT	HD	1	ULT	P	BPI	1	1	3469	.	114	4.1	563	442	29.1	29.1	34.4	22.6	97	53	05/02/81
CRT	HD	1	ULT	P	BPI	1	2	3667	.	114	4.1	563	442	29.1	29.1	34.4	22.6	97	53	
CRT	HD	1	ULT	P	BPI	1	3	2292	.	114	4.1	563	442	29.1	29.1	34.4	22.6	97	53	
CRT	HD	1	ULT	P	BPI	2	1	6654	.	113	4.7	643	422	28.4	28.4	33.5	22.4	87	49	06/02/82
CRT	HD	1	ULT	P	BPI	2	2	5483	.	113	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
CRT	HD	1	ULT	P	BPI	2	3	5117	.	113	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
CRT	HD	1	ULT	P	SOR	1	1	7071	.	106	11.2	1634	335	26.5	25.3	28.1	21.7	88	77	10/05/81
CRT	HD	1	ULT	P	SOR	1	2	5612	.	106	11.2	1634	335	26.5	25.3	28.1	21.7	88	77	
CRT	HD	1	ULT	P	SOR	1	3	5604	.	106	11.2	1634	335	26.5	25.3	28.1	21.7	88	77	
CRT	HD	1	ULT	P	SOR	2	1	7816	.	120	7.9	571	336	27.3	25.8	30.8	21.5	89	76	10/11/82
CRT	HD	1	ULT	P	SOR	2	2	5239	.	120	7.9	571	336	27.3	25.8	30.8	21.5	89	76	
CRT	HD	1	ULT	P	SOR	2	3	4878	.	120	7.9	571	336	27.3	25.8	30.8	21.5	89	76	
CWP	TP	3	AND	I	LPH	1	1	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	----
CWP	TP	3	AND	I	LPH	1	2	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
CWP	TP	3	AND	I	LPH	1	3	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
CWP	TP	3	AND	I	LPH	2	1	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	----
CWP	TP	3	AND	I	LPH	2	2	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
CWP	TP	3	AND	I	LPH	2	3	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
CWP	TP	3	AND	P	PAL	1	1	882	.	111	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	05/15/81
CWP	TP	3	AND	P	PAL	1	2	758	.	111	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	
CWP	TP	3	AND	P	PAL	1	3	753	.	111	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	
CWP	TP	3	AND	P	PAL	2	1	1164	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	06/29/82
CWP	TP	3	AND	P	PAL	2	2	1019	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	
CWP	TP	3	AND	P	PAL	2	3	972	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	
CWP	TP	3	ULT	I	NAK	1	1	163	40	56	4.3	20	386	29.4	27.1	37.4	23.7	99	31	07/01/82
CWP	TP	3	ULT	I	NAK	1	2	102	36	56	4.3	20	386	29.4	27.1	37.4	23.7	99	31	
CWP	TP	3	ULT	I	NAK	1	3	110	64	56	4.3	20	386	29.4	27.1	37.4	23.7	99	31	
CWP	TP	3	ULT	P	BPI	1	1	593	229	121	9.1	614	435	.	.	34.2	22.4	92	44	02/10/81

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
CWP	TP	3	ULT	P	BPI	1	2	464	219	121	9.1	614	435	.	.	34.2	22.4	92	44	
CWP	TP	3	ULT	P	BPI	1	3	482	154	121	9.1	614	435	.	.	34.2	22.4	92	44	
CWP	TP	3	ULT	P	BPI	2	1	924	418	75	5.9	25	430	.	.	34.2	22.2	98	47	02/11/82
CWP	TP	3	ULT	P	BPI	2	2	856	500	75	5.9	25	430	.	.	34.2	22.2	98	47	
CWP	TP	3	ULT	P	BPI	2	3	591	376	75	5.9	25	430	.	.	34.2	22.2	98	47	
CWP	TP	3	ULT	P	SOR	1	1	1126	1025	86	7.3	931	395	28.6	26.9	32.2	23.5	84	65	06/03/81
CWP	TP	3	ULT	P	SOR	1	2	837	992	86	7.3	931	395	28.6	26.9	32.2	23.5	84	65	
CWP	TP	3	ULT	P	SOR	1	3	884	1230	86	7.3	931	395	28.6	26.9	32.2	23.5	84	65	
CWP	TP	3	ULT	P	SOR	2	1	1374	0	77	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	07/02/82
CWP	TP	3	ULT	P	SOR	2	2	1233	0	77	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	
CWP	TP	3	ULT	P	SOR	2	3	1403	0	77	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	
FCN	TE	3	AND	H	IOL	2	1	2500	.	125	8.8	602	287	19.1	19.0	21.7	13.1	90	64	09/21/82
FCN	TE	3	AND	H	IOL	2	2	2710	.	125	8.8	602	287	19.1	19.0	21.7	13.1	90	64	
FCN	TE	3	AND	H	IOL	2	3	2030	.	125	8.8	602	287	19.1	19.0	21.7	13.1	90	64	
FCN	TE	3	AND	H	KUK	1	1	4170	.	145	4.5	1384	320	21.2	20.3	24.2	17.3	86	63	10/02/81
FCN	TE	3	AND	H	KUK	1	2	3900	.	145	4.5	1384	320	21.2	20.3	24.2	17.3	86	63	
FCN	TE	3	AND	H	KUK	1	3	4510	.	145	4.5	1384	320	21.2	20.3	24.2	17.3	86	63	
FCN	TE	3	AND	H	KUK	2	1	3830	.	130	9.0	721	346	21.9	20.6	26.1	18.7	84	61	09/10/82
FCN	TE	3	AND	H	KUK	2	2	4000	.	130	9.0	721	346	21.9	20.6	26.1	18.7	84	61	
FCN	TE	3	AND	H	KUK	2	3	4280	.	130	9.0	721	346	21.9	20.6	26.1	18.7	84	61	
FCN	TE	3	OXI	H	MOL	2	1	3950	.	122	17.1	443	460	21.2	20.8	28.0	20.2	99	84	09/17/82
FCN	TE	3	OXI	H	MOL	2	2	3050	.	122	17.1	443	460	21.2	20.8	28.0	20.2	99	84	
FCN	TE	3	OXI	H	MOL	2	3	3090	.	122	17.1	443	460	21.2	20.8	28.0	20.2	99	84	
FCN	TE	3	OXI	H	WAI	1	1	4260	0	112	7.3	358	352	19.0	17.7	29.6	20.0	88	53	09/16/81
FCN	TE	3	OXI	H	WAI	1	2	4260	0	112	7.3	358	352	19.0	17.7	29.6	20.0	88	53	
FCN	TE	3	OXI	H	WAI	1	3	4010	0	112	7.3	358	352	19.0	17.7	29.6	20.0	88	53	
FCN	TE	3	OXI	H	WAI	2	1	530	0	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	09/22/82
FCN	TE	3	OXI	H	WAI	2	2	930	0	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	
FCN	TE	3	OXI	H	WAI	2	3	795	0	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	
GCN	HD	2	AND	H	IOL	1	1	17300	12500	99	12.8	317	402	20.9	22.0	26.0	17.8	96	54	05/28/81
GCN	HD	2	AND	H	IOL	1	2	19600	11400	99	12.8	317	402	20.9	22.0	26.0	17.8	96	54	
GCN	HD	2	AND	H	IOL	1	3	16200	9600	99	12.8	317	402	20.9	22.0	26.0	17.8	96	54	
GCN	HD	2	AND	H	IOL	2	1	7520	9000	96	9.1	466	346	21.1	20.4	25.6	17.6	91	63	05/04/82
GCN	HD	2	AND	H	IOL	2	2	7390	7550	96	9.1	466	346	21.1	20.4	25.6	17.6	91	63	
GCN	HD	2	AND	H	IOL	2	3	7835	7690	96	9.1	466	346	21.1	20.4	25.6	17.6	91	63	
GCN	HD	2	AND	H	KUK	1	1	13565	0	111	11.3	211	514	23.7	22.2	25.1	17.4	87	59	06/03/81
GCN	HD	2	AND	H	KUK	1	2	12710	0	111	11.3	211	514	23.7	22.2	25.1	17.4	87	59	
GCN	HD	2	AND	H	KUK	1	3	11985	0	111	11.3	211	514	23.7	22.2	25.1	17.4	87	59	
GCN	HD	2	AND	H	KUK	2	1	10890	7410	88	7.8	534	414	23.2	21.8	24.8	17.3	86	66	05/03/82
GCN	HD	2	AND	H	KUK	2	2	9690	10180	88	7.8	534	414	23.2	21.8	24.8	17.3	86	66	
GCN	HD	2	AND	H	KUK	2	3	11450	9590	88	7.8	534	414	23.2	21.8	24.8	17.3	86	66	
GCN	HD	2	AND	I	ITK	1	1	4508	5987	136	5.2	315	310	23.1	23.1	26.4	15.5	99	47	05/21/81
GCN	HD	2	AND	I	ITK	1	2	6215	5173	136	5.2	315	310	23.1	23.1	26.4	15.5	99	47	
GCN	HD	2	AND	I	ITK	1	3	6014	6665	136	5.2	315	310	23.1	23.1	26.4	15.5	99	47	
GCN	HD	2	AND	I	LPH	1	1	4822	6203	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	03/07/81
GCN	HD	2	AND	I	LPH	1	2	4847	4346	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	
GCN	HD	2	AND	I	LPH	1	3	7334	4169	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	
GCN	HD	2	AND	I	LPH	2	1	5011	4215	137	3.9	595	320	23.4	21.8	26.8	14.3	99	61	04/26/82
GCN	HD	2	AND	I	LPH	2	2	4527	3749	137	3.9	595	320	23.4	21.8	26.8	14.3	99	61	
GCN	HD	2	AND	I	LPH	2	3	4709	4374	137	3.9	595	320	23.4	21.8	26.8	14.3	99	61	
GCN	HD	2	AND	P	PAL	1	1	9805	5891	79	5.6	643	369	27.9	23.2	34.1	21.3	99	58	03/11/82
GCN	HD	2	AND	P	PAL	1	2	9420	6744	79	5.6	643	369	27.9	23.2	34.1	21.3	99	59	
GCN	HD	2	AND	P	PAL	1	3	9650	6833	79	5.6	643	369	27.9	23.2	34.1	21.3	99	58	
GCN	HD	2	AND	P	PAL	2	1	8722	2057	79	6.1	16	427	32.2	24.7	35.9	20.4	99	34	04/04/83
GCN	HD	2	AND	P	PAL	2	2	10167	5850	79	6.1	16	427	32.2	24.7	35.9	20.4	99	34	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
GCN	HD	2	AND	P	PAL	2	3	9611	1787	79	6.1	16	427	32.2	24.7	35.9	20.4	99	34	
GCN	HD	2	OXI	H	MOL	1	1	9200	.	86	21.3	140	560	23.2	22.7	29.1	20.0	95	56	06/01/81
GCN	HD	2	OXI	H	MOL	1	2	8460	.	86	21.3	140	560	23.2	22.7	29.1	20.0	95	56	
GCN	HD	2	OXI	H	MOL	1	3	6590	.	86	21.3	140	560	23.2	22.7	29.1	20.0	95	56	
GCN	HD	2	OXI	H	MOL	2	1	6700	.	76	18.8	149	589	22.2	21.9	30.2	22.3	99	73	05/28/82
GCN	HD	2	OXI	H	MOL	2	2	7490	.	76	18.8	149	589	22.2	21.9	30.2	22.3	99	73	
GCN	HD	2	OXI	H	MOL	2	3	3490	.	76	18.8	149	589	22.2	21.9	30.2	22.3	99	73	
GCN	HD	2	OXI	H	WAI	1	1	9210	.	82	7.3	40	493	21.6	20.4	31.2	21.3	89	50	06/01/81
GCN	HD	2	OXI	H	WAI	1	2	14780	.	82	7.3	40	493	21.6	20.4	31.2	21.3	89	50	
GCN	HD	2	OXI	H	WAI	1	3	12860	.	82	7.3	40	493	21.6	20.4	31.2	21.3	89	50	
GCN	HD	2	OXI	H	WAI	2	1	7750	.	78	6.8	82	457	23.6	22.7	31.4	19.6	87	50	05/21/82
GCN	HD	2	OXI	H	WAI	2	2	9760	.	78	6.8	82	457	23.6	22.7	31.4	19.6	87	50	
GCN	HD	2	OXI	H	WAI	2	3	11760	.	78	6.8	82	457	23.6	22.7	31.4	19.6	87	50	
GCN	HD	2	ULT	I	NAK	1	1	4596	.	85	2.9	655	410	28.9	28.6	36.3	23.3	99	42	03/11/81
GCN	HD	2	ULT	I	NAK	1	2	6290	.	85	2.9	655	410	28.9	28.6	36.3	23.3	99	42	
GCN	HD	2	ULT	I	NAK	1	3	4588	.	85	2.9	655	410	29.9	28.6	36.3	23.3	99	42	
GCN	HD	2	ULT	I	NAK	2	1	4778	.	84	2.7	759	374	31.0	27.5	35.4	21.2	96	35	03/09/82
GCN	HD	2	ULT	I	NAK	2	2	4762	.	84	2.7	759	374	31.0	27.5	35.4	21.2	96	35	
GCN	HD	2	ULT	I	NAK	2	3	5334	.	84	2.7	759	374	31.0	27.5	35.4	21.2	96	35	
GCN	HD	2	ULT	P	BPI	1	1	7194	.	84	5.2	415	390	25.2	25.2	32.5	21.9	98	57	10/11/81
GCN	HD	2	ULT	P	BPI	1	2	6690	.	84	5.2	415	390	25.2	25.2	32.5	21.9	98	57	
GCN	HD	2	ULT	P	BPI	1	3	7080	.	84	5.2	415	390	25.2	25.2	32.5	21.9	98	57	
GCN	HD	2	ULT	P	BPI	2	1	4222	.	88	5.6	238	393	25.9	25.9	33.4	21.5	91	41	11/17/82
GCN	HD	2	ULT	P	BPI	2	2	4880	.	88	5.6	238	393	25.9	25.9	33.4	21.5	91	41	
GCN	HD	2	ULT	P	BPI	2	3	4440	.	88	5.6	238	393	25.9	25.9	33.4	21.5	91	41	
GCN	HD	2	ULT	P	SOR	1	1	10886	.	78	6.9	530	405	27.6	25.6	31.1	20.4	74	61	03/08/82
GCN	HD	2	ULT	P	SOR	1	2	9051	.	78	6.9	530	405	27.6	25.6	31.1	20.4	74	61	
GCN	HD	2	ULT	P	SOR	1	3	9338	.	78	6.9	530	405	27.6	25.6	31.1	20.4	74	61	
IPO	HD	1	AND	H	IOL	1	1	4550	4090	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	12/16/81
IPO	HD	1	AND	H	IOL	1	2	4100	3600	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	
IPO	HD	1	AND	H	IOL	1	3	3030	4830	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	
IPO	HD	1	AND	H	IOL	2	1	15975	17690	104	11.1	380	364	18.7	18.1	22.8	13.2	90	56	01/26/83
IPO	HD	1	AND	H	IOL	2	2	15205	21195	104	11.1	380	364	18.7	18.1	22.8	13.2	90	56	
IPO	HD	1	AND	H	IOL	2	3	17055	20935	104	11.1	380	364	18.7	18.1	22.8	13.2	90	56	
IPO	TE	1	AND	H	IOL	1	1	8230	.	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	12/16/81
IPO	TE	1	AND	H	IOL	1	2	8761	.	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	
IPO	TE	1	AND	H	IOL	1	3	8150	.	91	9.3	1086	251	18.1	17.9	24.2	15.6	91	60	
IPO	TE	1	AND	H	IOL	2	1	18330	.	103	11.1	380	364	18.7	18.1	22.8	13.2	90	56	01/26/83
IPO	TE	1	AND	H	IOL	2	2	19373	.	103	11.1	380	364	18.7	18.1	22.8	13.2	90	56	
IPO	TE	1	AND	H	IOL	2	3	15383	.	103	11.1	380	364	18.7	18.1	22.8	13.2	90	56	
IPO	HD	1	AND	H	KUK	1	1	13960	9745	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	01/20/81
IPO	HD	1	AND	H	KUK	1	2	11250	8950	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
IPO	HD	1	AND	H	KUK	1	3	11030	10010	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
IPO	HD	1	AND	H	KUK	2	1	20830	15600	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	12/11/81
IPO	HD	1	AND	H	KUK	2	2	19570	18600	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	
IPO	HD	1	AND	H	KUK	2	3	21400	17200	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	
IPO	HD	1	AND	H	KUK	3	1	22100	19555	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	01/21/83
IPO	HD	1	AND	H	KUK	3	2	23625	26640	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	
IPO	HD	1	AND	H	KUK	3	3	32565	25675	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	
IPO	TE	1	AND	H	KUK	1	1	16710	.	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	01/20/81
IPO	TE	1	AND	H	KUK	1	2	15090	.	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
IPO	TE	1	AND	H	KUK	1	3	13840	.	109	11.2	421	437	20.2	19.0	23.8	15.3	88	55	
IPO	TE	1	AND	H	KUK	2	1	15030	.	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	12/11/81
IPO	TE	1	AND	H	KUK	2	2	14320	.	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	
IPO	TE	1	AND	H	KUK	2	3	17530	.	113	6.6	1683	311	19.9	19.0	23.6	15.5	85	61	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
IPO	TE	1	AND	H	KUK	3	1	19215	.	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	01/21/83
IPO	TE	1	AND	H	KUK	3	2	20345	.	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	
IPO	TE	1	AND	H	KUK	3	3	24732	.	102	8.1	562	389	20.4	19.5	25.4	16.6	81	54	
IPO	HD	1	AND	I	LPH	1	1	2550	3780	88	4.0	1237	231	22.8	21.9	25.0	15.9	90	72	12/19/81
IPO	HD	1	AND	I	LPH	1	2	1129	2329	88	4.0	1237	231	22.8	21.9	25.0	15.9	90	72	
IPO	HD	1	AND	I	LPH	1	3	1842	2721	88	4.0	1237	231	22.8	21.9	25.0	15.9	90	72	
IPO	HD	1	AND	I	LPH	2	1	4487	3506	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	12/11/82
IPO	HD	1	AND	I	LPH	2	2	4075	3535	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	
IPO	HD	1	AND	I	LPH	2	3	5232	4067	84	3.5	1123	376	23.9	22.6	26.3	16.1	99	89	
IPO	HD	1	AND	P	PAL	1	1	0	0	.	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	10/22/81
IPO	HD	1	AND	P	PAL	1	2	0	0	.	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
IPO	HD	1	AND	P	PAL	1	3	0	0	.	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
IPO	HD	1	AND	P	PAL	2	1	8818	3834	97	5.3	786	322	25.1	22.7	31.1	20.2	99	66	10/15/82
IPO	HD	1	AND	P	PAL	2	2	8706	3140	97	5.3	786	322	25.1	22.7	31.1	20.2	99	66	
IPO	HD	1	AND	P	PAL	2	3	8630	2621	97	5.3	786	322	25.1	22.7	31.1	20.2	99	66	
IPO	HD	1	OXI	H	MOL	1	1	15460	.	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	01/05/82
IPO	HD	1	OXI	H	MOL	1	2	14590	.	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	
IPO	HD	1	OXI	H	MOL	1	3	15990	.	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	
IPO	HD	1	OXI	H	MOL	2	1	26620	.	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	01/26/83
IPO	HD	1	OXI	H	MOL	2	2	22455	.	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
IPO	HD	1	OXI	H	MOL	2	3	24985	.	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
IPO	TE	1	OXI	H	MOL	1	1	12450	11580	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	01/05/82
IPO	TE	1	OXI	H	MOL	1	2	12320	12110	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	
IPO	TE	1	OXI	H	MOL	1	3	12170	12100	106	16.1	524	419	20.2	20.0	24.0	16.9	97	74	
IPO	TE	1	OXI	H	MOL	2	1	19277	2617	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	01/26/83
IPO	TE	1	OXI	H	MOL	2	2	20482	3037	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
IPO	TE	1	OXI	H	MOL	2	3	19180	2460	111	16.0	104	506	19.6	19.4	27.3	18.2	99	76	
IPO	HD	1	OXI	H	WAI	1	1	27240	.	100	9.5	212	384	19.3	19.0	28.3	18.1	91	49	01/14/81
IPO	HD	1	OXI	H	WAI	1	2	29950	.	100	9.5	212	384	19.3	19.0	28.3	18.1	91	49	
IPO	HD	1	OXI	H	WAI	1	3	28250	.	100	9.5	212	384	19.3	19.0	28.3	18.1	91	49	
IPO	HD	1	OXI	H	WAI	2	1	17730	.	105	7.4	467	311	20.6	20.2	26.7	17.4	88	58	12/29/81
IPO	HD	1	OXI	H	WAI	2	2	18660	.	105	7.4	467	311	20.6	20.2	26.7	17.4	88	58	
IPO	HD	1	OXI	H	WAI	2	3	14970	.	105	7.4	467	311	20.6	20.2	26.7	17.4	88	58	
IPO	HD	1	OXI	H	WAI	3	1	31955	.	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	01/14/83
IPO	HD	1	OXI	H	WAI	3	2	35020	.	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
IPO	HD	1	OXI	H	WAI	3	3	37325	.	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
IPO	TE	1	OXI	H	WAI	1	1	27050	11840	99	9.5	212	384	19.3	19.0	28.3	18.1	91	49	01/14/81
IPO	TE	1	OXI	H	WAI	1	2	29960	12270	99	9.5	212	384	19.3	19.0	28.3	18.1	91	49	
IPO	TE	1	OXI	H	WAI	1	3	28740	12000	99	9.5	212	384	19.3	19.0	28.3	18.1	91	49	
IPO	TE	1	OXI	H	WAI	2	1	16950	16770	107	7.4	467	311	20.6	20.2	26.7	17.4	88	58	12/29/81
IPO	TE	1	OXI	H	WAI	2	2	17640	16210	107	7.4	467	311	20.6	20.2	26.7	17.4	88	58	
IPO	TE	1	OXI	H	WAI	2	3	15230	13700	107	7.4	467	311	20.6	20.2	26.7	17.4	88	58	
IPO	TE	1	OXI	H	WAI	3	1	36260	0	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	01/14/83
IPO	TE	1	OXI	H	WAI	3	2	34642	0	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
IPO	TE	1	OXI	H	WAI	3	3	36477	0	105	7.0	91	699	20.7	20.4	27.4	15.3	79	45	
IPO	HD	1	ULT	I	NAK	1	.	0	.	0	3.8	716	405	28.7	27.4	33.0	21.6	96	40	10/27/81
IPO	HD	1	ULT	I	NAK	1	2	0	.	0	3.8	716	405	28.7	27.4	33.0	21.6	96	40	
IPO	HD	1	ULT	I	NAK	1	3	0	.	0	3.8	716	405	28.7	27.4	33.0	21.6	96	40	
IPO	HD	1	ULT	I	NAK	2	1	0	.	0	3.4	1961	438	31.8	27.3	35.7	24.6	99	50	12/15/82
IPO	HD	1	ULT	I	NAK	2	2	0	.	0	3.4	1861	438	31.8	27.3	35.7	24.6	99	50	
IPO	HD	1	ULT	I	NAK	2	3	0	.	0	3.4	1861	438	31.8	27.3	35.7	24.6	99	50	
IPO	HD	1	ULT	P	BPI	1	1	0	.	0	3.5	353	416	29.1	29.1	34.3	22.5	97	55	05/26/81
IPO	HD	1	ULT	P	BPI	1	2	0	.	0	3.5	353	416	29.1	29.1	34.3	22.5	97	55	
IPO	HD	1	ULT	P	BPI	1	3	0	.	0	3.5	353	416	29.1	29.1	34.3	22.5	97	55	
IPO	HD	1	ULT	P	BPI	2	1	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	06/02/82

APPENDIX : CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
IPO	HD	1	ULT	P	BPI	2	2	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
IPO	HD	1	ULT	P	BPI	2	3	0	.	0	4.7	643	422	28.4	28.4	33.5	22.4	87	49	
IPO	HD	1	ULT	P	SOR	1	.	0	.	.	11.3	1498	334	26.3	25.2	27.7	21.7	88	81	10/29/81
IPO	HD	1	ULT	P	SOR	1	2	0	.	.	11.3	1498	334	26.3	25.2	27.7	21.7	88	81	
IPO	HD	1	ULT	P	SOR	1	3	0	.	.	11.3	1498	334	26.3	25.2	27.7	21.7	88	81	
MCB	HD	2	AND	H	IOL	1	1	29330	31200	56	8.7	355	383	19.8	18.9	25.0	17.1	92	62	04/14/82
MCB	HD	2	AND	H	IOL	1	2	42070	43240	56	8.7	355	383	19.8	18.9	25.0	17.1	92	62	
MCB	HD	2	AND	H	IOL	1	3	32950	37420	56	8.7	355	383	19.8	18.9	25.0	17.1	92	62	
MCB	HD	2	AND	H	KUK	2	1	25050	17020	53	7.9	610	383	21.1	19.9	23.3	16.1	87	66	04/13/82
MCB	HD	2	AND	H	KUK	2	2	29520	30820	53	7.9	610	383	21.1	19.9	23.3	16.1	87	66	
MCB	HD	2	AND	H	KUK	2	3	39320	31490	53	7.9	610	383	21.1	19.9	23.3	16.1	87	66	
MCB	HD	2	AND	I	LPH	2	1	12316	11969	67	3.7	444	310	23.8	22.4	26.9	15.2	98	70	04/26/82
MCB	HD	2	AND	I	LPH	2	2	14533	15081	67	3.7	444	310	23.8	22.4	26.9	15.2	98	70	
MCB	HD	2	AND	I	LPH	2	3	16586	16927	67	3.7	444	310	23.8	22.4	26.9	15.2	98	70	
MCB	HD	2	AND	P	PAL	1	1	14772	17439	42	6.2	231	352	26.9	22.1	32.8	20.2	99	61	02/20/82
MCB	HD	2	AND	P	PAL	1	2	13793	13167	42	6.2	231	352	26.9	22.1	32.8	20.2	99	61	
MCB	HD	2	AND	P	PAL	1	3	12960	16981	42	6.2	231	352	26.9	22.1	32.8	20.2	99	61	
MCB	HD	2	AND	P	PAL	2	1	3312	0	43	6.2	3	440	31.1	23.9	35.1	19.4	99	34	03/15/83
MCB	HD	2	AND	P	PAL	2	2	2025	0	43	6.2	3	440	31.1	23.9	35.1	19.4	99	34	
MCB	HD	2	AND	P	PAL	2	3	3472	0	43	6.2	3	440	31.1	23.9	35.1	19.4	99	34	
MCB	HD	2	OXI	H	MOL	1	1	9600	.	51	20.8	63	600	22.1	21.8	28.6	19.1	96	52	05/22/81
MCB	HD	2	OXI	H	MOL	1	2	10860	.	51	20.8	63	600	22.1	21.8	28.6	19.1	96	52	
MCB	HD	2	OXI	H	MOL	1	3	5900	.	51	20.8	63	600	22.1	21.8	28.6	19.1	96	52	
MCB	HD	2	OXI	H	WAI	1	1	20930	.	48	6.6	43	498	22.3	21.4	30.8	18.6	87	49	05/02/82
MCB	HD	2	OXI	H	WAI	1	2	16130	.	48	6.6	43	498	22.3	21.4	30.8	18.6	87	49	
MCB	HD	2	OXI	H	WAI	1	3	16340	.	48	6.6	43	498	22.3	21.4	30.8	18.6	87	49	
MCB	HD	2	ULT	I	NAK	1	1	1060	.	54	3.1	422	436	29.4	28.9	36.7	23.4	99	41	03/11/81
MCB	HD	2	ULT	I	NAK	1	2	7532	.	54	3.1	422	436	29.4	28.9	36.7	23.4	99	41	
MCB	HD	2	ULT	I	NAK	1	3	554	.	54	3.1	422	436	29.4	28.9	36.7	23.4	99	41	
MCB	HD	2	ULT	I	NAK	2	1	4214	.	69	2.7	656	397	31.2	27.7	35.1	20.1	95	32	03/09/82
MCB	HD	2	ULT	I	NAK	2	2	5072	.	69	2.7	656	397	31.2	27.7	35.1	20.1	95	32	
MCB	HD	2	ULT	I	NAK	2	3	2345	.	69	2.7	656	397	31.2	27.7	35.1	20.1	95	32	
MCB	HD	2	ULT	P	BPI	1	1	3625	.	53	4.7	457	409	26.1	26.1	33.9	22.0	98	57	09/28/81
MCB	HD	2	ULT	P	BPI	1	2	4925	.	53	4.7	457	409	26.1	26.1	33.9	22.0	98	57	
MCB	HD	2	ULT	P	BPI	1	3	4521	.	53	4.7	457	409	26.1	26.1	33.9	22.0	98	57	
MCB	HD	2	ULT	P	BPI	2	1	5071	.	45	5.0	327	414	26.3	26.3	34.1	21.6	90	44	11/05/82
MCB	HD	2	ULT	P	BPI	2	2	3208	.	45	5.0	327	414	26.3	26.3	34.1	21.6	90	44	
MCB	HD	2	ULT	P	BPI	2	3	6017	.	45	5.0	327	414	26.3	26.3	34.1	21.6	90	44	
MCB	HD	2	ULT	P	SOR	1	1	9186	.	45	10.2	293	379	25.8	24.4	28.1	19.8	76	65	02/16/82
MCB	HD	2	ULT	P	SOR	1	2	8894	.	45	10.2	293	379	25.8	24.4	28.1	19.9	76	65	
MCB	HD	2	ULT	P	SOR	1	3	6656	.	45	10.2	293	379	25.8	24.4	28.1	19.8	76	65	
MGB	TP	3	AND	I	LPH	1	1	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	----
MGB	TP	3	AND	I	LPH	1	2	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
MGB	TP	3	AND	I	LPH	1	3	0	.	0	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
MGB	TP	3	AND	I	LPH	2	1	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	----
MGB	TP	3	AND	I	LPH	2	2	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
MGB	TP	3	AND	I	LPH	2	3	0	.	0	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
MGB	TP	3	AND	P	PAL	1	1	196	.	87	6.1	1080	330	30.0	25.1	32.5	23.0	95	59	05/15/81
MGB	TP	3	AND	P	PAL	1	2	346	.	87	6.1	1080	330	30.0	25.1	32.5	23.0	95	59	
MGB	TP	3	AND	P	PAL	1	3	233	.	87	6.1	1080	330	30.0	25.1	32.5	23.0	95	59	
MGB	TP	3	AND	P	PAL	2	1	85	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	06/29/82
MGB	TP	3	AND	P	PAL	2	2	82	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	
MGB	TP	3	AND	P	PAL	2	3	74	.	76	6.9	1411	308	26.3	24.4	31.0	23.8	99	78	
MGB	TP	3	ULT	I	NAK	1	1	102	60	58	4.3	20	386	29.4	27.1	37.4	23.7	99	31	07/01/82
MGB	TP	3	ULT	I	NAK	1	2	124	76	58	4.3	20	386	29.4	27.1	37.4	23.7	99	31	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
MGB	TP	3	ULT	I	NAK	1	3	55	44	58	4.3	20	386	29.4	27.1	37.4	23.7	99	31	
MGB	TP	3	ULT	P	BPI	1	1	392	596	100	10.2	446	428	.	.	34.0	22.6	92	42	02/10/81
MGB	TP	3	ULT	P	BPI	1	2	592	425	100	10.2	446	428	.	.	34.0	22.6	92	42	
MGB	TP	3	ULT	P	BPI	1	3	658	287	100	10.2	446	428	.	.	34.0	22.6	92	42	
MGB	TP	3	ULT	P	BPI	2	1	1166	921	68	5.9	25	430	.	.	34.0	22.2	98	47	02/11/82
MGB	TP	3	ULT	P	BPI	2	2	1107	705	68	5.9	25	430	.	.	34.0	22.2	98	47	
MGB	TP	3	ULT	P	BPI	2	3	983	775	68	5.9	25	430	.	.	34.0	22.2	98	47	
MGB	TP	3	ULT	P	SOR	1	1	1329	1038	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	06/03/81
MGB	TP	3	ULT	P	SOR	1	2	954	1142	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
MGB	TP	3	ULT	P	SOR	1	3	971	1212	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
MGB	TP	3	ULT	P	SOR	2	1	566	480	76	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	07/03/82
MGB	TP	3	ULT	P	SOR	2	2	766	395	76	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	
MGB	TP	3	ULT	P	SOR	2	3	672	433	76	8.3	1017	356	27.8	26.2	29.8	22.3	80	71	
PNT	HD	3	AND	H	IOL	2	1	500	460	126	8.8	602	287	19.1	19.0	21.7	13.1	90	64	09/21/82
PNT	HD	3	AND	H	IOL	2	2	1170	660	126	8.8	602	287	19.1	19.0	21.7	13.1	90	64	
PNT	HD	3	AND	H	IOL	2	3	880	240	126	8.8	602	287	19.1	19.0	21.7	13.1	90	64	
PNT	HD	3	AND	H	KUK	1	1	1660	2290	117	7.3	718	347	22.4	21.5	24.6	18.4	87	65	09/10/81
PNT	HD	3	AND	H	KUK	1	2	1700	1830	117	7.3	718	347	22.4	21.5	24.6	18.4	87	65	
PNT	HD	3	AND	H	KUK	1	3	2440	2280	117	7.3	718	347	22.4	21.5	24.6	19.4	87	65	
PNT	HD	3	AND	H	KUK	2	1	1650	1630	126	9.0	701	346	22.2	20.9	26.2	18.9	83	61	09/09/82
PNT	HD	3	AND	H	KUK	2	2	1640	1510	126	9.0	701	346	22.2	20.9	26.2	18.9	83	61	
PNT	HD	3	AND	H	KUK	2	3	2080	2050	126	9.0	701	346	22.2	20.9	26.2	18.9	83	61	
PNT	TP	2	AND	I	ITK	1	1	3632	.	161	5.4	516	332	21.4	21.0	26.4	15.6	99	47	05/21/81
PNT	TP	2	AND	I	ITK	1	2	3214	.	161	5.4	516	332	21.4	21.0	26.4	15.6	99	47	
PNT	TP	2	AND	I	ITK	1	3	3840	.	161	5.4	516	332	21.4	21.0	26.4	15.6	99	47	
PNT	HD	3	AND	I	LPH	1	1	2917	3500	97	3.6	659	326	25.0	23.3	26.9	16.2	95	60	08/13/81
PNT	HD	3	AND	I	LPH	1	2	3917	3417	97	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
PNT	HD	3	AND	I	LPH	1	3	2967	3200	97	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
PNT	TP	2	AND	I	LPH	1	1	658	.	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	03/07/81
PNT	TP	2	AND	I	LPH	1	2	1275	.	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	
PNT	TP	2	AND	I	LPH	1	3	1070	.	134	3.6	1323	325	24.8	23.2	28.6	17.5	95	67	
PNT	TP	2	AND	I	LPH	2	1	1882	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	06/22/82
PNT	TP	2	AND	I	LPH	2	2	1834	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	
PNT	TP	2	AND	I	LPH	2	3	2644	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	
PNT	HD	3	AND	P	PAL	1	1	2333	2310	116	6.1	1226	334	30.0	25.1	32.4	23.0	95	59	05/15/81
PNT	HD	3	AND	P	PAL	1	2	2371	2294	116	6.1	1226	334	30.0	25.1	32.4	23.0	95	59	
PNT	HD	3	AND	P	PAL	1	3	2214	1294	116	6.1	1226	334	30.0	25.1	32.4	23.0	95	59	
PNT	HD	3	AND	P	PAL	2	1	2100	2070	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	06/23/82
PNT	HD	3	AND	P	PAL	2	2	2360	2408	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	
PNT	HD	3	AND	P	PAL	2	3	2479	2140	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	
PNT	TP	2	AND	P	PAL	1	1	3215	.	128	5.6	755	380	27.4	23.3	33.9	21.3	99	58	02/20/82
PNT	TP	2	AND	P	PAL	1	2	3050	.	128	5.6	755	380	27.4	23.3	33.9	21.3	99	58	
PNT	TP	2	AND	P	PAL	1	3	5028	.	128	5.6	755	380	27.4	23.3	33.9	21.3	99	58	
PNT	TP	2	AND	P	PAL	2	1	3744	.	105	6.2	19	425	31.5	24.4	35.4	20.5	99	37	03/14/83
PNT	TP	2	AND	P	PAL	2	2	2400	.	105	6.2	19	425	31.5	24.4	35.4	20.5	99	37	
PNT	TP	2	AND	P	PAL	2	3	3267	.	105	6.2	19	425	31.5	24.4	35.4	20.5	99	37	
PNT	HD	3	OXI	H	MUL	2	1	2590	.	117	17.8	442	451	21.3	21.0	28.3	20.4	98	81	09/15/82
PNT	HD	3	OXI	H	MUL	2	2	2120	.	117	17.8	442	451	21.3	21.0	28.3	20.4	98	81	
PNT	HD	3	OXI	H	MUL	2	3	1720	.	117	17.8	442	451	21.3	21.0	28.3	20.4	98	81	
PNT	HD	3	OXI	H	WAI	1	1	4130	.	119	7.3	352	372	19.4	18.2	30.2	20.2	88	51	08/27/81
PNT	HD	3	OXI	H	WAI	1	2	4840	.	119	7.3	352	372	19.4	18.2	30.2	20.2	88	51	
PNT	HD	3	OXI	H	WAI	1	3	3780	.	119	7.3	352	372	19.4	18.2	30.2	20.2	88	51	
PNT	HD	3	OXI	H	WAI	2	1	1850	.	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	09/20/82
PNT	HD	3	OXI	H	WAI	2	2	2160	.	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	
PNT	HD	3	OXI	H	WAI	2	3	2720	.	111	6.4	512	453	22.7	22.4	27.7	18.5	81	55	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
PNT	TP	2	ULT	I	NAK	1	1	740	932	102	2.9	684	413	29.0	28.6	35.9	23.3	99	43	03/11/81
PNT	TP	2	ULT	I	NAK	1	2	655	655	102	2.9	684	413	29.0	28.6	35.9	23.3	99	43	
PNT	TP	2	ULT	I	NAK	1	3	845	845	102	2.9	684	413	29.0	28.6	35.9	23.3	99	43	
PNT	TP	2	ULT	I	NAK	2	1	467	344	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	07/01/82
PNT	TP	2	ULT	I	NAK	2	2	467	256	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	
PNT	TP	2	ULT	I	NAK	2	3	333	183	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	
PNT	HD	3	ULT	P	BPI	2	1	4995	.	104	5.7	186	452	29.2	29.2	33.8	22.3	98	49	02/11/82
PNT	HD	3	ULT	P	BPI	2	2	5009	.	104	5.7	186	452	29.2	29.2	33.8	22.3	98	49	
PNT	HD	3	ULT	P	BPI	2	3	5532	.	104	5.7	186	452	29.2	29.2	33.8	22.3	98	49	
PNT	TP	2	ULT	P	BPI	1	1	3675	3833	116	5.5	696	390	.	.	32.3	21.8	98	57	09/28/81
PNT	TP	2	ULT	P	BPI	1	2	3292	3583	116	5.5	696	390	.	.	32.3	21.8	98	57	
PNT	TP	2	ULT	P	BPI	1	3	4148	3800	116	5.5	696	390	.	.	32.3	21.8	98	57	
PNT	TP	2	ULT	P	BPI	2	1	1844	2133	114	5.6	444	405	26.0	26.0	33.6	21.4	89	39	11/05/82
PNT	TP	2	ULT	P	BPI	2	2	1833	1277	114	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
PNT	TP	2	ULT	P	BPI	2	3	1967	1811	114	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
PNT	HD	3	ULT	P	SOR	1	1	2278	.	102	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	06/03/81
PNT	HD	3	ULT	P	SOR	1	2	1979	.	102	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
PNT	HD	3	ULT	P	SOR	1	3	1959	.	102	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
PNT	HD	3	ULT	P	SOR	2	1	2971	.	109	7.9	1163	364	27.9	26.3	30.4	22.4	82	72	07/01/82
PNT	HD	3	ULT	P	SOR	2	2	2540	.	109	7.9	1163	364	27.9	26.3	30.4	22.4	82	72	
PNT	HD	3	ULT	P	SOR	2	3	2863	.	109	7.9	1163	364	27.9	26.3	30.4	22.4	82	72	
PNT	TP	2	ULT	P	SOR	2	1	2094	1672	113	7.7	637	402	27.4	25.3	30.5	20.3	74	62	02/16/82
PNT	TP	2	ULT	P	SOR	2	2	1917	1654	113	7.7	637	402	27.4	25.3	30.5	20.3	74	62	
PNT	TP	2	ULT	P	SOR	2	3	1590	1528	113	7.7	637	402	27.4	25.3	30.5	20.3	74	62	
RIC	TP	1	AND	I	LPH	1	1	1459	.	178	3.8	2204	264	23.4	22.1	26.0	15.8	93	73	12/19/81
RIC	TP	1	AND	I	LPH	1	2	1181	.	178	3.8	2204	264	23.4	22.1	26.0	15.8	93	73	
RIC	TP	1	AND	I	LPH	1	3	1441	.	178	3.8	2204	264	23.4	22.1	26.0	15.8	93	73	
RIC	TP	1	AND	P	PAL	1	1	648	.	103	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	09/18/81
RIC	TP	1	AND	P	PAL	1	2	576	.	103	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
RIC	TP	1	AND	P	PAL	1	3	547	.	103	7.3	2085	287	25.8	23.5	30.0	21.2	96	68	
RIC	TP	1	AND	P	PAL	2	1	2927	.	122	5.4	1039	319	25.1	22.6	30.8	20.2	99	66	10/07/82
RIC	TP	1	AND	P	PAL	2	2	2946	.	122	5.4	1039	319	25.1	22.6	30.8	20.2	99	66	
RIC	TP	1	AND	P	PAL	2	3	3191	.	122	5.4	1039	319	25.1	22.6	30.8	20.2	99	66	
RIC	TP	1	ULT	I	NAK	1	1	1558	2213	113	3.7	925	397	28.7	27.2	32.5	21.2	96	42	10/27/81
RIC	TP	1	ULT	I	NAK	1	2	1310	2222	113	3.7	925	397	28.7	27.2	32.5	21.2	96	42	
RIC	TP	1	ULT	I	NAK	1	3	1906	1572	113	3.7	925	397	28.7	27.2	32.5	21.2	96	42	
RIC	TP	1	ULT	I	NAK	2	1	1265	1224	110	3.5	1625	443	31.7	27.3	35.6	24.6	99	50	12/15/82
RIC	TP	1	ULT	I	NAK	2	2	1242	958	110	3.5	1625	443	31.7	27.3	35.6	24.6	99	50	
RIC	TP	1	ULT	I	NAK	2	3	1343	733	110	3.5	1625	443	31.7	27.3	35.6	24.6	99	50	
RIC	TP	1	ULT	P	BPI	1	1	3860	50	134	4.3	839	447	.	.	34.4	22.5	97	53	05/04/81
RIC	TP	1	ULT	P	BPI	1	2	3666	38	134	4.3	839	447	.	.	34.4	22.5	97	53	
RIC	TP	1	ULT	P	BPI	1	3	3936	43	134	4.3	839	447	.	.	34.4	22.5	97	53	
RIC	TP	1	ULT	P	BPI	2	1	2146	1806	117	4.5	641	419	28.7	28.6	33.5	22.2	87	50	05/24/82
RIC	TP	1	ULT	P	BPI	2	2	1915	2162	117	4.5	641	419	28.7	28.6	33.5	22.2	87	50	
RIC	TP	1	ULT	P	BPI	2	3	1693	1497	117	4.5	641	419	28.7	28.6	33.5	22.2	87	50	
RIC	TP	1	ULT	P	SOR	1	1	738	188	96	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	09/24/81
RIC	TP	1	ULT	P	SOR	1	2	445	404	96	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
RIC	TP	1	ULT	P	SOR	1	3	248	377	96	9.6	1793	333	26.9	25.7	29.0	22.0	85	76	
RIC	TP	1	ULT	P	SOR	2	1	2590	2206	113	7.9	571	336	27.3	25.8	30.8	21.5	89	76	10/11/82
RIC	TP	1	ULT	P	SOR	2	2	2706	2072	113	7.9	571	336	27.3	25.8	30.8	21.5	89	76	
RIC	TP	1	ULT	P	SOR	2	3	2336	1901	113	7.9	571	336	27.3	25.8	30.8	21.5	89	76	
SOY	HD	3	AND	H	IOL	2	1	990	670	114	8.7	602	287	19.1	19.0	21.7	13.1	90	64	09/22/82
SOY	HD	3	AND	H	IOL	2	2	1060	752	114	8.7	602	287	19.1	19.0	21.7	13.1	90	64	
SOY	HD	3	AND	H	IOL	2	3	1233	433	114	8.7	602	287	19.1	19.0	21.7	13.1	90	64	
SOY	TE	2	AND	H	IOL	1	1	4260	.	130	12.4	370	408	21.6	20.9	25.8	17.7	95	54	05/13/81

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELUNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
SOY	TE	2	AND	H	IOL	1	2	3787	.	130	12.4	370	408	21.6	20.9	25.8	17.7	95	54	
SOY	TE	2	AND	H	IOL	1	3	3463	.	130	12.4	370	408	21.6	20.9	25.8	17.7	95	54	
SOY	TE	2	AND	H	IOL	2	1	2286	.	153	9.9	937	385	21.1	20.4	25.1	17.2	91	66	04/14/82
SOY	TE	2	AND	H	IOL	2	2	2225	.	153	9.9	937	385	21.1	20.4	25.1	17.2	91	66	
SOY	TE	2	AND	H	IOL	2	3	2648	.	153	9.9	937	385	21.1	20.4	25.1	17.2	91	66	
SOY	HD	3	AND	H	KUK	1	1	1083	1867	117	7.3	717	347	22.4	21.5	24.6	18.4	87	65	09/10/81
SOY	HD	3	AND	H	KUK	1	2	1307	1700	117	7.3	717	347	22.4	21.5	24.6	18.4	87	65	
SOY	HD	3	AND	H	KUK	1	3	1590	1697	117	7.3	717	347	22.4	21.5	24.6	18.4	87	65	
SOY	HD	3	AND	H	KUK	2	1	1513	1430	123	9.0	701	346	22.2	20.9	26.2	18.9	83	61	09/09/82
SOY	HD	3	AND	H	KUK	2	2	1227	1817	123	9.0	701	346	22.2	20.9	26.2	18.9	83	61	
SOY	HD	3	AND	H	KUK	2	3	1217	1817	123	9.0	701	346	22.2	20.9	26.2	18.9	83	61	
SOY	TE	2	AND	H	KUK	1	1	3202	.	111	10.8	247	502	23.8	22.4	25.2	17.6	87	60	05/27/81
SOY	TE	2	AND	H	KUK	1	2	3222	.	111	10.8	247	502	23.8	22.4	25.2	17.6	87	60	
SOY	TE	2	AND	H	KUK	1	3	3473	.	111	10.8	247	502	23.8	22.4	25.2	17.6	87	60	
SOY	TE	2	AND	H	KUK	2	1	2452	.	132	8.4	1174	404	23.0	21.6	24.9	17.6	86	66	04/13/82
SOY	TE	2	AND	H	KUK	2	2	2465	.	132	8.4	1174	404	23.0	21.6	24.9	17.6	86	66	
SOY	TE	2	AND	H	KUK	2	3	3097	.	132	8.4	1174	404	23.0	21.6	24.9	17.6	86	66	
SOY	HD	3	AND	I	LPH	1	1	1071	958	98	3.6	659	326	25.0	23.3	26.9	16.2	95	60	03/12/81
SOY	HD	3	AND	I	LPH	1	2	1147	938	98	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
SOY	HD	3	AND	I	LPH	1	3	892	1239	98	3.6	659	326	25.0	23.3	26.9	16.2	95	60	
SOY	HD	3	AND	I	LPH	2	1	2008	1256	117	4.3	850	486	24.2	22.4	27.2	15.2	99	61	09/16/82
SOY	HD	3	AND	I	LPH	2	2	2024	1590	117	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
SOY	HD	3	AND	I	LPH	2	3	2041	1391	117	4.3	850	486	24.2	22.4	27.2	15.2	99	61	
SOY	TP	2	AND	I	LPH	1	1	520	.	101	3.6	1125	333	25.1	23.3	29.1	17.8	96	68	03/07/81
SOY	TP	2	AND	I	LPH	1	2	380	.	101	3.6	1125	333	25.1	23.3	29.1	17.8	96	68	
SOY	TP	2	AND	I	LPH	1	3	414	.	101	3.6	1125	333	25.1	23.3	29.1	17.8	96	60	
SOY	TP	2	AND	I	LPH	2	1	1394	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	06/22/82
SOY	TP	2	AND	I	LPH	2	2	1741	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	
SOY	TP	2	AND	I	LPH	2	3	1914	.	140	4.3	344	385	23.3	21.5	26.8	13.8	99	53	
SOY	HD	3	AND	P	PAL	1	1	2419	2493	112	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	05/15/81
SOY	HD	3	AND	P	PAL	1	2	2625	2137	112	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	
SOY	HD	3	AND	P	PAL	1	3	2539	2011	112	6.2	1146	333	30.0	25.1	32.3	23.0	95	59	
SOY	HD	3	AND	P	PAL	2	1	1527	1232	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	06/28/82
SOY	HD	3	AND	P	PAL	2	2	1457	1323	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	
SOY	HD	3	AND	P	PAL	2	3	1504	1401	114	7.2	1911	302	26.2	24.0	30.4	23.1	99	76	
SOY	TP	2	AND	P	PAL	2	1	2566	.	107	6.2	19	425	31.5	24.4	35.4	20.5	99	37	03/14/83
SOY	TP	2	AND	P	PAL	2	2	2753	.	107	6.2	19	425	31.5	24.4	35.4	20.5	99	37	
SOY	TP	2	AND	P	PAL	2	3	2501	.	107	6.2	19	425	31.5	24.4	35.4	20.5	99	37	
SOY	TP	2	AND	P	PAL	1	1	936	.	94	5.7	652	367	27.6	23.0	33.8	20.9	99	58	02/20/82
SOY	TP	2	AND	P	PAL	1	2	921	.	94	5.7	652	367	27.6	23.0	33.8	20.9	99	58	
SOY	TP	2	AND	P	PAL	1	3	1069	.	94	5.7	652	367	27.6	23.0	33.8	20.9	99	58	
SOY	TE	2	OXI	H	MOL	1	1	2772	0	129	20.8	144	571	22.8	22.4	29.0	19.7	94	53	05/12/81
SOY	TE	2	OXI	H	MOL	1	2	2762	0	129	20.8	144	571	22.8	22.4	29.0	19.7	94	53	
SOY	TE	2	OXI	H	MOL	1	3	2472	0	129	20.8	144	571	22.8	22.4	29.0	19.7	94	53	
SOY	TE	2	OXI	H	MOL	2	1	2408	0	118	19.2	171	567	22.1	21.7	30.0	22.2	98	72	05/06/82
SOY	TE	2	OXI	H	MOL	2	2	2489	0	118	19.2	171	567	22.1	21.7	30.0	22.2	98	72	
SOY	TE	2	OXI	H	MOL	2	3	1842	0	118	19.2	171	567	22.1	21.7	30.0	22.2	98	72	
SOY	HD	3	OXI	H	WAI	1	1	3260	.	107	7.4	293	388	19.7	18.5	30.2	20.5	88	50	08/27/81
SOY	HD	3	OXI	H	WAI	1	2	2180	.	107	7.4	293	388	19.7	18.5	30.2	20.5	88	50	
SOY	HD	3	OXI	H	WAI	1	3	3090	.	107	7.4	293	388	19.7	18.5	30.2	20.5	88	50	
SOY	HD	3	OXI	H	WAI	2	1	1530	.	91	6.2	439	468	23.3	22.8	28.3	18.8	81	54	09/20/82
SOY	HD	3	OXI	H	WAI	2	2	1200	.	91	6.2	439	468	23.3	22.8	28.3	18.8	81	54	
SOY	HD	3	OXI	H	WAI	2	3	1080	.	91	6.2	439	468	23.3	22.8	28.3	18.8	81	54	
SOY	TE	2	OXI	H	WAI	1	1	3385	425	127	7.5	91	488	21.2	20.0	30.8	20.7	89	49	05/01/81
SOY	TE	2	OXI	H	WAI	1	2	3250	439	127	7.5	91	488	21.2	20.0	30.8	20.7	89	49	

APPENDIX 1 CROPWISE YIELD AND AGROCLIMATIC DATA FOR CROPPING SYSTEMS EXPERIMENTS ON ALL SITES

CROP	PAT	SEASN	SOIL	REGN	SITE	YEAR	REP	YIELDI KG/HA	YIELDNI KG/HA	DUR DYS	WINDV KM/HR	TPPT MM	SLRD LNGY	STMX (C)	STMN (C)	ATMX (C)	ATMN (C)	RHMX (%)	RHMN (%)	PLANTING DATE
SOY	TE	2	OXI	H	WAI	1	3	3980	410	127	7.5	91	488	21.2	20.0	30.8	20.7	89	49	
SOY	TE	2	OXI	H	WAI	2	1	4615	910	137	7.1	360	525	23.4	22.8	30.7	20.0	85	52	04/27/82
SOY	TE	2	OXI	H	WAI	2	2	3695	1267	137	7.1	360	525	23.4	22.8	30.7	20.0	85	52	
SOY	TE	2	OXI	H	WAI	2	3	3550	863	137	7.1	360	525	23.4	22.8	30.7	20.0	85	52	
SOY	HD	3	ULT	I	NAK	1	1	396	.	86	4.3	86	386	29.4	27.1	37.4	23.7	99	31	06/06/82
SOY	HD	3	ULT	I	NAK	1	2	454	.	86	4.3	86	386	29.4	27.1	37.4	23.7	99	31	
SOY	HD	3	ULT	I	NAK	1	3	641	.	86	4.3	86	386	29.4	27.1	37.4	23.7	99	31	
SOY	TP	2	ULT	I	NAK	1	1	1243	1059	104	2.9	684	413	29.0	28.7	35.9	23.3	99	43	03/11/81
SOY	TP	2	ULT	I	NAK	1	2	1311	1052	104	2.9	684	413	29.0	28.7	35.9	23.3	99	43	
SOY	TP	2	ULT	I	NAK	1	3	1323	1146	104	2.9	684	413	29.0	28.7	35.9	23.3	99	43	
SOY	TP	2	ULT	I	NAK	2	1	1112	1054	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	03/09/82
SOY	TP	2	ULT	I	NAK	2	2	1309	1017	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	
SOY	TP	2	ULT	I	NAK	2	3	878	1106	109	2.7	848	374	30.6	27.5	35.4	21.2	96	35	
SOY	HD	3	ULT	P	BPI	2	1	62	.	100	5.7	186	452	29.2	29.2	33.8	22.3	98	49	02/11/82
SOY	HD	3	ULT	P	BPI	2	2	95	.	100	5.7	186	452	29.2	29.2	33.8	22.3	98	49	
SOY	HD	3	ULT	P	BPI	2	3	130	.	100	5.7	186	452	29.2	29.2	33.8	22.3	98	49	
SOY	HD	3	ULT	P	BPI	1	1	433	.	121	9.1	614	435	.	.	34.2	22.4	92	44	02/10/81
SOY	HD	3	ULT	P	BPI	1	2	442	.	121	9.1	614	435	.	.	34.2	22.4	92	44	
SOY	HD	3	ULT	P	BPI	1	3	183	.	121	9.1	614	435	.	.	34.2	22.4	92	44	
SOY	TP	2	ULT	P	BPI	2	1	828	654	111	5.6	444	405	26.0	26.0	33.6	21.4	89	39	11/05/82
SOY	TP	2	ULT	P	BPI	2	2	861	690	111	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
SOY	TP	2	ULT	P	BPI	2	3	819	652	111	5.6	444	405	26.0	26.0	33.6	21.4	89	39	
SOY	HD	3	ULT	P	SUR	1	1	1608	.	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	06/03/81
SOY	HD	3	ULT	P	SUR	1	2	1825	.	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
SOY	HD	3	ULT	P	SUR	1	3	1664	.	100	7.2	1143	405	28.6	27.0	32.5	23.5	83	63	
SOY	HD	3	ULT	P	SUR	2	1	2209	.	86	7.9	1070	364	27.9	26.3	30.4	22.4	82	72	07/06/82
SOY	HD	3	ULT	P	SUR	2	2	2200	.	86	7.9	1070	364	27.9	26.3	30.4	22.4	82	72	
SOY	HD	3	ULT	P	SUR	2	3	2269	.	86	7.9	1070	364	27.9	26.3	30.4	22.4	82	72	
SOY	TP	2	ULT	P	SUR	2	1	1875	517	83	8.3	404	394	26.7	24.9	29.7	19.9	75	63	02/16/82
SOY	TP	2	ULT	P	SUR	2	2	1802	597	83	8.3	404	394	26.7	24.9	29.7	19.9	75	63	
SOY	TP	2	ULT	P	SUR	2	3	1923	642	83	8.3	404	394	26.7	24.9	29.7	19.9	75	63	

Appendix 4.1. Yield of crops, calories and protein production for two cropping patterns, WAI site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
TE	1	Potato -	Kennebec	1/14/81	4/22/81	28580	20292	486
	2	Soybean -	Davis	5/1/81	9/4/81	3538	11711	1235
	3	Corn /	X304C	9/16/81	1/5/82	4177	14578	380
	Side Crops	Cassava	Sabre	4/6/81	2/16/82	7545	7394	53
		Pigeon Pea	Not known	4/6/81	11/20/81	520	1747	108
		Taro	Not known	4/6/81	11/18/81	1150	897	21
HD	1	Bush Bean +	Tendercrop	1/15/81	3/12/81	6060	1818	127
		Carrot +	Scarlet Nantes*	1/15/81	5/7/81	7470	2316	67
		Cabbage ,	Copenhagen Market	1/15/81	3/22/81	15990	3518	256
		Potato -	Kennebec	1/14/81	4/23/81	28480	20221	484
	2	Bush Bean +	Tendercrop	5/12/81	7/12/81	9250	2775	194
		Green Corn ,	Supersweet	6/1/81	8/21/81	12283	6142	196
		Mustard Cabbage +	Local**	No harvest				
		Bush Bean -	Tendercrop	5/12/81	7/12/81	5855	1756	123
	3	Soybean ,	Davis	8/27/81	12/11/81	2843	9410	992
		Peanut /	Red Spanish	8/27/81	12/23/81	4250	8372	416
	Side Crops	Taro	Not known	1/23/81	11/18/81	7660	5975	138

[†] Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

* Slight moisture stress

** Bad seed

Appendix 4.2. Yield of crops, calories and protein production for two cropping patterns, WAI site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/Ha	Protein† kg/ha
TE	1	Potato -	Kennebec	12/29/81	4/14/82	16610	11793	282
	2	Soybean -	Davis	4/27/82	9/10/82	3953	13084	1380
	3	Corn /	X304C	9/22/82	1/10/83	752*	2624	68
	Side Crops	Cassava	Sabre	2/17/82	11/29/8	7820	7664	55
		Pigeon Pea	Not known	5/3/82	11/8/82	321	1079	66
		Taro		No harvest				
HD	1	Bush Bean +	Bountiful	12/8/81	2/12/82	3577	1073	75
		Carrot +	Scarlet Nantes	11/6/81	3/10/82	17497	5424	157
		Cabbage ,	Copenhagen Market	12/7/81	2/20/82	8900	1958	142
		Potato -	Kennebec	12/29/81	4/12/82	17120	12155	291
	2	Bush Bean +	Tendercrop	5/2/82	6/19/82	5840	1752	123
		Green Corn ,	Supersweet	5/21/82	8/6/82	9757	4879	156
		Mustard Cabbage +	Local	5/2/82	6/19/82	17800	2670	267
		Bush Bean -	Tendercrop	5/2/82	6/21/82	7430	2229	156
	3	Soybean ,	Davis	9/20/82	12/20/82	1297	4293	453
		Peanut /	Spanish red	9/20/82	1/9/83	2243	4419	220
	Side Crops	Taro	Not known	5/3/82	12/10/82	2682	2092	48

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Hurricane damage

Appendix 4.3. Yield of crops, calories and protein production for two cropping patterns, WAI site, 1983.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/Ha	Protein† kg/ha
TE	1	Potato -	Kennebec	1/14/83	4/29/83	35793	25413	608
	2	Soybean -		Not planted				
	3	Corn /		Not planted				
	Side Crops	Cassava		Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				
HD	1	Bush Bean +	Tendercrop	2/11/83	4/12/83	6323	1897	133
		Carrot +	Scarlet Nantes	1/14/83	4/27/83	27725	8595	250
		Cabbage ,	Copenhagen Market	2/11/83	4/12/83	14480	3186	232
		Potato -	Kennebec	1/14/83	4/29/83	34767	24685	591
	2	Bush Bean +		Not planted				
		Green Corn ,		Not planted				
		Mustard cabbage +		Not planted				
		Bush Bean -		Not planted				
	3	Soybean ,		Not planted				
		Peanut /		Not planted				
	Side Crops	Taro		Not planted				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.4. Yield of crops, calories and protein production for two cropping patterns, MOL site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
TE	1	Potato -		Not planted				
	2	Soybean -	Davis	5/12/81	9/17/81	2669	8834	931
	3	Corn /						
	Side Crops	Cassava		Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				
HD	1	Bush Bean +		Not planted				
		Carrot +		Not planted				
		Cabbage ,		Not planted				
		Potato -		Not planted				
	2	Bush Bean +	Tendercrop	5/14/81	7/14/81	2370	711	50
		Green Corn ,	Supersweet	6/1/81	8/25/81	8083	4042	129
		Mustard	Local	5/22/81	7/11/81	8790	1318	132
		Cabbage +						
		Bush Bean +	Tendercrop	5/14/81	7/14/81	2820	846	59
	3	Soybean		Not planted				
		Peanut		Not planted				
	Side crop	Taro		Not planted				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.5. Yield of crops, calories and protein production for two cropping patterns, MOL site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
TE	1	Potato -	Kennebec	1/5/82	4/20/82	12313	8742	209
	2	Soybean -	Davis	5/6/82	9/2/82	2246	7434	784
	3	Corn /	X304C	9/17/82	1/17/83	3363	11737	306
	Side Crops	Cassava	Sabre	2/22/82	12/8/82	4112	4030	29
		Pigeon Pea	Not known	5/7/82	10/20/82	94	316	19
		Taro				No data		
HD	1	Bush Bean +	Tendercrop	1/5/82	3/9/82	2207	662	46
		Carrot +	Scarlet Nantes	11/6/81	3/3/82	13630	4225	123
		Cabbage ,	Copenhagen Market	1/4/82	3/24/82	6967	1533	112
		Potato -	Kennebec	1/5/82	4/20/82	15350	10898	261
	2	Bush Bean +	Tendercrop	5/6/82	7/9/82	3507	1052	74
		Green Corn ,	Supersweet	5/28/82	8/13/82	5893	2945	94
		Mustard Cabbage +	Local		No harvest			
		Bush Bean -	Tendercrop		No harvest			
	3	Soybean ,	Davis	9/15/82	1/5/83	846	2800	295
		Peanut /	Spanish red	9/15/82	1/10/83	2143	4222	210
	Side Crops	Taro				No data		

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.6. Yield of crops, calories and protein production for two cropping patterns, MOL site, 1983.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
TE	1	Potato –	Kennebec	1/26/83	5/17/83	19647	13949	334
	2	Soybean –		Not planted				
	3	Corn /		Not planted				
	Side Crops	Cassava		Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				
HD	1	Bush Bean +	Tendercrop	2/23/83	4/25/83	345*	194	7
		Carrot +	Scarlet Nantes	1/27/83	5/7/83	16555	5132	149
		Cabbage ,	Copenhagen Market	2/23/83	4/25/83	8740	1923	140
		Potato /	Kennebec	1/26/83	5/17/83	24687	17528	420
	2	Bush Bean +		Not planted				
		Green Corn,		Not planted				
		Mustard Cabbage +		Not planted				
		Bush Bean –		Not planted				
	3	Soybean ,		Not planted				
		Peanut /		Not planted				
	Side Crops	Taro						

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Bad seed

Appendix 4.7. Yield of crops, calories and protein production for two cropping patterns, IOLE site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +		Not planted				
		Carrot +		Not planted				
		Cabbage ,		Not planted				
		Potato –		Not planted				
	2	Bush Bean +	Tendercrop	5/14/81	7/15/81	5210	1563	109
		Green Corn,	Supersweet	5/28/81	9/4/81	17700	8850	283
		Mustard	Local		No harvest*			
		Cabbage +						
		Bush Bean –	Tendercrop	5/14/81	7/15/81	5420	1626	114
	3	Soybean ,		Not planted				
		Peanut		Not planted				
	Side Crops	Taro						
TE	1	Potato –		Not planted				
	2	Soybean –	Davis	5/13/81	9/20/81	3837	12700	1339
	3	Corn	X304C	Not planted				
	Side Crops	Cassava	Sabre	Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Bad seed

Appendix 4.8. Yield of crops, calories and protein production for two cropping patterns, IOLE site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Tendercrop	12/16/81	No harvest*			
		Carrot +	Scarlet Nantes	12/16/81	4/7/82	3857**	1196	35
		Cabbage ,	Copenhagen Market	12/3/81	2/27/82	6127**	1348	98
		Potato	Kennebec	12/16/81	3/16/82	3893**	2861	68
	2	Bush Bean +	Tendercrop	4/15/82	6/21/82	830	849	59
		Green Corn ,	Supersweet	5/4/82	8/8/82	7582	3791	121
		Mustard Cabbage +	Local	4/14/82	6/8/82	34780	5217	522
		Bush Bean -	Tendercrop	4/15/82	6/21/82	3870	1161	81
	3	Soybean ,	Davis	9/22/82	1/14/83	1094	3621	382
		Peanut /	Spanish red	9/21/82	1/24/83	850	1674	83
	Side Crops	Taro	Not known	4/14/82	12/9/82	8800	6864	158
TE	1	Potato -	Kennebec	12/16/81	3/16/82	8380	5914	142
	2	Soybean -	Davis	4/14/82	9/13/82	2386	7898	833
	3	Corn /	X304C	9/21/82	1/24/83	2413	8421	220
	Side Crops	Cassava	Sabre	1/22/82	12/9/82	2530	2479	18
		Pigeon Pea		No data				
		Taro		No data				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Bird Damage
** Storm Damage

Appendix 4.9. Yield of crops, calories and protein production for two cropping patterns, IOLE site, 1983.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Tendercrop	3/1/83	5/4/83	5178	1553	109
		Carrot +	Scarlet Nantes	1/26/83	5/18/93	15902	4930	143
		Cabbage ,	Copenhagen Market	1/26/83	4/28/83	14353	3158	230
		Potato -	Kennebec	1/26/83	5/10/83	18009	12786	306
	2	Bush Bean +		Not planted				
		Green Corn ,		Not planted				
		Mustard Cabbage +		Not planted				
		Bush Bean -		Not planted				
	3	Soybean ,		Not planted				
		Peanut		Not planted				
	Side Crop	Taro		Not planted				
TE	1	Potato -	Kennebec	1/26/83	5/9/83	17695	12563	301
	2	Soybean -		Not planted				
	3	Corn /		Not planted				
	Side Crops	Cassava		Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.10. Yield of crops, calories and protein production for two cropping patterns, KUK site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
HD	1	Bush Bean +	Bountiful	1/24/81	3/24/81	1427*	428	30
		Carrot +	Scarlet Nantes	1/20/81	5/7/81	9057	2808	82
		Cabbage ,	Copenhagen Market	2/6/81	4/12/81	18437	4056	295
		Potato -	Kennebec	1/20/81	5/8/81	12077	8575	205
	2	Bush Bean +	Tendercrop	5/21/81	7/22/81	5142	1543	108
		Green Corn ,	Supersweet	6/3/81	9/8/81	12753	6376	204
		Mustard Cabbage +	Local		No harvest*			
		Bush Bean -	Tendercrop	5/21/81	7/22/81	3180	954	67
	3	Soybean ,	Davis	9/10/81	1/4/82	1541	5101	538
		Peanut /	Spanish red	9/10/81	1/4/82	1933	3808	189
	Side Crop	Taro	Not known	1/21/81	12/10/81	3090	2410	56
TE	1	Potato -	Kennebec	1/20/81	5/8/81	15216	10803	259
	2	Soybean -	Davis	5/27/81	9/23/81	3299	10920	1151
	3	Corn /	X304C	10/2/81	2/23/82	4193	14634	382
	Side Crops	Cassava	Sabre	4/7/81	2/19/82	5190	5086	36
		Pigeon Pea	Not known	4/7/81	12/10/81	55	185	11
		Taro			No harvest			

[†] Conversion factors obtained from a F.A.O. publication (F.A.O. 1972)

* Storm Damage

** Bad seed

ppendix 4.11. Yield of crops, calories and protein production for two cropping patterns, KUK site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
HD	1	Bush Bean +	Tendercrop	12/7/81	2/10/82	3617	1085	76
		Carrot +	Scarlet Nantes	11/3/81	3/5/82	10863	3368	98
		Cabbage ,	Copenhagen Market	12/3/81	2/22/82	10777	2371	172
		Potato -	Kennebec	12/11/81	4/2/82	20600	14626	350
	2	Bush Bean +	Tendercrop	4/13/82	6/15/82	2060	618	43
		Green Corn,	Supersweet	5/3/82	7/30/82	10677	5338	171
		Mustard Cabbage +	Local	4/13/82	6/10/82	31300	4695	470
		Bush Bean	Tendercrop	4/13/82	6/15/82	2780	834	58
	3	Soybean ,	Davis	9/9/82	1/10/83	1504	4978	525
		Peanut /	Spanish red	9/9/82	1/12/83	1790	3526	175
	Side Crop	Taro	Not known	4/13/82	12/14/82	2908	2268	52
TE	1	Potato -	Kennebec	12/11/81	4/2/82	15630	11097	266
	2	Soybean -	Davis	4/13/82	8/23/82	2671	8841	932
	3	Corn /	X304C	9/10/82	1/18/83	4037	14089	367
	Side Crops	Cassava	Sabre	1/22/82	12/9/82	2528	2477	18
		Pigeon Pea		No harvest				
		Taro		No harvest				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.12. Yield of crops, calories and protein production for two cropping patterns, KUK site, 1983.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Tendercrop	2/25/83	4/27/83	2722	817	57
		Carrot +	Scarlet Nantes	1/21/83	5/17/83	20838	6460	188
		Cabbage ,	Copenhagen Market	2/25/83	4/27/83	18491	4068	296
		Potato -	Kennebec	1/21/83	5/3/83	26097	18529	444
	2	Bush Bean +		Not planted				
		Green Corn,		Not planted				
		Mustard Cabbage +		Not planted				
		Bush Bean -		Not planted				
	3	Soybean,		Not planted				
		Peanut /		Not planted				
	Side Crop	Taro		Not planted				
TE	1	Potato -	Kennebec	1/21/83	5/3/83	21431	15216	364
	2	Soybean -		Not planted				
	3	Corn /		Not planted				
	Side Crops	Cassava		Not planted				
		Pigeon Pea		Not planted				
		Taro		Not planted				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

Appendix 4.13. Yield of crops, calories and protein production for two cropping patterns, PAL site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Tendercrop	10/22/81	No harvest*			
		Carrot +	CRC-5*	10/3/81	1/18/82	157*	49	1
		Cabbage ,	KK Cross*	10/22/81	1/22/82	1539*	339	25
		Potato -	Isola*	10/22/81	No harvest*			
	2	Bush Bean +	Tendercrop	2/20/82	5/1/82	1706	512	36
		Green Corn,	Supersweet	3/11/82	5/29/82	9625	4812	154
		Mustard Cabbage +	Local	2/20/82	4/3/82	13842	2076	208
		Bush Bean -	Tendercrop	2/20/82	5/1/82	4055	1216	85
	3	Soybean ,	Davis	5/15/81	9/4/81	2527	8364	882
		Peanut /	Spanish white	5/15/81	9/8/81	2306	4543	226
	Side Crop	Taro	Dasheen	5/15/81	6/21/82			
TP	1	Rice +	IR-50	9/18/81	12/29/81	590*	2124	40
		Green Corn-	X304C	9/18/81	No harvest*			
	2	Soybean ,	UPL-SY-2	2/20/82	5/25/82	975**	3227	340
		Peanut -	Spanish white	2/20/82	6/28/82	3764	7415	369
	3	Cowpea ,	All seasons	5/15/81	9/7/81	798***	2729	183
		Mungbean /	Pag-sa I	5/15/81	8/19/81	258****	890	57
	Side Crop	Cassava	Amarillo	5/15/81	6/21/82	11694	11460	82

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Typhoon Damage
** Bad Seed
*** Excess Vegetative growth
**** Matured early

Appendix 4.14. Yield of crops, calories and protein production for two cropping patterns, PAL site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
HD	1	Bush Bean +	Tendercrop	11/15/82	1/15/83	404*	121	8
		Carrot +	CRC-5	10/15/82	2/8/83	4201*	1302	38
		Cabbage ,	KK Cross	11/15/82	2/1/83	4187*	921	67
		Potato -	Cosima	10/15/82	1/20/83	8718**	6190	148
	2	Bush Bean +	Tendercrop	3/15/83	4/27/83	496	149	10
		Green Corn,	Supersweet	4/4/83	6/22/83	9500	4750	152
		Mustard Cabbage +	Local	3/15/83	4/27/83	2936**	440	44
		Bush Bean -	Tendercrop	3/15/83	5/18/83	456	137	10
	3	Soybean ,	UPL SY-2	6/28/83	10/20/82	1496	4952	522
		Peanut /	Spanish white	6/28/82	10/17/82	2313	4557	227
	Side Crop	Taro	Dasheen	3/14/82	6/23/83	2824		
TP	1	Rice +	UPL-R-5	10/7/82	2/7/83	3021	10876	202
		Green Corn-	Supersweet	10/7/82	12/24/82	4965	2482	79
	2	Soybean ,	Davis	3/14/83	6/29/83	2607	8629	910
		Peanut -	Florunner	3/14/83	6/27/83	3137	6180	307
	3	Cowpea ,	All seasons	6/29/82	9/13/82	1052*	3598	241
		Mungbean /	Pag-sa I	6/29/82	9/13/82	80*	276	18
	Side Crop	Cassava	Amarillo	3/14/83	6/22/83	2198	2154	15

[†] Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Typhoon Damage
** Attacked by worms

Appendix 4.15. Yield of crops, calories and protein production for two cropping patterns, LPH site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Tendercrop	12/19/81	2/23/82	356*	107	8
		Carrot +	Cipanas	12/19/81	4/12/82	11122*	3448	100
		Cabbage ,	Danish	12/19/81	2/12/82	4284	942	68
		Potato -	Granola	12/19/81	3/16/82	2392*	1698	41
	2	Bush Bean +	Tendercrop	3/7/81	5/5/81	1271	381	27
		Green Corn,	Supersweet	3/7/81	7/18/81	5668	2834	91
		Mustard	Local**	3/7/81	No harvest**			
		Cabbage +						
		Bush Bean -	Tendercrop	3/7/81	7/18/81	1340	402	28
	3	Soybean ,	Orba	8/12/81	11/17/81	1037	3432	362
		Peanut /	Spanish red	8/13/81	11/17/81	3267	6436	320
	Side Crop	Taro	unidentified	3/7/81	12/9/81	7937	6191	111
TP	1	Rice +	C-22	12/19/81	6/14/82	1360***	4896	91
		Green Corn-	Supersweet	12/19/81	4/6/82	Data not available		
	2	Soybean ,	Davis	3/7/81	6/15/81	438*	1450	153
		Peanut /	Spanish red	3/7/81	7/10/81	1001***	1972	98
	3	Cowpea ,		Data not available				
		Mungbean /		Data not available				
	Side Crop	Cassava	Unidentified	3/7/81	12/10/81	16821	16485	115

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Rain Damage
** Bad seed
*** Late maturity

Appendix 4.16. Yield of crops, calories and protein production for two cropping patterns, LPH site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
HD	1	Bush Bean +	Pangalangan	12/11/82	3/7/83	1547*	464	32
		Carrot +	Cipanas	12/11/82		9524	2952	86
		Cabbage ,	Danish	12/11/82	3/12/83	5686*	1251	91
		Irish Potato -	Granola	12/11/82	3/5/83	4598*	3265	78
	2	Bush Bean +	Pangalangan**	4/26/82	7/20/82	935**	280	20
		Green corn ,	Supersweet	4/26/82	9/10/82	4749	2374	76
		Mustard	Local	4/26/82	7/2/82	14478	2172	217
		Cabbage + Bush Bean -	Pangalangan	4/26/82	7/20/82	2842	853	60
	3	Soybean ,	Orba	9/16/81	1/11/83	2024	6699	706
		Peanut /	Spanish red***	9/16/82	1/11/83	719***	1416	70
	Side Crop	Taro			Data not available			
TP	1	Rice +	Sirandah-Putih	12/11/82	No harvest			
		Green Corn -	X304C	12/11/82	4/21/83	3180	1590	51
	2	Soybean ,	Davis	6/22/82	11/9/82	1683	5571	587
		Peanut -	Gajah	6/22/82	11/9/82	2120	4176	208
	3	Cowpea ,	All seasons**		No harvest**			
		Mungbean /	MB 129****		No harvest****			
	Side Crop	Cassava			Data not available			

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Rain damage
** Bad seed
*** Pod borer
**** Wild pigeon damage

Appendix 4.17. Yield of crops, calories and protein production for two cropping patterns, ITKA site, 1982-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
HD	1	Bush Bean +		Not planted				
		Carrot +		Not planted				
		Cabbage ,		Not planted				
		Potato -		Not planted				
	2	Bush Bean +	Tendercrop*	5/21/81	8/4/81	858*	257	18
		Green Corn,	Supersweet	5/21/81	10/4/81	5579	2790	89
		Mustard	Local	5/21/81	8/4/81	2563	384	38
		Cabbage +						
		Bush Bean -	Tendercrop	5/21/81	10/4/81	905	272	19
	3	Soybean ,		Not planted				
		Peanut /		Not planted				
	Side Crop	Taro		Not planted				
TP	1	Rice +		Not planted				
		Green Corn -		Not planted				
	2	Soybean ,	Davis	5/21/81	9/9/81	861**	2850	300
		Peanut -	Spanish red	5/21/81	10/25/81	3562	7017	349
	3	Cowpea ,		Not planted				
		Mungbean /		- Not planted				
	Side Crop	Cassava						

[†] Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

* Rain damage

** Bad seed

Appendix 4.18. Yield of crops, calories and protein production for two cropping patterns, NAK site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
TP	1	Rice +	C-C4	10/27/81	2/16/82	1797*	6469	120
		Corn -	Supersweet	10/27/81	1/11/82	Data missing		
	2	Soybean ,	Davis	3/11/81	6/22/81	1292	4276	451
		Peanut -	Spanish red**	3/11/81	6/20/81	747**	1472	73
	3	Cowpea ,		Not planted				
		Mungbean /		Not planted				
	Side Crop	Cassava	unidentified	3/11/81	10/10/81	***		
HD	1	Bush Bean +	Pangalangan	10/27/81		5339****	1602	112
		Carrot +	Cipanas	10/27/81	1/15/82	1231	382	11
		Cabbage ,	Danish		No harvest			
		Potato -	Granola		No harvest			
	2	Bush Bean +	Tendercrop	3/11/81	4/23/81	770	231	16
		Green Corn,	Supersweet	3/11/81	6/4/81	5158	2579	82
		Mustard	Local	3/11/81	5/4/81	3049	457	46
		Cabbage +						
		Bush Bean -	Tendercrop	3/11/81	4/23/81	817	245	17
	3	Soybean ,		Not planted				
		Peanut		Not planted				
	Side Crop	Taro	unidentified	3/11/81	10/12/81	1654	1290	30

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Blast incidence
** Pod borer
*** Harvested prematurely
**** Viny variety

Appendix 4.19. Yield of crops, calories and protein production for two cropping patterns, NAK site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
TP	1	Rice +	Sirendah-Putih*	12/15/82	4/4/83	1283*	4619	86
		Corn ,	X304C	12/15/82	2/22/83	2376	1188	38
	2	Soybean ,	Davis	3/9/82	6/25/82	1100	3641	384
		Peanut -	Gajah**	7/1/82	8/26/82	422**	831	41
	3	Cowpea ,	All seasons	7/1/82	8/28/81	125	428	29
		Mungbean /	unidentified	7/1/82	8/28/82	94***	324	21
	Side Crop	Cassava	unidentified		No harvest			
HD	1	Bush Bean +	Pangalangan	12/15/82	2/28/83	637****	191	13
		Carrot +	Cipanas	12/15/82	4/28/83	2097	650	19
		Cabbage ,	Danish		No harvest			
		Potato -	Granola		No harvest			
	2	Bush Bean +	Tendercrop	3/9/82	4/8/82	174****	52	4
		Green Corn,	Supersweet	3/9/82	5/31/82	4958	2479	79
		Mustard Cabbage +	Local	3/9/82	5/17/82	3877	582	58
		Bush Bean -	Tendercrop	3/9/82	4/8/82	159	48	3
	3	Soybean ,		6/6/82	8/31/82	497	1645	173
		Peanut /			No harvest			
	Side Crop	Taro		No harvest				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Lodged
** Pod borer damage
*** Wild pigeon damage
**** Poor germination

Appendix 4.20. Yield of crops, calories and protein production for two cropping patterns, BPI site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
TP	1	Rice +	C-22	5/4/81	9/15/81	3821	13756	256
		Green Corn -	Supersweet	5/4/81	7/10/81	data missing		
	2	Soybean ,	Davis	9/28/81	1/7/82	236*	781	82
		Peanut -	Spanish white	9/28/81	1/21/82	3705	7299	363
	3	Cowpea ,	All seasons	2/10/81	6/11/81	513**	1754	117
		Mungbean /	Pagasa I	2/10/81	5/20/81	547**	1887	121
	Side Crop	Cassava	Amarillo	9/24/81	5/10/82	19474	19084	136
HD	1	Bush Bean +	Tendercrop***	5/26/81	8/15/81	519***	156	11
		Carrot +	CRC-5	5/2/81	8/24/81	3143	974	28
		Cabbage ,	KK Cross	5/26/81	8/8/81	847	186	14
		Potato -	Isola	5/26/81	No harvest			
	2	Bush Bean +	Tendercrop	9/28/81	12/4/81	672***	202	14
		Green Corn ,	X304C	10/11/81	1/4/82	6968	3494	112
		Mustard	Local	9/28/81	11/19/81	4357****	654	65
		Cabbage +						
		Bush Bean -		9/28/81	12/4/81	315	94	7
	3	Soybean ,	Davis	2/10/81	6/11/81	353*****	1168	123
		Peanut /	Unidentified	2/10/81	6/11/81	1459******	2874	143
	Side Crop	Taro	Dasheen	5/10/81	Data not available			

† Conversion factors obtained from F.A.O. publications (F.A.O. 1972)
* Bad seed
** Irrigation failed
*** Bean fly damage
**** Attacked by worms
***** Loss at harvest
****** Low yielding variety

Appendix 4.21. Yield of crops, calories and protein production for two cropping patterns, BPI site, 1982-83.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie† K cal/ha	Protein† kg/ha
TP	1	Rice +	C-22	5/24/82	9/18/82	1918*	6905	128
		Corn -	Supersweet	5/24/82	8/5/82	3735	13035	340
	2	Soybean ,	Davis	11/5/82	2/25/83	836	2767	292
		Peanut -	Spanish white	11/5/82	2/28/83	1881	3706	184
	3	Cowpea ,	All seasons	2/11/82	4/27/82	790	2702	181
		Mungbean /	Pagasa I	2/11/82	4/20/82	1085	3743	241
	Side crop	Cassava	Amarillo	7/13/82	2/19/83	6112	5990	43
HD	1	Bush Bean +	Tendercrop	7/9/82	10/4/82	1637	491	34
		Carrot +	CRC-5	6/2/82	9/23/82	5751	1783	52
		Cabbage ,	KK Cross	6/2/82	No harvest			
		Irish Potato-	Isola	6/2/82	No harvest			
	2	Bush Bean +	Tendercrop	11/5/82	2/17/83	1436	431	30
		Green Corn ,	Supersweet	11/17/82	2/7/83	4514	2257	72
		Mustard Cabbage +	Local	11/5/82	12/20/82	4765	715	72
		Bush Bean -	Tendercrop	11/5/82	2/17/83	618	185	13
	3	Soybean ,	Davis	2/11/82	5/21/82	96**	318	34
		Peanut /	Spanish white	2/11/82	5/25/82	5179	10203	507
	Side crop	Taro	Dasheen	7/13/82	2/19/83	2774	2164	50

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)

* Bird damage

** Bad seed

Appendix 4.22. Yield of crops, calories and protein production for two cropping patterns, SOR site, 1981-82.

Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
TP	1	Rice +	IR-50	9/24/81	12/28/81	477*	1717	32
		Green Corn-	X304C	9/24/81	12/8/81	4566	2283	73
	2	Soybean , Peanut -		Not planted				
	3	Cowpea ,	All seasons	6/3/81	8/28/81	949	3246	217
		Mungbean /	Pag-sa I	6/3/81	9/10/81	1085	3743	241
	Side crop	Cassava	Amarillo	11/9/81	9/18/82	1171**	1148	8
HD	1	Bush Bean +	Tendercrop	10/29/81	No harvest*			
		Carrot +	CRC-5	10/5/81	1/18/82	6096	1890	55
		Cabbage ,	KK Cross	10/29/81	No harvest			
		Potato -	Isala	10/29/81	No harvest			
	2	Bush Bean +		Not planted				
		Green Corn,		Not planted				
		Mustard		Not planted				
		Cabbage +						
		Bush Bean -		Not planted				
	3	Soybean ,	Davis	6/3/81	9/10/81	1699	5624	593
		Peanut /	Spanish white	6/3/81	9/12/81	2072	4082	203
	Side crop	Taro	Dasheen	7/1/81	10/18/82	1715	1338	31

[†] Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Typhoon damage
** Pruning damage

Appendix 4.23. Yield of crops, calories and protein production for two cropping patterns, SOR site, 1982-83.

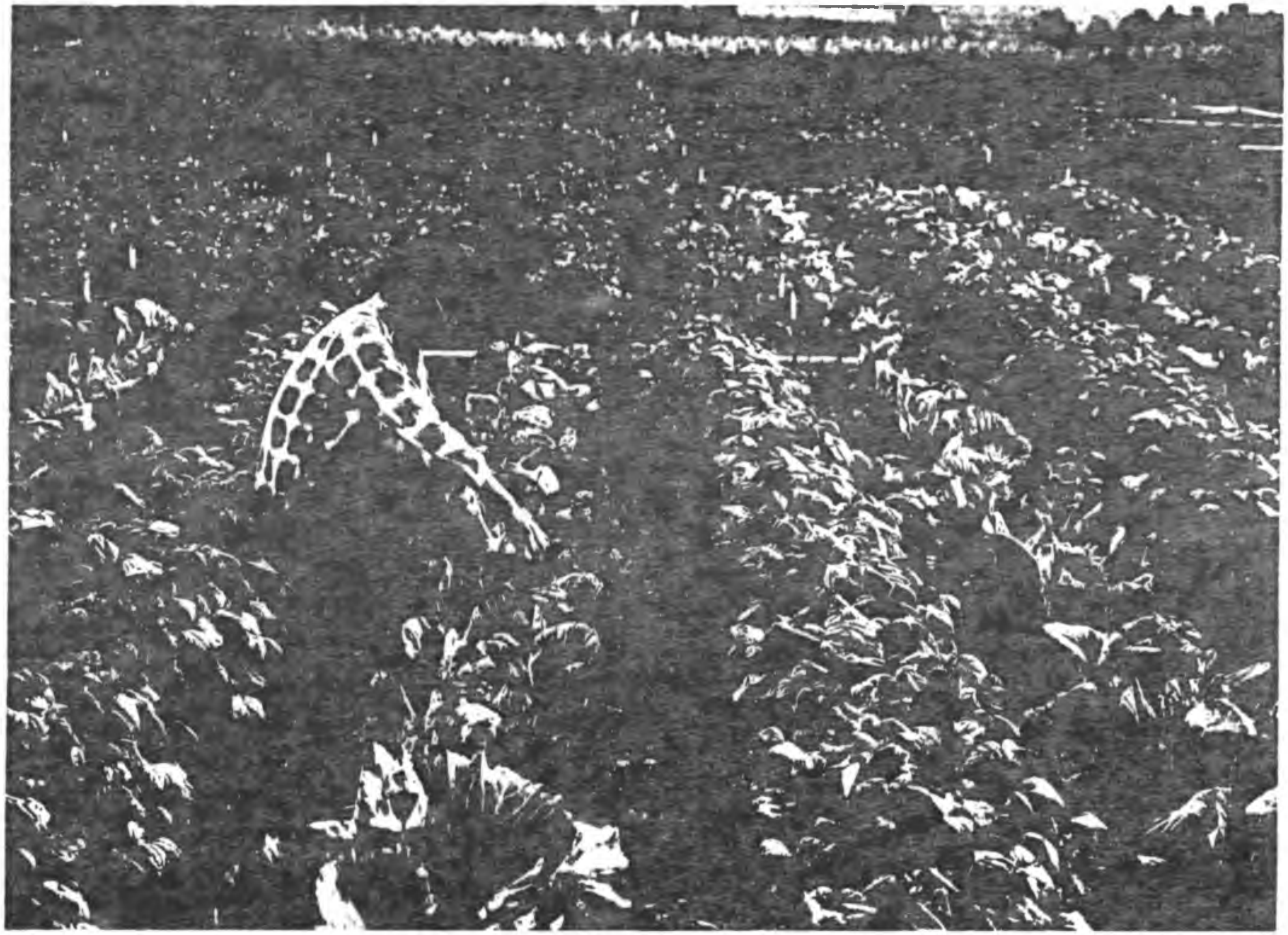
Crop Pattern	Season	Crop	Variety	Planting Date	Harvest Date	Irrigated Yield (mean) kg/ha	Calorie[†] K cal/ha	Protein[†] kg/ha
TP	1	Rice +	IR-50	10/11/82	2/2/83	2544*	9158	170
		Green Corn −	X304C	10/11/82	12/26/82	Data not available		
	2	Soybean ,	UPL SY-2	2/16/82	5/10/82	1867	6180	652
		Peanut −	Spanish white	2/16/82	5/7/82	1867	3678	183
	3	Cowpea ,	All seasons	7/2/82	9/17/82	1337**	4572	306
		Mungbean /	Pagasa-I	7/3/82	9/17/82	668**	2305	148
	Side crop	Cassava	Amarillo					
HD	1	Bush Bean +	Tendercrop	11/16/82	1/19/83	1204**	361	25
		Carrot +	CRC-5	10/11/82	2/9/83	5978	1853	54
		Cabbage ,	KK Cross	11/17/82	1/26/83	1808	398	29
		Irish Potato-	Cosima	--				
	2	Bush Bean +	Tendercrop	2/16/82	4/20/82	2425	728	51
		Green Corn ,	X304C	3/8/82	5/25/82	9757	4878	156
		Mustard	Local	2/16/82	4/2/82	8245	1237	124
		Cabbage +						
		Bush Bean −	Tendercrop	2/16/82	4/20/82	4838	1451	102
	3	Soybean ,	UPL SY-2	7/6/82	9/30/82	2226	7368	777
		Peanut /	Spanish white	7/1/82	10/18/82	2791	5498	274
	Side crop	Taro	Dasheen	Data not available				

† Conversion factors obtained from F.A.O. publication (F.A.O. 1972)
* Limited bird damage
** Typhoon damage

Appendix 4.24 Luxuriant growth of Irish potato crop on the Eutrustox site of WAI (Hawaii) during the first season (TE pattern). Under irrigation.

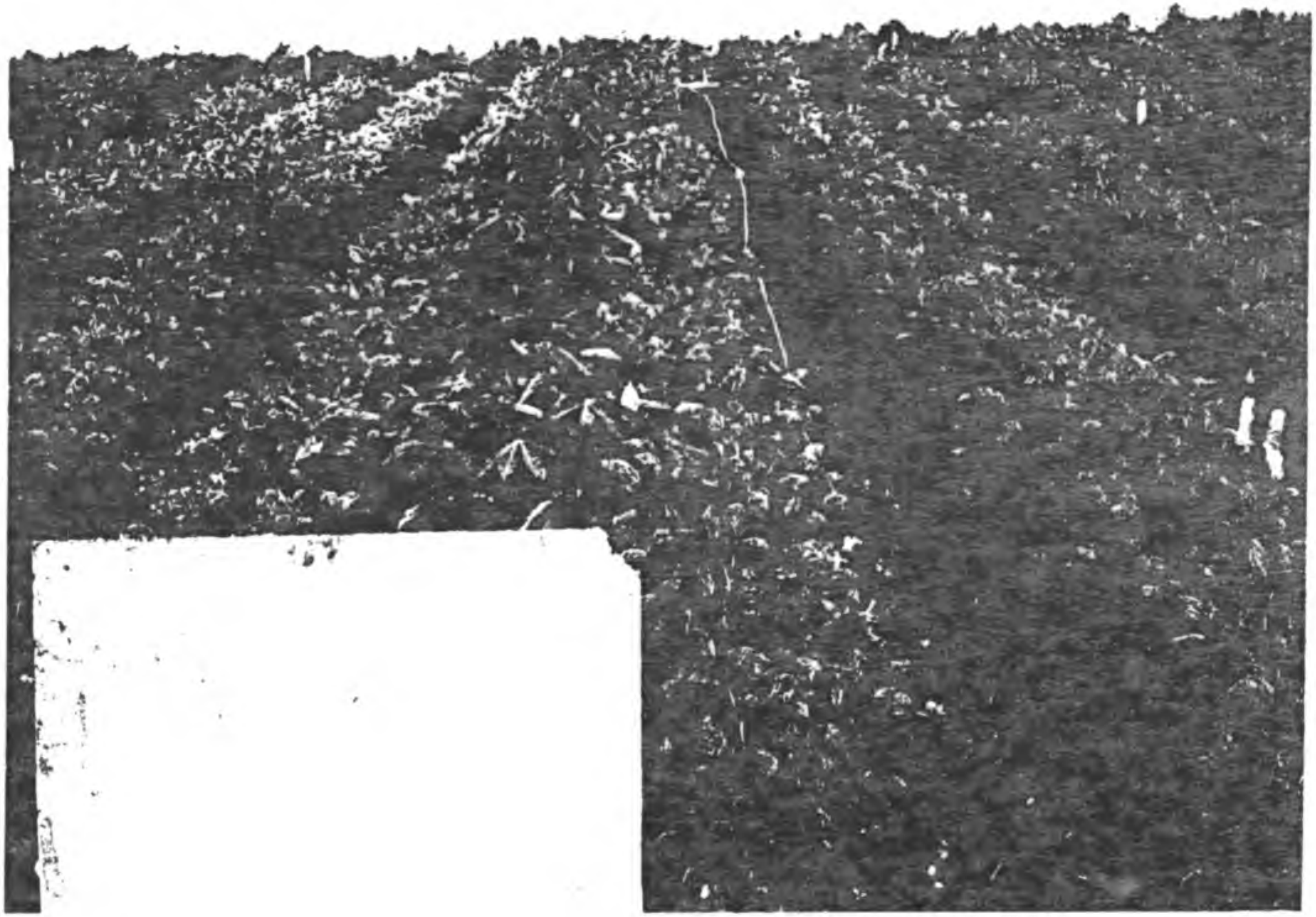
Appendix 4.25 Harvested Irish potato crop on the Tropeptic Eutrustox site of WAI (Hawaii) grown during the first season (TE pattern, irrigated).

Appendix 4.26 Growth of Irish potato and "cabbage+carrot+bushbean" combination under non-irrigated condition on the Dystrandept site of KUK (Hawaii), during the first season (HD pattern).

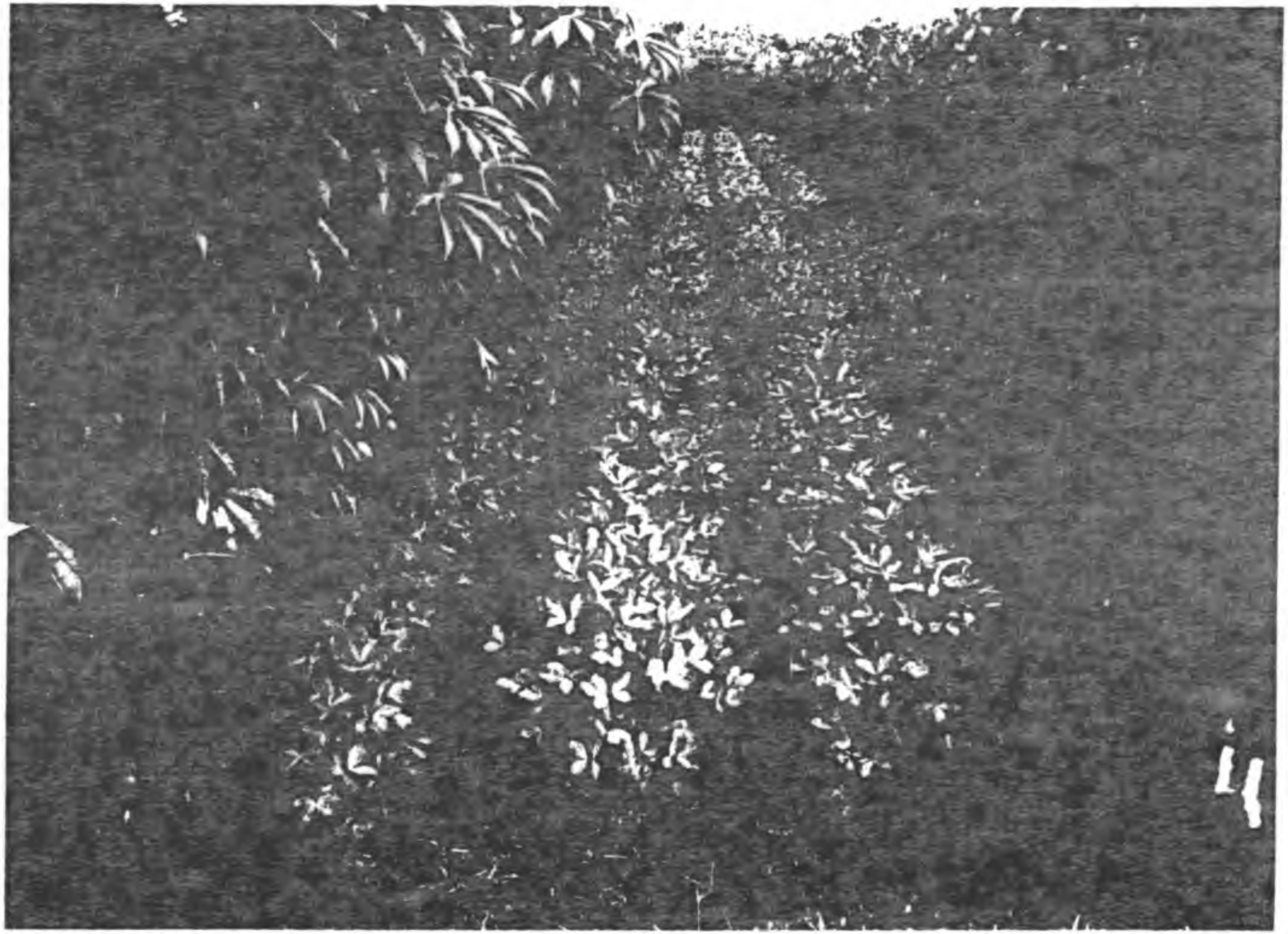


Appendix 4.27 Growth of Irish potato (background) and "cabbage+carrot+bushbean" combination on the Eutrustox site of WAI (Hawaii), during the first season (HD pattern) under irrigation.

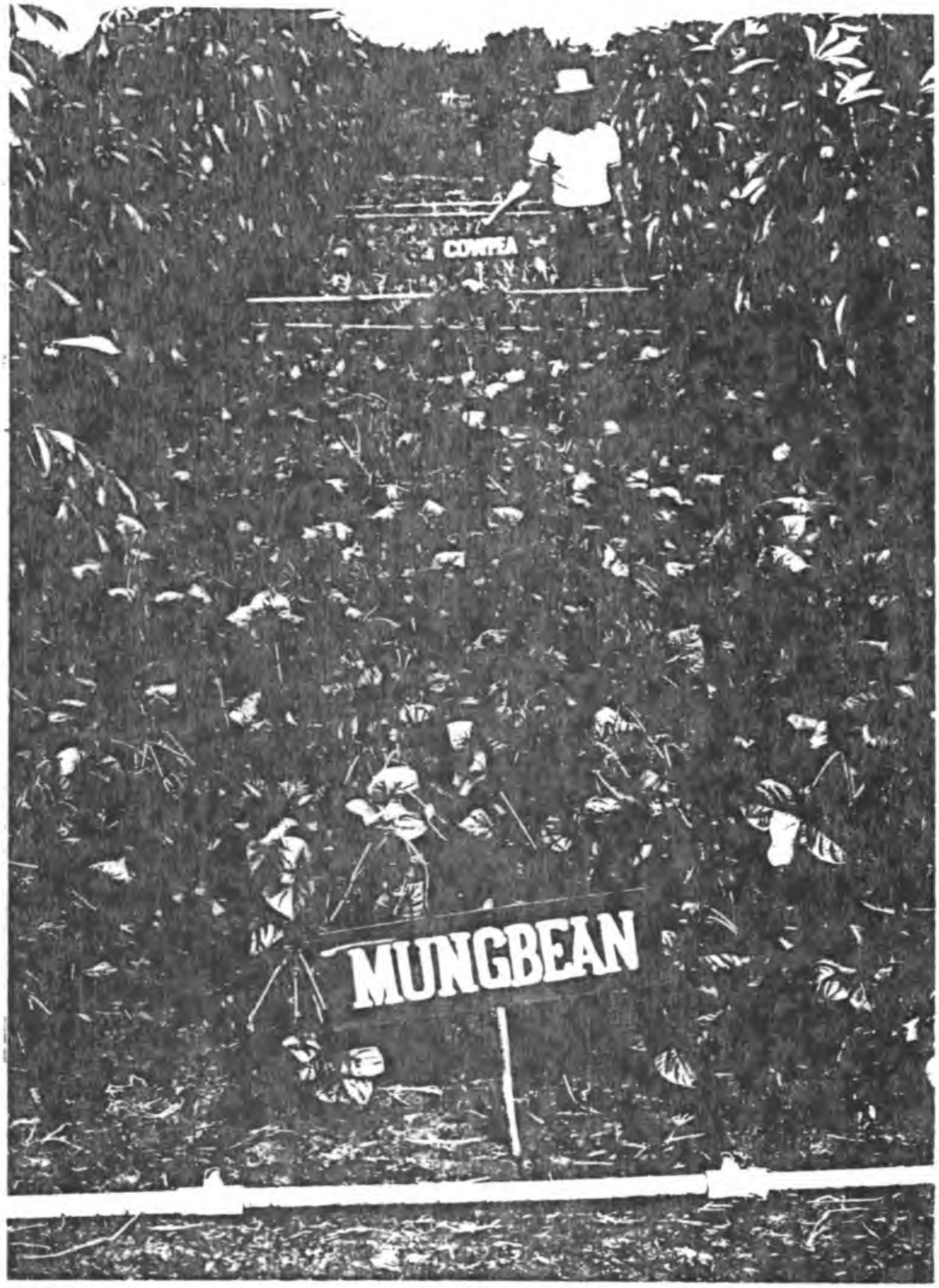
Appendix 4.28 Growth of the soybean crop on the Tropeptic Eutrustox site of WAI (Hawaii) during the second season (TE pattern) under irrigation.



Appendix 4.29 Soybean crop and the border crop of cassava during the second season on the Paleudult site of SOR (The Philippines) under irrigation (TP pattern).



Appendix 4.30 Peanut crop (TP pattern irrigated) on the Paleudult site of BPI (The Philippines) showing the shading effect of cassava on outer rows.



Appendix 4.31 Growth of mungbean and cowpea during the third season (TP pattern, irr.) on the Paleudult site of SOR (The Philippines.

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