EFFECT OF NUTRITION AS INFLUENCED BY IRRIGATION ON GROWTH AND YIELD OF OIL PAL (*Elaeis guineensis* Jacq.)

By

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THESIS
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DECLARATION

I hereby declare that this thesis entitled "EFFECT OF NUTRITION AS INFLUENCED BY IRRIGATION ON GROWTH AND YIELD OF OIL PALM (*Elaeis guineensis* Jacq.)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me any degree, diploma, associateship, fellowship or any other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "**EFFECT OF NUTRITION AS INFLUENCED BY IRRIGATION ON GROWTH AND YIELD OF OIL PALM (*Elaeis guineensis* Jacq.)**" is a record of research work done independently by Sri. P. Thomas Varghese under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CONTENTS

LIST OF ABBREVIATIONS AND SYMBOLS

ABW	-	Average bunch weight
BDM	-	Bunch dry matter
^{o}C	-	Degree celsius
CGR	-	Crop growth rate
cm	-	Centimetre
CPCRI	-	Central Plantation Crops Research Institute
DRIS	-	Diagnosis and Recommendation Integrated System
DS	-	Dry spell
DV	-	Diurnal variation
g	-	Gram
FFB	-	Fresh fruit bunches
h	-	Hour
ha	-	Hectare
ICAR	-	Indian Council of Agricultural Research
l	-	Litre
KCl	-	Potassium chloride
LAI	-	Leaf area index
LWP	-	Leaf water potential
m	-	metre
MAT	-	Maximum temperature
MIT	-	Minimum temperature

mm	-	Millimetre
MOP	-	Muriate of Potash
MPa	-	Megapascals
NAR	-	Net assimilation rate
NB	-	Number of bunches
NII	-	Nutrient imbalance inde
NS	-	Not significant
PE	-	Pan evaporation
Pn	-	Net photosynthesis
PORIM	-	Palm Oil Research Institute of Malaysia
R^2	-	Coefficient of determination
r	-	Correlation coefficient
RD	-	Rainy days
RF	-	Rainfall
RH	-	Relative humidity
RWC	-	Relative water content
S*	-	Significant at P = 0.05 level
S**	-	Significant at P = 0.01 level
t	-	tonne
TDM	-	Total dry matter
VDM	-	Vegetative dry matter

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INTRODUCTION

1. INTRODUCTION

The oil palm, Elaeis guineensis Jacq., is a palm indigenous to the West Coast of Africa, where it grows wild. From its centre of origin in West Africa it was distributed to different countries of the tropical world and is mostly domesticated in the warm humid tropical regions between 13°N and 13°S latitudes.

The first effort in introducing oil palm in India was made by the Government of Kerala at a research station in Thodupuzha in 1960. At present oil palm is cultivated in an area of 3050 ha in Kerala. The crop occupies an area of 9800 ha in India and is proposed to be increased to 5.75 lakh hectares (Anonymous, 1988). The possible areas of oil palm cultivation in India are indicated in Fig. 1. Andhra Pradesh and Karnataka together accounts for 87 per cent of the total area identified for its cultivation.

Oil palm is a relatively new crop to India and the crop demands high level of technical and agronomical management for achieving maximum yield. Only limited research on agronomy of oil palm has been reported from India. In all

Fig. 1. Area suitable for oil palm cultivation in India

other oil palm growing countries, separate fertilizer doses are recommended for the different growth phases. In India the recommendations are available only for the early growing stage based on an experiment conducted at Central Plantation Crops Research Institute (CPCRI) (Nair and Sreedharan, 1982). No information is available on the fertilizer needs of oil palm during its mature phase in India. At present only a blanket recommendation is given for this phase, not supplemented by experimental data.

No studies have been conducted so far on the irrigation requirement of oil palm in India. Since oil palm cultivation is envisaged mostly under irrigated conditions a study on this aspect is also important. Considering the topographical situation in which the crop is grown and scarcity of water in such areas the possibility of drip irrigation is assessed in the experiment.

Foliar analysis has been practiced in oil palm for planning and evaluation of fertilizer programmes on the basis of critical nutrient level approach. This approach evaluate only single deficiency or excess at a time and does not measure nutritional balance. The influence of nutrient ratios and their interaction on productivity of crops are well known. No such attempt has been made with reference to oil palm. The Diagnosis and Recommendation Integrated System (DRIS) was developed by Beaufils (1957, 1971 and 1973) to overcome the defects in the diagnostic procedure using critical nutrient level approach. The DRIS approach has been adopted with advantage in many crops and not on oil palm. This is probably the first attempt on the crop.

Plant growth being genetically controlled and environmentally modulated it is highly essential to assess the effect of climatic factors on the performance of oil palm. Considering their strong relationship it is possible to forecast the yield based on the climate experienced by the crop several months before the harvest of the crop. An investigation in this direction is attempted for the first time on oil palm in India.

Taking into consideration of the above situations the present investigation is attempted with the following objectives:

1. To establish the fertilizer requirement of adult oil palm,

2. To assess its irrigation requirement through drip system of irrigation,

3. To assess the possibility of adopting DRIS approach in oil palm and

4. To evaluate the influence of climatic parameters experienced by the crop from primordia initiation to harvest.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

An investigation on the effect of fertilizer and irrigation on growth and yield of oil palm was conducted with a view to assess the fertilizer needs of the adult oil palm. The irrigation requirement as influenced by the supply of different quantities of water to the palm is also to be assesed. It is also intented to asses the interrelationship of nutrients and to identify the nutrient inadequacies if any.

The review pertaining to the crop nutrition, irrigation requirement, the interrelationship of nutrients and climatic effect on subsequent yield of the crop are presented here under.

2.1 Need for irrigation and nutrition for oil palm

Long term nutrient supplying power of many tropical soils is poor. During a crop cycle of 25-30 years, considerable quantity of nutrients are either removed in the bunches, stored in the trunk, leaves and roots, or returned to the soil in dead leaves and roots. An idea on the proportions of nutrient that have been lost in the produce or have been returned to the soil is essential for optimum fertilizer management.

The effect of major nutrients NPK and secondary nutrients Ca and Mg on the growth and yield of oil palm has been studied in other oil palm growing countries in Asia and Africa. Corley et al. (1976) and Hartley (1988), had given the role of these nutrients on oil palm physiology.

Ng (1970) reported that the soil moisture status also determined the nutrient status of oil palm leaves.

2.2 Effect of irrigation on growth parameters and yield

Desmarest (1967) reported that in Ivory coast the annual vegetative dry matter production of a palm was relatively constant over a wide range of planting densitites Corley (1973) and Van der Vossen (1974) reported that vegetative growth was affected by water stress. It is now generally understood that oil palm requires ample water supply evenly distributed throughout the year (about 167 mm per month) for good vegetative growth and high bunch yield (Hartley, 1988). Jacquemard (1979) found out that the annual growth increment of trunk was 40.88cm in Mondoni, Cameroon where there was greater water deficit compared to 47.86cm recorded at La Me.

Prioux (1989) reported that in the absence of rain, irrigation should supply 60 per cent of evaporation from pan-evaporimeter so that water diffuses and fluctuates with in acceptable range. Rey et al. (1991) observed that oil palm was capable of extracting water up to five meters down once they have removed available water from surface horizon. Almost 50% of available water was in first two meters and the remaining was up to five meters down.

2.2.1 Growth parameters

Seasonal effect was observed on leaf production by Broekmans (1957) and Ochs (1963) with flush of leaf opening along with rainy season. Difference in leaf production between palms of similar genetic origin at different sites was reported to be due to the variation in rainfall by

Broekmans (1957). The number of newely opened fronds produced per palm was found greater with irrigation by Henson and Chang (1989).

Corley and Mok (1972) observed that nitrogen and potassium fertilizers increased leaf area. Van der Vossen (1974) noticed correlation between leaf area and water stress which was confounded with soil type and fertility. So it is presumed that different rates in leaf area increase is due to difference in soil fertility or in soil moisture. Taffin and Ochs (1973) demonstrated that optimum K levels and cost effective fertilizer rates varied according to the intensity of moisture stress which influenced tree production. Increase in leaf production by K application of 3.63kg MOP per palm was reported by Tan (1973). Villalobos et al. (1990b) reported that the magnitude of reduction in leaf area was in direct relation with intensity of stress and leaf area is reduced to reduce the transpiration through leaves.

Increase in frond dry weight due to irrigation was observed by Henson and Chang (1989).

2.2.2 Crop physiological aspects

Wormer and Ochs (1959) noticed the occurence of stomatal closure during dry season in Ivory Coast. Corley (1973) observed stomatal closure during dry season in Malaysia. In west Africa there is a long annual period of overcast weather, and during dry season moisture stress limited the usefulness of sunlight in photosynthesis (Hardon et al. 1969). Rainfall affected adversely because at that time light was a limiting factor due to overcast skies which has reduced photosynthesis.

Benami and Ofen (1983) recommended that drip irrigation should ensure water to 25-30 per cent of the area being watered. Chillard et al. (1983) from the irrigation trial conducted in Benin concluded that by supplying 5 mm of water in a day, the depressive effect of drought on leaf contents of nitrogen and potassium was eliminated. Caliman et al. (1987) observed that water saving techniques as mulching resulted in remarkable growth improvement of oil palm. Premature closing of stomata was observed in soils which showed lower water holding capacity.

Dufrene (1989) reported that photosynthetic activity of 4-10 year old oil palm was affected by stomatal closing.

Short dry spells reduced photosynthesis in oil palm (Henson and Chang, 1989). Water stress reduced the photosynthetic activity of their leaves and the efficient translocation of nutrients to the rest of the plant (Umana and Chinchilla, 1991).

Stomatal closure is a common response to water deficit which has been observed for oil palm in West Africa by Rees (1961) and in Malaysia by Corley (1973). A higher stomatal resistance during drought stress is known to help checking transpirational loss of water from tissues (Turner, 1974). Daniel (1979) indicated on the use of stomata test ie., measuring the opening of stomata using isopropyl alcohol (Mollish infiltration technique) to control oil palm water supply in plantation. Caliman (1992) noticed that with adequate water supply when stomata remained open, evapotranspiration was 80 per cent of PET where as it was only 20 per cent under limited water supply. Mid day stomatal conductance was low in unirrigated plot than irrigated plots (Henson and Chang, 1989). Villalobos et al. (1990 b) observed higher value of abaxial water vapour conductivity (c) in irrigated plants (c = 1.14 cm/s) compared to unirrigated (c = 0.15cm/s). Premature bending of lower leaves was very low in irrigated plots. A faster response in conductivity was observed in younger leaves after irrigation (Villalobos et al., 1992). Dufrene et al. (1993) reported that the stomatal conductance varied from 6 to 6.6 mm s^{-1}. With reduction in soil moisture, stomatal conductance was reduced to 1.5 mm s^{-1}. Stomatal resistance behaved in the opposite manner.

Corley et al. (1976) reported that the photochemical efficiency was decreased above 35°C in oil palm as was not ideal for most of the crops. Hence during dry period high leaf temperatures may be a limiting factor for photosynthesis.

Taffin and Daniel (1976) observed that sufficient water supply to oil palm was obtained when the area wetted by drip irrigation was 35-40 per cent of the total volume of soil explored by palm roots.

2.2.3 Yield attributes and yield

Increase in average bunch weight due to irrigation had been reported by Taffin and Daniel (1976).

In Ivory coast, at locations with long periods of water stress, irrigation raised yields from 7.5 to 26.0 tonnes of fresh fruit bunches ha^{-1} $year^{-1}$ (IRHO, 1962). Differences in bunch yields due to variation in moisture stress was reported by Sparnaaij et al. (1963) and Turner (1977). Desmarest (1967) indicated that in Ivory Coast, irrigation during summer months caused a reduction in inflorescence abortion rate. Taffin and Daniel, (1976) observed from slow irrigation trial conducted in the Republic of Benin that by irrigating 34-45 per cent of soil volume explored by roots, yield of 30t bunches ha^{-1} $year^{-1}$ was obtained. The number of both male and female inflorescences were initially found increased due to a reduction in abortion rate and later the number of male inflorescences produced were lower in irrigated plots indicating the effect of irrigation on sex differentiation. (IRHO, 1970). Corley et al. (1976) observed abnormaly high male inflorescence production 19 to 22 months after a drought due to lower sex ratio during dry periods. Chillard et al. (1983) reported that though yield potential was increased by irrigation, it also increased export of mineral nutrients and decreased leaf nutrient content particularly of N, K and Ca. Chan et al. (1985) reported yield benefits of irrigation in areas of intense dry period in Malaysia. Foster et al. (1987) reported increase in leaf N and P levels corresponding to yield increase due to rainfall and water availability. Foster and Chang (1989) observed that in highly laterite soils having low water holding capacity maximum yield was limited by inadequate moisture. In trials with mature palms, bunch yield was reduced in unirrigated compared to irrigated palms (Henson and Chang, 1989). Von Uexkull and Fairhurst (1991) reported that prolonged water stress caused a sharp decrease in the number of female inflorescences and an increase in male inflorescences. A drop in yield due to the poor sex ratio that occurred 22 months after a prolonged drought corresponded with the interval between floral initiation and flower emergence. Extended drought resulted in the abortion of female inflorescences. Prioux et al. (1992) observed an yield increase of 20 per cent in irrigated plot over unirrigated plots in Ivory Coast. Yields were 22.7t and 18.8t FFB ha^{-1} $year^{-1}$ in irrigated and unirrigated plots respectively. Irrigation did not modify the mineral nutrition management in oil palm. Irrigation had a considerable effect on bunch number. The effect on mean bunch weight varied in one direction or other in different years without any definite trend.

2.2.4 Irrigation and nutrient relations

Smilde and Chapas (1963) reported that leaf N and P decreased during dry season and increased when there was adequate moisture supply through rains. Quencez and Taffin (1981) observed that higher K deficits were associated with low K levels in dry season. Critical threshold for K was shown as 0.7 per cent when water deficit was 600 mm which was increased to 0.87 per cent with adequate water. Chillard <u>et al</u>. (1983) observed that irrigation had increased export of nutrients. By eliminating the depressive effect of drought, irrigation increased yield potential and lead to an increase in removal of nutrients with a reduction of leaf levels (Chillard <u>et al</u>., 1983). Ataga and Okoye (1984) noticed that palms which received supplementary irrigation @ 51 mm week^{-1} during dry season caused significant increase in N and P in leaf, slight increase for K and variable effect on Mg and Ca. Fertilizer application increased leaf K and decreased Mg. Low correlation between leaf nutrients and bunch yields were recorded. Irrigating palm with 5 mm of water in a day with application of higher doses of KCl improved leaf contents significantly. With the application of 0.6, 1.4, 2.2 and 3 kg KCl palm^{-1} year^{-1}, the per cent leaf K content were 0.768, 0.842, 0.908 and 0.933 and the yield of palms were 136, 161 and 142 kg palm^{-1} year^{-1} respectively (IRHO, 1989b).

Amount of water held by soils reported by various workers were 83mm in sedimentary soils of Nigeria (Rees and Chapas, 1963); 140mm in Ivory Coast (Ochs and Olivin, 1965) 167mm in Gambia (Hill, 1969) and 100mm (Surre and Ziller, 1963) for one meter depth. Soil water deficit commonly observed in west Africa, South America and certain Asian regions have been the main limiting factors for oil palm production in those regions. (Devuyst, 1948 and Sparnaaij et al., 1965). Irrigation improved the trees' mineral nutrition at Grand Drewin, Ivory Coast. The nitrogen status of the irrigated trees remained statisfactory even in the dry season, compared to unirrigated trees (Desmarest, 1967). At Pobe, Dahomey, the nutrition of the trees was appreciably improved within two months after watering but at La Me, in Ivory Coast, where the water deficits was lower, the effect of irrigation was correspondingly smaller. Taffin and Daniel

(1976) observed improvement in K nutrition of palm due to irrigation.

On coastal soils, leaf P and K increased with increased soil moisture. Ollagnier (1985) reported reduced efficiency of K fertilizers due to drought. Quencez et al. (1987) observed cumulative and annual yield increase in hydromorphic peat soils than in tertiary sand because of the better moisture conditions of hydromorphic soils. Critical level of potassium in leaf was linked with water supply to the palm. Based on experiements conducted in Benin and Sumatra, Ollangnier et al. (1987) concluded that with water deficit decreasing from 600 to 250mm, critical level of K increased from 0.62 to 1.05 per cent, and for water deficits from 250mm to 0 (no deficit), critical level fell from 1.05 to 0.69 per cent i.e. critical level 0.6 and 0.8 per cent are found both under very low and very high water deficit conditions. Critical leaf nutrient values reported by them at various levels of water deficits were 600mm -0.60; 510mm - 0.75; 470mm - 0.775; 400 to 250mm - 0.9 - 1.5; and less than 250mm - 1.65-0.69. Ugbah et al. (1990) reported that irrigation did not make any significant effect on any leaf nutrient concentration in oil palm. Ochs et al. (1991) reported leaf K as a function of water deficit and the relationship made it possible to establish a scale of critical K level values according to the mean deficit for the period. The critical K levels proposed for different water deficit values are : 150 to 200mm - 0.9%, 200to 250mm - 0.95%, 250 to 400mm - 0.95%, 400 to 600mm - 0.85%, and 600 to 750mm - 0.75%.

2.3 Effect of nutrition on growth parameters and yield

2.3.1 Growth parameters

Corley (1976a) reported the influence of nutrient supply on specific aspects of vegetative growth such as leaf area, leaf weight and consequently on yield increase.

Rosenquist (1962) indicated a high rate of leaf production and total number of leaves on the crown with increased nitrogen application. Corley and Mok (1972) also observed increase in leaf production due to nitrogen application. Nitrogen was required for the rapid growth of oil palm (Hartley, 1988). Nitrogen primarily affected leaf area, rate of leaf production and net assimilation rate. A good response to nitrogen was noticed by Corley (1976a) and Hartley (1988) wherever the leaf area index (LAI) was below five. Singh (1989) had reported significant increase in leaf area, leaf dry matter, rachis length and annual frond production due to nitrogen application. Nitrogen fertilizer was reported to significantly increase the leaf area index by Wilkie and Foster (1989).

Increased leaf production due to phosphorus application was reported by Tan (1976a). Phosphate application has also significantly improved leaf area, leaf dry matter, rachis length and frond production (Singh, 1989). Von Uexkull and Fairhurst (1991) reported that leaves deficient in P did not show specific symptoms, other than reduced frond length. Trunk diameter and bunch size of P deficient palms were also found reduced. Pyramiding in palms was associated with the progressive depletion of soil phosphorus.

Corley and Mok (1972) gave an account of the effects of NPK and Mg on leaf area, dry matter production and yield of oil palm and reported that potassium application increased the dry matter production and yield by increasing leaf area. Singh (1989) obtained increase in leaf dry weight and leaf area due to K application. He has also reported that nitrogen increased both leaf area and net assimilation rate and consequently vegetative dry matter attained a fairly constant level at higher rates of fertilizer application. Nair (1981) reported that application of nitrogen, phosphorus and potassium at higher levels increased the rate of leaf production and number of functional leaves. Squire (1986) reported that added nutrients brought about an increase in the area of fronds by about 12 per cent. However the relation between area and weight of fronds was little affected by fertilizers, so the increase in frond area was accompanied by an increase in frond weight. Wilkie and Foster (1989) has recorded significant increase in vegetative dry matter and total dry matter production due to nitrogen and potassium application.

2.3.2 Effect of nutrition on physiological parameters

Increased photosynthetic activity and reduction in sex ratio due to nitrogen application was reported by Sparnaaij (1960). Chillard et al. (1983) reported that depressive effect of drought on leaf content of N and P was eliminated, with adequate moisture suply.

Villalobos et al. (1990a) noticed an increase in relative water content of oil palm during dry season as a response to K fertilizer application. Corley et al. (1976) had reported considerable increase in stomatal resistance due to potassium deficiency.

The oil palm has relatively shallow root system with most of the active roots found in the upper 30 cm of soil (Gray, 1969). Omoti and Ataga (1983) from their studies on root activity of 15 year old palm using p^{32} has concluded that P uptake was greatest at a distance of 50cm from the trunk and at 15cm depth. Dufrene (1989) reported that 96% of primary and secondary roots and 49% of tertiary and quaternaries were found in top 40cm layer of soil. Foster and Dolmat et al. (1989) recommended that nitrogen fertilizers must be placed in the weeded circle where there are more feeding roots so that it is intercepted by roots before being leached out.

2.3.4 Effect of nutrition on yield attributes

Beirnaert (1935) indicated that oil palm sex ratio might depend on ratio of carbon assimilation to mineral nutrition. Helsop-Harrison (1957) has reported that nitrogen nutrition influenced sex defferntiation. The female inflorescence production was attributed to high rate of carbon assimilation to mineral absorption and N has an important role in this phenomenon. With furthur increase in nitrogen, male flower production has also increased and the sex ratio decreased (Sparnaaij, 1960). Ollagnier et al. (1970) found out that insufficient water supply affected sex ratio of trees and the number of bunches produced. The elements required for vegetative growth and for removal through bunches were nitrogen and potassium. Under less favourable ecological conditions, water deficit had considerable effect on oil palm sex differentiation, rate of female inflorescence abortion and plant growth. Tan (1973) reported association of increased female flower production with increased leaf production due to potassium fertilization. Nair and Sreedharan (1982) observed a decrease in sex ratio due to nitrogen application and increase in male inflorescence production. Phosphorus and potassium application was found to increase the sex ratio. Increased leaf nutrient content of these elements were positively correlated with female flower production. Calcium and magnesium had no influence on flower production.

Ollagnier (1985) reported positive influence of fertilizers on yield of oil palm.

Increase in bunch number production due to nitrogen application has been obtained by Wilkie and Foster (1989).

Foo and Omar (1987) indicated increase in bunch number due to K application. Yield response to K fertilizer was reported to be due to increase in bunch number rather than increase in mean weight by Foster et al. (1987). Increase in average bunch weight as a result of K application was recorded by Foo and Omar (1987) and Wilkie and Foster (1989).

2.3.5 Effect of nutrition on Fresh Fruit Bunch (FFB) yield

Yield increase in oil palm due to nitrogen application was reported by Sly and Chapas (1963), Van der Vossen (1970), Green (1972), Warrier and Piggot (1973), and Hew et al. (1973). Tan (1976b) recommended 0.88 kg N palm^{-1} year^{-1} as optimum dose. Ummar Akbar et al. (1977) reported increase in yield due to nitrogen fertilizer application. Chan (1981a) recommended 0.95 kg N palm^{-1} year^{-1} using ammonium sulphate for better yields in Malaysia. Teoh and Chew (1984) recommended 0.57 kg N palm^{-1} year^{-1} for adult palms. Nair and Sreedharan (1982), Agamuthu and Broughton (1985), Cheopte et al. (1988) and Foo and Omar (1987) have reported increase in FFB yield due to N application. Application of nitrogen had significantly increased the mean yield by 8-12 per cent (Singh, 1989). Yield was found closely correlated with leaf N levels by Wilkie and Foster (1989). Nitrogen content of leaf corresponding to optimum yield was 2.5 to 2.6 per cent and P was 0.16 to 0.17 per cent as reported by Bull (1964). Increase in yield up to 0.17 per cent leaf P was observed by Forde et al. (1965). Ollangnier et al. (1970) got response to P application and obtained increased yield with P content above 0.15 per cent. Chapman and Gray (1949) obtained 17 per cent increase in yield by phosphorus fertilization in a 12 year old plantation. Rosenquist (1962) and Bachy (1968) reported positive response of oil palm due to phosphorus fertilization. Yield increase due to P application was reported by Van der Vossen (1970) in Ghana, Mollegard (1971) in Malaysia and Green (1972) in Cameroon. The most conclusive response which the IRHO has obtained with phosphate fertilization was from Brazil (Martin, 1972). Green (1972), Warrier and Piggot (1973) and Foster and Chang (1977) also observed increase in leaf P and corresponding bunch yield increase in oil palm. Lo et al. (1973), Foster and Goh (1977), Ummar Akbar et al. (1977), Nair and Sreedharan (1982), Ng (1986) and Cheopte et al.

(1988) also reported benificial effect of phosphatic fertilizers in oil palm. Quantity of fertilizers applied per palm for which response was obtained were 2.7 kg rock phosphate (Rosenquist, 1962) 2.0 kg dicalcium phosphate (Bachy, 1968), 4.54 kg single superphosphate (Van der Vossen, 1970), 3.8 kg rock phosphate (Mollegard, 1971) and 3 kg super phosphate (Ummar Akbar et al., 1977). Phosphorus requirement to get an FFB yield of 30 t ha^{-1} $year^{-1}$ was found to be 5 kg $palm^{-1}$ $year^{-1}$ of Christmas Island Rock phosphate (Dolmat et al., 1989).

Bachy (1968) in Ivory Coast observed that in areas derived from savanah, plots yielding 17 kg per palm were raised to 82 kg per palm by annual application of one kilogram KCl per palm. Hew et al. (1973) obtained significant yield response due to potassium application. Breure and Rosenquist (1977) reported that application of muriate of potash at the rate of 3 kg per palm per year has increased the FFB yield. Potassium recommendation given for adult palms in Malaysia as reported by various workers were 2.2 kg $palm^{-1}$ $year^{-1}$ (Foo and Omar, 1987) ; 1.9 kg K_2O $palm^{-1}$ $year^{-1}$ (Tan, 1976b) and 2.2 to 2.7 kg K_2O $palm^{-1}$ $year^{-1}$ (Chan, 1981b). Improved bunch yields due to K fertilization had also been reported by Nair and Sreedharan (1982), Foo and

Omar (1987) and Chepote et al. (1988). Mutert (1993) reported that potassium is the largest single nutrient affecting yield of oil palm in many soils. Application of potassium together with nitrogen caused synergestic effects in improving vegetative dry matter, bunch yield and oil to bunch ratio. High uptake rates of K depressed leaf tissue contents of other cationic nutrients such as Ca and Mg.

Singh (1989) reported an yield increase of 10 per cent due to nitrogen and 32 per cent due to phosphate application. Zakaria et al. (1991) reported that annual application 3-4 kg of Christmas Island Rock phosphate was profitable and the full P response depended on adequate supply of N, and no response to N was obtained when P supply was inadequate. A strong response to P fertilizer was obtained when soil extractable P was below 15 ppm.

Foster et al. (1986) reported that application of 2.5 kg of both ammonium sulphate and potassium chloride per palm per year raised FFB yields from 21 to 24 t ha^{-1} $year^{-1}$. Optimum rate of one fertilizer nutrient depended on the rates of other fertilizer nutrients applied. Yield increase due to application of nitrogen and potassium was also reported by Wilkie and Foster (1989).

FFB yield increase due to higher P and K fertilizer levels was reported by Zakaria et al. (1989). From a trial conducted in Indonasia, Pundjaitan (1985) reported that maximum yield of 25.2 t ha^{-1} was obtained with 3.02 kg ammonium sulphate, 3.24 kg rock phosphate and 2.38 kg potassium chloride per palm applied annually. Dolmat et al. (1989) recommended a minimum of 4 kg ammonium sulphate, 4 kg nitrate of potash and 3 kg rock phosphate per palm per year to maintain optimum yield. Positive NPK interaction which gave yield of 29.4 t ha^{-1} $year^{-1}$ that was 14 per cent higher than the control was reported by Singh (1989). Von Uexkull and Fairhurst (1991) reported details on role of fertilizers for high sustainable yield along with nutrient interactions and assessment of fertilizer needs of palm. Response of oil palm yield to fertilizer application had been reported by many workers like Teoh and Chew (1984), Foster et al. (1985) and Dolmat et al. (1989). The main effect of potassium fertilization and its positive interaction with other plant nutrients was reported to be due to increased efficiency of conversion of intercepted radiation by Mutert (1993).

Nutrient concentration in the fruit of crops is not generally related by yield, and has also been found true in oil palm by Ng and Thamboo (1967). Corley (1973) from four experiments conducted in Malaysia reported that oil to bunch ratio was found to decrease with increased dose of fertilizers in all experiments. Potash increased kernel to fruit ratio of oil palm at the expense of mesocrap (Breure, 1982). Ochs and Ollagnier (1977) observed a significant increase in oil to bunch ratio due to application of magnesium sulphate. So the depressive effect of KCl on the oil to bunch ratio was reported to be due to the reduction in Mg uptake by palm. Potassium chloride treatments were reported to depress the oil to bunch ratio (Wood, 1978). Breure (1982) also noticed a decline in oil content of bunches due to application of potassium chloride. Foster et al. (1987) reported that potassium chloride application has significantly depressed the oil content of bunches by significantly reducing the oil to bunch and mesocrap to fruit ratios. The kernel to bunch and kernel to fruit ratio were also found increased. Appreciable reduction in oil content of dry mesocarp was observed by Foster et al. (1987). KCl fertilizer application has increased FFB yield by 24 per cent but due to the reduction in the oil to bunch ratio the mesocarp oil increased only by 12 per cent (Foster et al. 1987). Hagstrom (1988) based on work on New Britain reported that there was very good correlation between Mg levels and oil yield. Von Uexkull and Fairhurst (1991) reported that excess K lowered the oil content in the fruit.

2.4 Effect of fertilizers on concentration and uptake of nutrients by palm

Pacheco et al. (1985) from studies conducted in Brazil concluded that while nutrition was adequate, P deficiency caused poor growth and reduced leaf area and when it was corrected, the yield quadrupled in 12-15 years. Because of the depressive effect of P on K nutrition in low exchangeable K soils, cheaper natural phosphate was found more efficient. Von Uexkull and Fairhurst (1991) reported that palms deficient in P had a low growth rate, short fronds, small trunk diameter and small bunches. It has also been indicated that oil palm was very efficient in utilizing both soil and fertilizer P, due to effective mycorrhyzal association.

Ochs (1965) reported that an improvement in leaf potassium by 0.1 per cent had resulted in an annual yield increase of 7 to 16 kg bunches per tree, representing about 10 per cent of the maximum production. Ollagnier et al. (1970) reported that the response to potassium was more when the leaf K per cent fell below critical level. Foster and Chang (1977) obtained an yield increase of 1 t ha^{-1} with an increase of K level from 0.05 to p.08 per cent. Ollagnier and Olivin (1984) concluded that the effect of potassium fertilizer on mineral nutrition of the palm persisted only for two years as the leaf K levels fell from 0.907 per cent to 0.7 per cent after two years. Fallavier and Olivin (1988) found out that through export and fixation with a mean annual per hectare yield of 15 tonnes of FFB, the palm mobilised 100kg potassium per hectare which had to be substituted with K fertilizers. Foster (1989) reported that K was required by leaflets to maintain an optimum rate of photosynthesis and leaflet K as the most relevant indicator of K status. Increased K levels in leaf due to KCl application was reported by Wilkie and Foster (1989). Ochs et al. (1991) indicated the effectiveness and profitability of potassium fertilization when the leaf content of K was less than 0.9 per cent and suggested a general critical level of 0.95 per cent. When the K content increased or decreased by 0.1 per cent, relative production increased or decreased at the rate of around 5 per cent of maximum possible production when other ecological factors were favourable.

Ruer (1966) reported that leaf K content increased with moisture availability and K uptake was limited by inadequate moisture. MOP application has depressed K levels and raised Cl levels which was ascribed to an active uptake of chlorine accompanied by an uptake of cations other than potassium especially Ca and Mg as reported by Taffin and Quencez (1980). Wilkie and Foster (1989) observed that KCl fertilizer had significantly increased the overall K uptake by palms.

Synergistic effect of N and P was observed in a trial conducted on oil palms in ultisol in Sumatra by Ummar *et al*. (1977). Synergism was because phosphorous and nitrogen are closely linked in cell formation and metabolic processes. Ollagnier and Ochs (1981) found that leaf level of P varied with level of N. Ollagnier and Ochs (1981) from their studies of N/P relationship reported that an N content of even 2.5 per cent can lead to a deficiency if P is 0.17 per cent, and at the same time it is sufficient when the P is

0.14 per cent. Existance of general N/P relationship was reported by Ochs (1985) as: P% = 0.0487 N% + 0.039. He has suggested the P content of oil palm as a function of nitrogen ie, P = f (N). It was reported by IRHO (1989a) that phosphorus content of leaves increased with increased supply of nitrogen through urea application. Application of ammonium sulphate has significantly increased N and P leaf nutrient levels and decreased Mg content as reported by Wilkie and Foster (1989). Tampubolon et al. (1990) concluded that nitrogen deficiency of oil palms in Indonasia was accompanied by insufficient levels of P. So simultaneous application of triple superphosphate and urea increased yield from 12.5 to 22 t ha^{-1} $year^{-1}$ in 17-28 year old plantations and proposed that fertilizer planning should be based on N/P balance.

Prevot and Ollagnier (1961) also observed that only when leaf N level has reached 2.7 per cent, they could obtain a positive correlation with K level and yield. Beneficial effect of nitrogen and potassium in increasing the yield was reported by Chew and Khoo (1973).

Significant synergism between P and K has also been observed by Poon et al. (1970) in Malaysia.

The annual nutrient removal by oil palm reported were: 0.53 kg N, 0.07 kg P, 0.69 kg K and 0.19 kg Mg per palm (Ng, 1970) and 30 kg N, 7 kg P, 18 kg K, 13 kg Ca and 10 kg Mg per ha (Ollagnier et al, 1970). Foster and Chang (1976) concluded that an increase in bunch yield of 1 tonne per hectare was obtained by increase in leaf nutrient levels of 0.03 to 0.05 per cent of dry matter for N, 0.003 to 0.005 per cent for P and 0.05 to 0.08 per cent for K. Foster and Goh (1977) also found that the response to individual nutrients were dependent on the adequacy of other nutrients. It was observed that though the P uptake was lesser than the K uptake, the proportion of phosphorous diverted to the bunches was large. Nitrogen is removed in a lower proportion through bunches than phosphorus. Mg accumulated in trunk and lower proportion was removed through bunches (Hartley, 1988). Turner and Gillbanks (1988) reported that oil palm removed 93.5 kg N, 11 kg P, 92.7 kg K, 19.3 kg Mg and 20.3 kg Ca. Taniputra and Pandjaitan (1981) reported that ammonium sulphate had no effect on nitrogen levels of fronds in the first three years, but there was a significant increase during the subsequent two years. Rock phosphate application increased the phosphorus content of leaves significantly though there was no added advantage at higher levels. In contrast to the N and P levels, frond potassium levels increased with increased rates of application of muriate of potash in all the five years. Full responses on yield of oil palm to both N and K fertilizers depended on adequate P fertilization (Chan, 1982). Hartley (1988) reported increase in both leaf N and leaf P and decrease in leaf K due to nitrogen application. When the leaf N, P, K and Mg content of the control and optimum fertility treatments were compared, leaf N, P and K content indicated a marked decline below its optimum levels in the absence of fertilizer supply as reported by Dolmat et al. (1989). Foster (1989) reported that uptake of N, P and K has been limited by the availability of moisture. Singh (1989) reported that nitrogen increased N, P and K levels of oil palm leaves. Low yield levels of palms with low leaf nutrient concentration of N, P and K values were observed by Dolmat et al. (1989).

Ng (1972) has pointed out that fertilizers which often contained another anion or cation than the nutrient supplied, can affect uptake of other nutrients. Thus the presence of calcium in phosphorus fertilizers supress potassium absorption. The magnesium requirement of oil palm was reported to be about five times less than its potassium requirement by Ollagnier and Olivin (1984). They found that magnesium was easily absorbed by palms grown on desaturated laterite soils. Ollagnier and Olivin (1984) reported that the decrease in K content was due to Cl-Ca synergism (Cl from KCl) and also due to K-Ca antagonism. This dual effect was accentuated by high soil exchangeable Ca content as given by high Ca/K ratio in soil solution. In Brazil, Pacheco et al. (1985) recommended Mg application to mature oil palm of 8-10 years because of the K-Mg antagonism in oil palm plantations. Ochs (1985) observed that the variation in leaf content of a given element was accompanied by a corrective variation of certain others. In Ivory Coast the correction in potassium deficiencies was accompanied by a reduction in Ca and especially Mg contents which are antagonists. This corrections caused a profound change in ionic balances. Foo and Omar (1987) reported that leaf Mg was depressed by N and K application. Hartley (1988) reported antagonistic effect of leaf K on leaf Ca and leaf Mg but did not notice any marked effect of leaf K on nitrogen and phosphorous. Comparatively a higher content of 0.29 to 0.35 per cent magnesium and a low content of 0.61 to 0.72 per cent calcium in leaf has been reported by Wanasuria et al. (1993).

2.5 Soil nutrient relationships and yield

Foster et al. (1985b) based on oil palm fertilizer trials carried out in Malaysia reported that on inland soils, FFB yields in the absence of N and K fertilizers were related to soil N and K levels respectively. However critical soil test levels corresponding to potential yields were found too variable for practical use. Increase in total nitrogen in 0-30cm layer and decrease in exchangeable magnesium was reported by Ugbah et al. (1990).

Tinker (1974) reported that to maintain an adequate concentration of nutrients at the root surface for uninterrupted uptake, a much higher concentration in the soil solution would be required. Very few soils only can therefore supply the nutrient needs of high yielding oil palms and that is why oil palms respond to fertilizer application even on tropical soils considered to be comparatively fertile. Application of 0, 44 and 88 kg P ha^{-1} year^{-1} as Christmas Island rock phosphate for 17 years were reported to have significantly increased the Olsen's extractable P in top soil by Zaharah et al. (1985). Bosshart et al. (1989) indicated that the available P concentration should be above 10-15 ppm P at 0-10 cm layer meet the peak crop demand by oil palm.

Application of phosphate was found to increase the availability P and the exchangeable Ca level in soil by Singh (1989).

Fremond and Orgias (1952) reported response to potassium in soils where soil K was below 0.1meq. Tinker and Ziboh (1959) observed relationship between exchangeable K and yield of oil palm. Bachy (1965) noticed that when exchangeable K was 0.2meq, leaf K was 0.9 per cent and when exchangable K was 0.1meq, leaf K was only 0.3 to 0.5 per cent. Ollagnier et al. (1970) concluded that K deficiency was certain at soil K levels below 0.15 - 0.20 meq/100g of exchangable K. Ng (1977) observed that the exchangable K in the top soil (0 - 15cm) and subsoil (15 - 30cm) had increased during nine years of KCl fertilization of oil palm grown on a Selangor series soil of Malaysia with a high K buffer capacity. Zahrah et al. (1985) reported that P enrichment was mainly observed at top 10cm soil depth and it was distributed in inorganic fractions in the order Ca - P > Fe - P > Al - P. Fallavier et al. (1989) from studies conducted at La Me' reported that initial exchangeable K of 0.05 meq/100g was raised to 0.1 meq/100g when enriched with K and recommended annual application of 6.45 KCl per palm. Foster and Chang (1989) observed that maximum yields have been significantly related to the maximum level of soil exchangeable K which was maintained through fertilizer application. Application of potassium was found to markedly increase the exchangeable K in top soil and lowered Ca and Mg levels (Singh, 1989).

N and P both being constituents of plant protein, to keep it at its normal composition both have to increase or decrease in a similar fashion, if not the plant will not synthesize its proteins and N might accumulate as reported by Ollagnier et al. (1970). Ollagnier and Ochs (1981) found that the critical level of P generally varied with the level of leaf N. Foster et al. (1987) reported that leaf N, leaf P, yield and rainfall were related.

Foo and Omar (1987) reported that the negative response of leaf Mg to N and K was due to the antagonistic effect between leaf Mg and leaf N and also between leaf Mg and leaf K. Tinker and Smilde (1963) indicated that the ratio of exchangeable magnesium to exchangeable potassium was a better indicator, since potassium is antagonistic to magnesium uptake. Bosshart et al. (1989) found out that the concentration of mobile nutrients, particularly K and Mg has decreased with increase in soil depth. Ng (1968) suggested a detailed criteria to asses soil suitability for oil palms based on physical and chemical properties. Deficiency levels for the surface 0-20cm layer of soil as given by him were carbon - 1%, mineral nitrogen - 1%, total P 300-400 ppm, Olson assimilable P-30 ppm, Brey's P-15ppm. Exchangeable K - 2 meq/100g and pH - no known level but pH 4 was more suitable. Based on studies conducted by various workers, Corley (1976b) concluded that soil must supply 1.3 kg N, 0.2 kg P and 1.8 kg K to each palm per year. Quantity of P was not large when the composition was 100-200 ppm in top soil, K was low at 0.1 to 0.5 meq/100g (ie 40 - 200 ppm or 80 - 400 kg ha^{-1}) and also indicated that K was highly required in all soils. Breure and Rosenquist (1977) reported that palms did not show any yield responses to either P, K or Mg fertilizer.

treatments over three years where as it increased the concentrations of these nutrients in soil.

2.6. Nutrient interactions and correlation of nutrient with other parameters

The fluctuations in N and P was due to changes in the rate of mineralization of organic matter which were more during rainy season. In dry season soil microbial population became inactive and considerably reduced. The mineralisation occured with rains and soil microbial population developed rapidly and attacked soil organic matter resulting in marked increase of available nutrients. Irrigation treatments also enhanced physiological activity of roots and leaves. Nair (1981) reported positive correlation of leaf N and leaf K with soil N, soil P and soil K. In P deficient soils, response to applied N and K were often absent unless P deficiency was corrected (Von Uexkull and Fairhurst, 1991). Varghese and Byju (1993) reported that in laterite soils, P mobility is hindered and accumulated in the surface horizon.

Wormer and Ochs (1959) obtained positive correlation between soil moisture content and leaf N and P content. Sparnaaij et al. (1963) assumed that high sex ratio period originated during dry season because of better photosynthetic production of carbohydrate as a result of higher solar radiation but moisture deficit during dry season caused stomatal closure to reduce the photosynthesis. Ochs (1965) demonstrated a high correlation between yield and leaf K levels when leaf P exceeded 0.15 per cent but not when leaf P levels were lower. Positive relationship between leaf area and bunch yield was illustrated by Hardon et al. (1969). Apparently many attempt to correlate soil nutrient levels with yield and to develop a critical levels failed as reported by Foster and Chang (1977). Breure (1982) found out that progeny yields were positively correlated with leaf magnesium levels. Ochs (1985) reported that yields were found positively correlated with leaf K ($r=0.8^{**}$) and negatively correlated with leaf Mg ($r = -0.78^{**}$). Corley (1983) confirmed that in oil palm the leaves remained photosynthetically active throughout their life, and explained the high harvest index and yields obtained from the crop. Chang et al.(1988) reported that correlation between monthly yield and frond production was highly significant and the regression equation indicated that variation in frond production accounted for almost the same proportion of yield variations. FFB yield was found correlated with leaf N and leaf K content by Wilkie and Foster (1989). Root development was found improved with increased number of fronds in oil palm by Sihan et al. (1990). He had also reported a quadratic relationship between frond number and yield of palm.

2.7. Leaf nutrient ratios and the Diagnosis and Recommendation Integrated System (DRIS)

Beaufils (1957) and Sumner (1979) indicated the Diagnosis and Recommendations Integrated System (DRIS) as an alternate approach that uses nutrient concentration ratios, rather than concentrations themselves, to interpret tissue analysis. Reference ratios or DRIS norms were defined as the average values of important nutrient ratios from a desirable high yielding subpopulation (Sumner, 1977b). DRIS indices were calculated form a formula that included these reference ratios, their standard deviations, and the observed ratios of the sample being evaluated (Jones, 1981). DRIS indices are negative or positive depending on the degree of relative deficiency or suplus. DRIS reflected the nutritional balance and indicated not only the nutrient more likely to be limiting, but also the order in which other nutrients are likely to become limiting as stated by Beaufils (1973), Beaufils and Sumner (1977), Sumner (1975, 1977b and 1977c)..

Studies have been conducted applying DRIS approach to rubber (Beaufils, 1957); sugarcane (Beaufils and Sumner, 1976 and 1977; Jones, 1981, Mayer, 1981 and Elwali and Gascho, 1984); potatoes (Meldal - Johnson, 1975); corn (Beaufils, 1971; Sumner, 1977c and Escano et al. 1981); soybeans (Sumner, 1977a); oranges (Beverly et al. 1984); and sweet cherry (Davee et al., 1986). In most instances, DRIS has been found reliable in diagnoising nutrient requirements despite changes in the tissue sampled or time of sampling.

2.8 Climate and yield relationship of oil palm

Correlation of yield or bunch number with climatic variables gives an idea about the intensity of influence of these variables on yield of oil palm. Michaux (1961) examined curves of average monthly bunch number and average monthly climatic factors and obtained correlation using five climatic factors for 12 months yield. Broekmans (1957) has shown that floral abortion about five months before anthesis was related to the intensity of the dry season. This was also confirmed in Malaysia by Corley (1973).

Taffin and Daniel (1976) stated that relative humidity was required to keep the stomata open under high temperature. High temperature without relative humidity resulted in closing the stomata.

Frere (1986) reported three important periods during which oil palm was sensitive to water deficit as:

(a) Between 30 and 33 months before harvest (b) Between 19 and 24 months and (c) Between 7 and 13 months before harvest which corresponds to aborting period.

Obisesan and Fatunla (1987) identified annual relative humidity, annual rainfall and sunshine hours as the three climatic factors with greatest influence on fresh fruit bunch yield in oil palm in Nigeria. The annual mean temperature and annual rainfall had largest effect on bunch weight. Annual heat unit accumulation had largest influences on number of bunches. Subronto et al. (1987) studied the influence of climatic parameters on yield of oil palm in Indonesia using time lags of 0,1,2 and 3 years, as the period between initiation of flower and maturity of bunch is almost 40 months. They found out that the most critical factors affecting bunch yields were minimum temperature, morning and evening relative humidity, number of rainy days and duration of sunshine.

Chang et al. (1988) reported that frond production followed bimodel pattern as that of rainfall and rainfall caused a flush of frond production that was more pronounced in seasonally wet and dry climates. Variation in frond production accounted for proportionate yield variation. In irrigated plots which received adequate water in all months the favourable response was due to higher humidity and low leaf temperatures. Frond production, rainfall during sex differentiation and floral abortion period accounted for 77.4% of the monthly fluctuations in yield. Dufour et al. (1988) determined the correlation of yield with the climatic factors rainfall, temparature and water deficit and concluded that climate influenced the yield mainly 13 to 6 months before harvest. Water deficit played a major role during a period from 33 to 6 months before harvest. Henson and Chang (1989) reported that productivity of young palms could be enhanced substantialy if a high humidity is maintained around the palm due to increased photosynthesis rates. Breure et al. (1990) suggested that inflorescence development was slower and reduced under less favourable environments.

The ideal rainfall regime is between 2500-3500mm per year, evenly distributed with no month having rainfall below 120mm. Von Uexkull and Fairhurst (1991) emphasised adequate rainfall as an important factor in the fruit ripening process, and for the development of a high oil to bunch ratio. Yield variations of oil palm due to environmental variation on total bunch weight was reported by Ataga (1993).

Influence of climatic parameters on oil palm yield had been studied in limited number by workers of other oil palm growing countries. Devuyst (1948) reported a positive correlation between yield and total rainfall of the consecutive 12 months and 33 months before harvest. A negative correlation between bunch yield and precipitation 31 months earlier, and positive correlation 12 months earlier were reported by Hemptinne and Ferwerda (1961) in West Africa. Sparnaaij et al. (1963) emphasised the relationship between annual sunshine hour and yield of oil palm. Robertson and Foo (1976) stated that solar radiation was least influential on yield out of the three parameters ie., temperature, moisture and solar radiation. Reduction in sex ratio as a result of female flower abortion due to drought two years before had been reported by Corley (1976c) and Turner (1977). Highest yielding oil palm plantations were reported to be present in areas with smallest annual variation in monthly mean temperatures by Ferwerda (1977). The necessity of studies on the influence of climatic variable on oil palm production has also been reported by Wood (1978). Ong (1982 a, 1982 b and 1983) has attempted a system analysis approach to study the relationship between climatic parameters and yield using the yield data from Malaysia.

The review of literature indicated that research on irrigation and nutrient requirements of mature oil palm has not been conducted in India. No attempt has ever been made to interpret the interrelationship of leaf nutrients of oil palm using the DRIS analysis. Influence of various climatic parameters has not been considered together to predict palm yields well in advance. Therefore, the present study is formulated to investigate on these aspects of oil palm in detail.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Site description

The field experiment was carried out in the oil palm plantations of the Central Plantation Crops Research Institute (Research Centre), Palode, Trivandrum District, Kerala which is located at $8^{o}45'00"$ to $8^{o}45'14"$ N latitude and $76^{o}59'45"$ to $77^{o}00'00"$ E longitude. The Plantation area was under reserve forest prior to oil palm planting in 1976. The colour of the top soil is dark and is gravelly. Palode is located at an elevation of 210 m above mean sea level.

3.1.1 Climate

The tropical climate of the mostly forested area of Palode, Kerala is characterised by a long rainy season from April-May to September-October and the remaining months being dry. Average annual rainfall was 2668mm for the 10 year period from July 1983 to June 1993. Mean daily temperature showed very little change with seasons and years.

3.1.2 Weather parameters

The year round weather parameters viz: rainfall, rainy days, maximum temperature, minimum temperature, relative humidity and evaporation were daily recorded at 07.22 and 14.22 hrs. at the meteorological station of the research station located 200 meters away from the experimental field. Details of weather parameters recorded at Palode for the ten year period from July 1983 to June 1993 are given in Appendix I.

3.1.3 Soil

The soil of the experimental area is laterite and gravelly. The soil is taxonomically designated as oxic haplustult and is located in the agro ecological region of warm humid tropics. Mechanical composition of the soil of the site was determined using the method of mechanical analysis (Piper, 1966). The textural class of the soil is sandy clay loam and the soil constituted 11.87 % fine sand, 43.34 % course sand, 9.53 % silt and 35.1 % clay.

pH of the surface soil ranged from 5 to 5.5, organic carbon content from 2 to 2.5%, available N content from 140 to 160 ppm and available P content from 5 to 9 ppm. The CEC was 6 to 8 C mol (p^+) kg^{-1}, exchangeable K - 0.12, exchangeable Ca -0.24 and exchangeable Mg - 0.22 C mol (p^+) kg^{-1}.

3.2 Experimental details

The experiment was laid out on a gently undulating terrain. Spacing adopted was 9 x 9 x 9 m triangular system. The layout plan of the experimental field is given in Fig. 2. Detailed technical programme of the experiment is given below:

Planting material	:	*Tenera* oil palm hybrids
Planting density	:	143 palms ha^{-1}
Spacing	:	9 x 9 x 9 m triangular system
Year of planting	:	1976
Year of layout of experiment	:	1984
Date of first fertilizer treatment	:	September, 1984
Date of first irrigation treatment	:	December, 1988
Plot size	:	9 experimental palms per plot
Experimental design	:	Factorial experiment in RBD with 4 fertilizer treatments and 3 irrigation treatments

Fig. 2. Layout of field experiment

N

Replication I

$I_2 F_0$	$I_0 F_2$	$I_2 F_3$	$I_1 F_0$
$I_0 F_1$	$I_2 F_1$	$I_1 F_1$	$I_0 F_0$
$I_1 F_2$	$I_0 F_3$	$I_1 F_3$	$I_2 F_2$

Replication II

$I_2 F_1$	$I_2 F_2$	$I_0 F_0$	$I_1 F_1$
$I_1 F_3$	$I_0 F_1$	$I_1 F_2$	$I_2 F_3$
$I_0 F_3$	$I_0 F_2$	$I_2 F_0$	$I_1 F_0$

Replication III

$I_0 F_2$	$I_1 F_0$	$I_2 F_0$	$I_0 F_1$
$I_0 F_0$	$I_2 F_1$	$I_1 F_1$	$I_0 F_3$
$I_1 F_2$	$I_1 F_3$	$I_2 F_3$	$I_2 F_2$

Levels of Fertilizers

F_0 - 0 : 0 : 0 (N : P_2O_5 : K_2O) g $palm^{-1}$ $year^{-1}$
F_1 - 600 : 300 : 600 (N : P_2O_5 : K_2O) g $palm^{-1}$ $year^{-1}$
F_2 - 1200 : 600 : 1200 (N : P_2O_5 : K_2O) g $palm^{-1}$ $year^{-1}$
F_3 - 1800 : 900 : 1800 (N : P_2O_5 : K_2O) g $palm^{-1}$ $year^{-1}$

Levels of Irrigation

I_0 - No Irrigation
I_1 - 45 l $palm^{-1}$ day^{-1}
I_2 - 90 l $palm^{-1}$ day^{-1}

Replications : Three

Details of planting material : Indigenously evolved *tenera* oil palm hybrids were used. It is a hybrid between *dura* and *pisifera* with a mesocarp content of 65 - 90 per cent.

Fertilizer treatments:

1. F_0 : No fertilizer (control)
2. F_1 : 600:300:600 $(N:P_2O_5:K_2O)$g $palm^{-1}$ $year^{-1}$
3. F_2 : 1200:600:1200 $(N:P_2O_5:K_2O)$g $palm^{-1}$ $year^{-1}$
4. F_3 : 1800:900:1800 $(N:P_2O_5:K_2O)$g $palm^{-1}$ $year^{-1}$

Fertilizers were applied in two equal splits during April-May and September-October by broadcasting the fertilizer in the weeded circle in an area of 2.5m round the base in the active root zone of each palm when the soil is moist. Fertilizers used were urea (45.8% N), Mussorie rock phosphate (21.5% P_2O_5) and muriate of potash (59.7% K_2O).

Irrigation treatments:

1. I_0 : No irrigation
2. I_1 : 45 litres $palm^{-1}$ day^{-1}
3. I_2 : 90 litres $palm^{-1}$ day^{-1}

Irrigation treatments were given during the summer months from the end of November to the beginning of April ie., from cessation of NE monsoon to the commencement of SW monsoon every year. Monthly evaporation exceeded rainfall during this period as shown in Fig. 3. Irrigation treatments were given through drip irrigation system by keeping four drippers for every palm. Water was supplied through each dripper at a discharge rate of three litres per hour. Drippers were placed at a distance of 1.25 metres away from the base of the palm on four sides. The discharge rate remained the same for I_1 and I_2 treatments but I_1 was irrigated only for 3 hours and 45 minutes where as I_2 was given irrigation for 7 hours and 30 minutes every day.

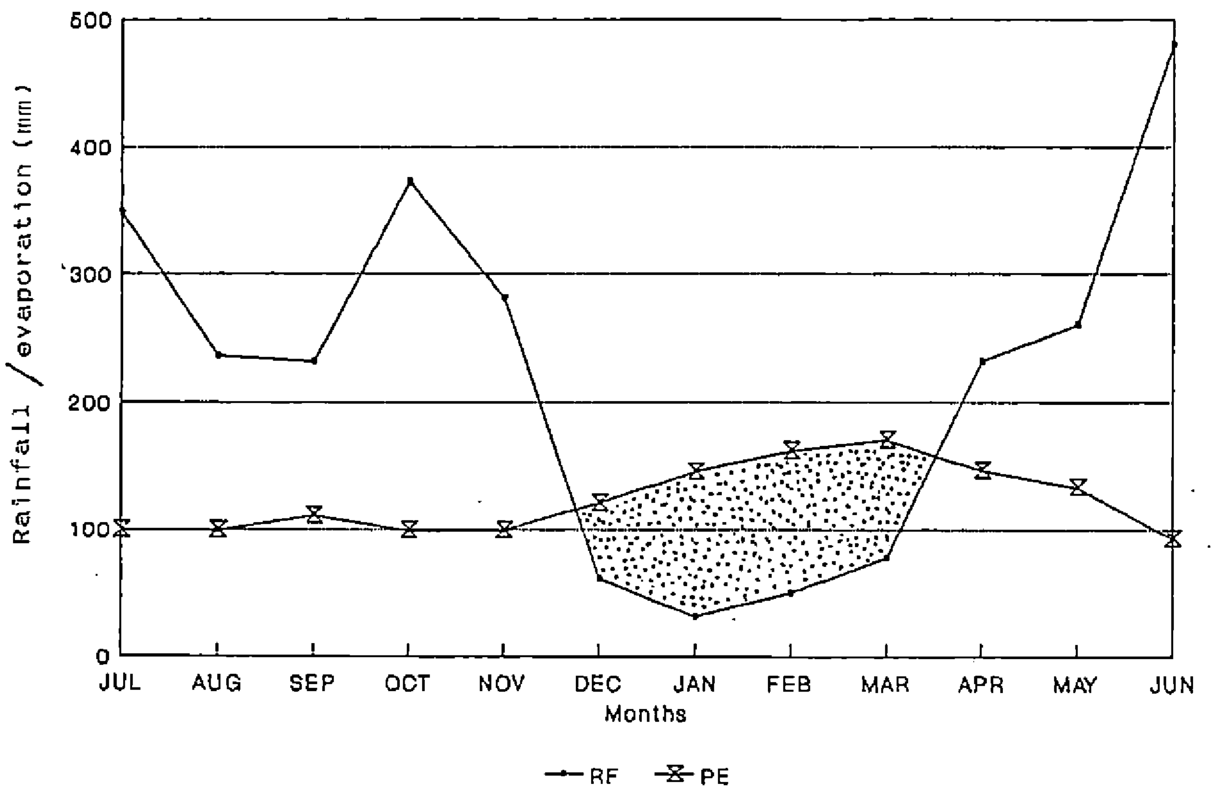
3.3 Growth parameters

Following growth parameters were recorded for three years ie., 1990, 1991 and 1992.

3.3.1 Rate of leaf production

This is the number of new leaves produced per time period, usually expressed in leaves $year^{-1}$. This was

Fig. 3. Mean monthly variation in rainfall (mm) and evaporation (mm) at Palode (1983-1993)



measured by painting the petiole of leaf number one exactly every three months and by counting the leaves produced in the interval.

3.3.2 Number of leaves on the crown

For this parameter all the green leaves found at a time in the eight spirals were counted.

3.3.3 Length of petiole

Measured from leaf base to the beginning of rachis where leaflets originate.

3.3.4 Length of rachis

This parameter was measured from the petiole and rachis union, up to the rachis apex.

3.3.5 Number of leaflets per leaf

This parameter was determined by counting the leaflets of one rachis' side and multiplying it by two. It is used as a component to calculate the leaf area.

3.3.6 Length of leaflet

This parameter is measured by sampling three leaflets from each side of the rachis at a point of 60 per cent of the distance from the rachis base to rachis apex.

3.3.7 Width of leaflet

The same six leaflets used to measure the length were folded at its centre to find their midpoint, and the width of the doubled part was measured. Later on the average width of the six leaflets were calculated.

3.3.8 Trunk height

Trunk height was measured from the base of 41^{st} leaf to the ground. The annual trunk increment measurements are more precise because they were measured between the leaf bases painted at the beginning and at the end of the year.

3.3.9 Diameter of the trunk

The diameter of the trunk was measured at a distance of 1.5 m from the ground.

3.3.10 Leaf area of a single leaf

The leaf area was estimated on leaf No.17, in the middle of the crown of leaves. The leaf area was estimated using the formula as L = b (n x lw) given by Hardon et al. (1969) and Corley and Breure (1981).

where	L	=	foliar area (m^2)
	n	=	number of leaflets of a leaf
	l	=	mean length of six central leaflets (cm)
	w	=	mean width of six central leaflets (cm)
	b	=	constant (0.54)

3.3.11 Leaf area per palm

The foliar area per palm was estimated by multiplying the leaf area of a leaf with the number of green leaves on the crown.

3.3.12 Leaf Area Index (LAI)

Leaf Area Index was calculated from the leaf area per palm and the number of palms per hectare (Corley et al., 1971 b).

$$\text{LAI} = \frac{\text{Leaf area of a palm x 143}}{10{,}000}$$

3.3.13 Net Assimilation Rate (NAR)

The net assimilation rate (g dm^2 $week^{-1}$) is the amount of dry matter produced per unit of foliar area, per unit time. (Corley et al., 1971 b).

$$\text{NAR} = \frac{\text{Crop Growth Rate}}{\text{Leaf Area}}$$

3.4 Dry matter production

3.4.1 Trunk dry matter

The trunk dry weight was estimated with reference to the annual trunk growth. The increase in the trunk height and trunk diameter were the data used to calculate the increase in trunk volume ($\pi r^2 h$).

where r = trunk radius and

h = height increment

Density of the trunk was also determined by removing a small piece of trunk from two palms each in every plot. Volume of trunk when multiplied with its density gave the trunk weight. The dry weight/fresh weight ratio of the sample was also determined to estimate the annual trunk dry matter production (Corley et al. 1971a and Corley and Breure, 1981).

3.4.2 Leaf dry matter

Leaf dry weight was estimated from the area of the transversal section of the petiole (Corley et al., 1971 b).

Leaf dry weight (kg) = 0.1023P + 0.2062

where P = width x depth of the petiole in cm

Petiole width and depth were measured just at the place where petiole joined with rachis.

3.4.3 Dry matter of male inflorescences

Mature and partialy dried male inflorescences were collected and oven dried and weight determined. Three flowers each were collected from three different palms in every plot for two years.

3.4.4 Vegetative Dry Matter (VDM)

This parameter was determined as the sum of the annual dry weight increments of leaves, trunk and male flower.

3.4.5 Bunch Dry Matter (BDM)

The bunch dry weight was estimated from the fresh bunch weight as determined by Corley et al. (1971b). The bunch dry weight is 0.53 x fresh weight of bunch.

3.4.6 Total Dry Matter (TDM)

The total dry matter is the sum of the vegetative dry matter (VDM) and the bunch dry matter (BDM).

3.4.7 Bunch Index (BI)

The bunch index is the proportion of total dry weight that is used by the palm in the production of bunches (Corley et al., 1971b).

$$BI = \frac{\text{Bunch dry weight (kg)}}{\text{Total dry matter (kg)}}$$

3.5 Crop physiological studies and water relations

3.5.1 Relative Water Content (RWC) of leaf

Leaf samples were collected from 17th leaf at mid day and placed in ice chest until processing. Fresh weight (FW), turgid weight (TW) and dry weight (DW) of ten leaf discs of 25 mm in diameter including central vein were determined and the RWC was calculated using the formulae RWC = (FW-DW)/(TW-DW) x 100 as given by Villalobos et al. (1990a).

3.5.2 Leaf Water Potential (LWP)

Pre dawn leaf water potentials were measured on leaflet samples collected from 17^{th} frond of three different palms in each plot. The sample leaves were enclosed in polythene bags just before detaching from the plant. Water potential was determined by using Scholander type pressure chamber (Soil Moisture Equipment Corporation, Ohio, USA)

3.5.3 Stomatal resistance

An infra-red gas analyser (IRGA) system which is a portable photosynthesis system (L1-6200, Li-Cor, Nebraska, USA) was used to measure the stomatal resistance of leaves.

An average of four leaflets from two palms in a plot were sampled. A steady state porometer (Model Li-1600, Li-Cor Nebraska, USA) was used in 1990 and also simultaneously during 1991 in 1992 for cross-checking with infra-red gas analyser system. Stomatal resistance on lower surface of two leaflets from central portion of each leaf was measured between 0900 and 1100 hrs. during the month of February/March every year.

3.5.4 Net photosynthesis (Pn)

Leaf net photosynthesis (Pn) was measured for two years during 1991 and 1992 using a portable infra-red gas analyser (Model Ll-6200, Li-Cor, Nebraska, USA) fitted with a one litre chamber. The IRGA was frequently calibrated using a known gas mixture of CO_2. The measurements were recorded on the computer console supplied with the instrument. Pn was calculated in the same console using the software provided by the manufacturer.

3.5.5 Leaf temperature

Leaf temperature was also determined between 0900 and 1100 hrs. using the infra-red gas analyser. (Model Li-6200, Li-Cor, Nebraska, USA).

3.5.6 Moisture distribution pattern

Studies on area wetted by a dripper was determined through moisture estimation studies of soil at different soil depths of different lateral distances by gravimetric method. Moisture determination was conducted during March for two years from two palms each in I_1 and I_2 plots. Soil samples were collected prior to irrigation at every 15 cm depth to a total depth of 1.05 m and at every 15 cm distance to a lateral distance of 1.05 m from the place of discharge through a dripper.

3.5.7 Root distribution

Root distribution study was conducted by excavating soil to a depth of 30 cm in a width of 50 cm from the base of the palm up to a lateral distance of 4.5 m and the entire roots of this area were collected, washed and oven dried. Root excavation was carried out for a single palm in all plots. The concentration of roots thus determined is expressed as g m^2.

3.6 Yield attributes and yield

3.6.1 Sex ratio

Sex ratio is the ratio of female inflorescences to the total inflorescences produced.

3.6.2 Number of bunches produced

The number of bunches removed during every harvest from individual trees were recorded. The palm wise and plot wise bunch production were thus determined from July to June every year.

3.6.3 Average bunch weight

Weight of every harvested bunch is recorded separately. The average bunch weight of a bunch is the mean bunch weight of the total number of bunches produced in a year. This is also recorded for every treatment.

3.6.4 Fresh Fruit Bunches (FFB) production

Every harvested bunch from individual trees in each treatment were weighed separately and weights recorded. The total FFB production of a tree was thus recorded from July to June every year. Plot wise FFB production was determined.

3.7 Post harvest observations

3.7.1 Bunch analysis studies

The bunch and fruit analysis was conducted using methods developed by Blaak et al. (1963). The bunch which had at least 3-5 naturally detached fruits and a general appearance of acceptable ripeness were taken. The bunch length, width, depth, polar circumference and non polar circumferance were recorded. The bunch was weighed (B kg), and then the spikelets were separated from the stalk using a narrow blade axe. The stalk was also weighed (St kg). From the total number of spikelets with fruits, 20 spikelets with fruits were sampled by successively dividing the spikelets, i.e., initially the total number of spikelets were divided into two groups, then half of the spikelets were again split in to two samples. This process was repeated until it reached to 20 spikelets and fruits sample, which was called sample one (S_1). S_1 was weighed in kg and stored for 24 hours in a closed plastic container in order to stimulate easy handloosening of the fruits. Next day the fruits were hand-separated from the bunch. Then all fruits from S_1 were weighed (F kg). Using the information obtained, the bunch composition parameters were calculated as follows:

Fruit to bunch: (F/B - per cent)

$$F/B = \frac{F}{S_1} \times \frac{B - St}{B} \times 100$$

$$\text{Waste to bunch} = 1 - \frac{F/B}{100}$$

3.7.2 Fruit quality

From the total number of fruits in S_1 weighed for calculating F/B, a sample of 100 g undamaged fruits (S_2) was taken at random. The number of fruits in S_2 was counted and the mesocarp was removed with a sharp knife. The mesocarp removed was collected directly in aluminum boxes with known weight (M). The nuts (shell + kernels) were weighed (N), and then dried for 2 days at room temperature. The dried nuts were broken to separate the kernels from the shell. Then the kernels were weighed (K). Using the information obtained, the fruit quality parameters were calculated as follows:

a) Mesocarp to fruits: (M/F - per cent)

$$M/F = \frac{M}{S_2} \times 100$$

b) Kernel to fruit: (K/F - per cent)

$$K/F = \frac{K}{S_2} \times 100$$

3.7.3 Oil content in the mesocarp and kernel

The mesocarp obtained was dried in the oven at 105°C until it reached constant weight. After drying the mesocarp, a sample of 5g was extracted. This sample was then pounded and oil was extracted by Soxhlet method. Oil content as percentage in kernel was also determined similarly.

3.8 Plant analysis

3.8.1. Leaf analysis

Sample leaves were collected from 17th frond of five palms each in each plot before the fertiliser application in April/May. The samples were taken from five pairs of healthy undamaged leaflets from the central portion of the leaf. These leaflets were cleaned and 30cm of middle portion of these leaflets were separated, their midribs were removed separating the left and right parts of leaflets. The outer 2mm marginal portion of the laminae were also removed. These strips of laminae were chopped up into smaller sizes of 1-2 cm and were oven dried at 70-80^{o}C for three days. These samples were then milled using a wiley mill and passed the sample powder through 1 mm sieve. These samples were used for nutrient estimation studies.

3.8.2 Other plant materials

Other plant materials such as trunk, male inflorescence, petiole and rachis, bunch waste, mesocarp, shell and kernel were also collected, choped, oven dried, powdered and were analysed for nutrient content similarly as in the case of leaf samples.

3.8.3 Analytical details

Leaf sample were analysed for N, P, K, Ca and Mg. Nitrogen was estimated using Kjeltech (Tecator) auto analyser. Determination of other nutrients were carried out after wet digestion of the plant samples with 1:1 HNO_3 – $HClO_4$ diacid mixture (Johnson and Ulrich, 1959). One gram of dried powdered plant sample was digested with the diacid mixture, filtered, washed with hot water and made up to 100ml. This extract was used for further nutrient analysis.

Phosphorus in the digest was estimated colorimetrically using Barton's reagent (Jackson, 1973) in a Spectronic 20 D at 470 nm. Potassium in the extract was determined using flame photometer. Ca and Mg in the extract were determined using atomic absorption spectrophotometer. Other plant part samples were also analysed similarly for nutrient contents.

3.9 Soil studies

3.9.1 Soil nutrients

Soil samples from three depths viz. 0-25cm, 25-50 cm and 50-75 cm were taken from all the treatment plots before fertilizer application in April 1991 and 1992. Samples were collected from a lateral distance of 1.25 m away from the base of the palms. Each composite sample was made from six random cores.

The soil samples were air dried under shade on a polythene sheet and sieved to pass through 2mm sieve and were stored in small polythene bags for analysis.

The soil chemical analysis methods adopted are given in Table 1.

Table 1. Details of methods adopted for soil chemical analysis

Characteristics	Method of estimation	Reference
pH (Water)	1:2.5 soil solution using pH meter	Jackson (1973)
Organic Carbon	Walkley - Black method	Jackson (1973)
Available N	Alkaline permanganate method	Subbiah and Asija (1956)
Available P	BrayI. Molybdenum blue (pH 7) Colorimetric method using Spectronic 20D	Jackson (1973)
Exchangeable K	N - Ammonium acetate method using Flame photometer (Corning 400)	Jackson (1973)
Exchangeable Ca	N - Ammonium acetate method using Atomic absorption spectrophotometer (Varian AA-975)	Jackson (1973)
Exchangeable Mg	N-Ammonium acetate method using Atomic absorption spectrophotometer (Varian AA-975).	Jackson (1973)

3.9.2 Soil moisture content

Soil moisture content was measured gravimetrically from soils sampled from four layers of 0-25, 25-50, 50-75 and 75 - 100 cm depth. Soil samples were taken from three palm basins in every plot during February/March for two years. Samples were collected from a distance of 1.25 m away from the base of the palm.

3.10.1 Correlation studies

Correlation studies were conducted between various characters associated with growth, nutrition and yield of oil palm by determining the correlation coefficient 'r' values.

3.10.2 B.C Ratio

The benefit cost ratio of different treatments were determined by determining the gross expenditure and gross returns using the existing price rates of products and produces. B:C ratio presented is the return per rupee invested.

3.10.3 Statistical analysis

All research results were subjected to statistical analysis to determine the treatment effects. Analysis of variance, simple correlations, regressions and testing of significance were carried out to bring out the effect of treatments and also to study the relationship between different variables (Cochran and Cox, 1965., Panse and Sukhatme, 1967). Little (1981) had given improvements for better interpretation of results of factorial experiments. A PC/AT 386 model computer was used for statistical analysis of the entire data.

3.11 Part II - Leaf nutrient ratios and the Diagnosis and Recommendation Integrated System (DRIS)

For the purpose of conducting studies on nutrient ratios, on the basis of average annual yield of FFB recorded four years, the palms were grouped initially in to three subgroups viz. (1) palms yielding less than 50 kg FFB $palm^{-1}$ (2) palms yielding 50 to 100 kg FFB $palm^{-1}$ and (3) palms yielding more than 100 kg FFB $palm^{-1}$. To differentiate between these groups, they were designated as low, medium and high yielders. Leaf samples were collected from frond 17 from 40 palms each in each group for two years which were analysed separately for the nutrients N, P, K, Ca and Mg. These samples were also collected from *tenera* palms of CPCRI, other than those of the irrigation and fertilizer experiment.

All possible nutrient ratios of the designated elements were determined using a PC/AT 386 computer. Further analysis of these ratios through DRIS approach as described by Beaufils (1973) were applied for nutrient ratio studies in oil palm.

DRIS uses nutrient concentrations and yield to obtain accurate estimates of means and variances of certain ratios of nutrients that discriminate between desirable and less desirable or a high and low yielding subpopulations. Ratios and products of nutrients remain fairly constant. The actual cut off value to decide high and low yield group is not critical but is fixed at a logical desirable level (Walworth and Sumner, 1987). The first step in implementing DRIS was to establish standard values or norms for oil palm. For this, the population of observations were divided into high and low yield groups using 100 kg FFB palm^{-1} as yardstick to separate the subpopulation to obtain estimates of parameter optima. DRIS reference norms were established using the criterian of variance ratio between desirable and undesirable sub populations (Beaufils, 1973). For each pair of nutrient combination, those forms of expression which gave highest variance ratio between two subpopulation constituted the DRIS reference parameter.

Leaf tissue samples were analysed for N,P,K, Ca, and Mg concentrations. For the two subpopulations, the mean, SD, and variance (S^2) were calculated for each nutrient concentrations (N/P, P/N, etc.). A variance ratio (S^2 for low yield population/S^2 for high yield population) was calculated for each nutrient concentration ratios, and of the two ratios involving each pair of nutrients, the one with the large variance ratio was selected. The product of nutrients were also tested for its significance and were discarded if found not significant. The method of calculation of DRIS norms and DRIS indices have been described in detail by many workers (Beaufils, 1971; Beaufils, 1973; Beaufils and Sumner, 1976; Sumner 1975; Sumner, 1977a, 1977b, 1977c; Beverly et al. 1984; Davee et al. 1986 and Walworth and Sumner, 1987). Subpopulations of two years of observations were combined, thus desirable and less desirable population for the entire sample period were obtained. A total of 240 individual trees were evaluated of which 80 were assigned to the high yielding subpopulation and

160 for the low yield. A computer assisted calculation of all possible ratios among the measured elements were done. Those ratios that discriminated between high and low yielding subpopulations by a high variance ratio were separated and the norms of these ratios were used for calculating the DRIS indices. DRIS Indices were calculated using the following formulae;

$$\text{A index} = \frac{f(A/B) + f\ (A/C) + f\ (A/D)\ \ldots\ldots. + f\ (A/X)}{Z}$$

$$\text{B index} = \frac{-f(A/B) + f\ (B/C) + f\ (B/D)\ \ldots\ldots. + f\ (B/X)}{Z}$$

$$\text{X index} = \frac{-f(A/X) - f\ (B/X) - f\ (C/X)\ \ldots\ldots. - f\ (W/X)}{Z}$$

where when (i) $A/B \geq a/b$

$$f\ A/B = \left(\frac{A/B}{a/b} - 1\right) \frac{1000}{CV}$$

(ii) $A/B < a/b$

$$f\ A/B = \left(1 - \frac{a/b}{A/B}\right) \frac{1000}{CV}$$

where A/B, A/C etc. = observed ratio of the two nutrient elements of sample being diagnosed

a/b = optimum or norm of the ratio of desirable population.

CV = Coefficient of variation of the norm

Z = is the number of functions of all ratios comprising a nutrient.

Nutrient imbalance index was worked out for the major nutrients N, P, K, Ca and Mg. This was compared with treatment combinations of the field experiment to evaluate the ratio of nutrients in relation to yield performance (Walworth and Sumner, 1987).

The experiment was used as data base to test the standard reference norms developed. Nutritional imbalance indices (NII) were calculated as a measure of balance among nutrients for each DRIS index irrespective of the sign. Nutritional imbalance indices were plotted against yield as a means of assessing the reliability of this approach.

3.12 Part III - Climate and yield relationship of oil palm

Monthly yield data of the experimental palms in the irrigation and fertilizer experiment during the three years from January 1990 to December 1992 were recorded and used for the purpose. The monthly yield of 27 palms in the representative treatments of control (I_0F_0), irrigated (I_2F_0), fertilized (I_0F_2) and irrigated and fertilized (I_2F_2) were used for the purpose of correlation studies.

Meteorological data from the plantation is used for the study. Weather parameters recorded up to 42 months prior to each months harvest were used for analysis. The climatic parameters considered as relevant in this study were (1) Rainfall - RF (2) Rainy days - RD (3) Dry spell - DS (4) Maximum temperature - MAT (^{o}C) (5) Minimum temperature - MIT (^{o}C) (6) Diurnal variation - DV (7) Relative Humidity - RH(%) and (8) Daily Pan Evaporation - PE (mm). Mean monthly values of all the eight climatic parameters were correlated with the yield (number of bunches produced, FFB yield and the average bunch weight. Based on the information gathered during the course of investigation, simple as well as multiple regression analysis were carried out to study the influence of these weather parameter on the yield. Based on these relationships an attempt was also made to forecast the yield of oil palm well in advance.

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Part I EFFECT OF NUTRITION AND IRRIGATION ON GROWTH AND YIELD OF OIL PALM

An experiment was conducted on indigenously evolved mature tenera hybrid oil palm plantation on laterite soils at the Central Plantation Crops Research Institute, Palode, Kerala to study the effect of fertilizers and irrigation on growth and yield of the crop. The various observations recorded were statistically analysed and the important results are presented and discussed.

4.1 Effect on morphological growth characters

4.1.1 Rate of leaf production

The data on average annual leaf production per palm during three years from 1989-92 are given in Table 2.

Both fertilizer and irrigation treatments had significantly influenced the rate of leaf production of oil palm.

Table 2. Effect of fertilizer and irrigation on growth characters of palm

Characters / Treatment	Annual Leaf production of a palm	Number of functional leaves	Length of petiole (m)	Length of rachis (m)	Number of leaflets per leaf	Length of leaflets (cm)	Width of leaflets (cm)
Fertilizer							
F_0	18.2	32.6	1.31	5.36	321	91.5	4.9
F_1	19.3	34.1	1.36	5.52	331	97.7	5.5
F_2	20.7	35.5	1.38	5.64	329	97.1	5.6
F_3	21.8	35.6	1.33	5.53	331	95.4	5.4
F test	S^{**}	S^{**}	NS	NS	NS	NS	NS
SEM	0.4	0.3	0.03	0.07	4	1.6	0.09
CD (.05)	1.2	0.8	..	..	..	..	0.3
Irrigation							
I_0	17.2	32.6	1.35	5.50	322	94.2	5.3
I_1	20.9	35.3	1.36	5.43	326	94.3	5.3
I_2	21.7	35.4	1.33	5.60	336	97.7	5.4
F test	S^{**}	S^{**}	NS	NS	S^{**}	NS	NS
SEM	0.4	0.3	0.03	0.06	3	1.4	0.08
CD (.05)	1.1	0.7	..	..	9	..	..

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

Annual leaf production increased significantly with increased level of fertilizers. However the significance was confined only upto F_2 level of fertilizer application. Thus the data indicate that for optimum leaf production a fertilizer level of 1200g N + 600g P_2O_5 + 1200g K_2O plam^{-1} year^{-1} is needed.

Under different agroclimatic situations where oil palm is grown, the annual average rate of leaf production usually varied between 18 and 24 leaves per palm (Corley _et al_. 1976). The mean annual rate of leaf production recorded in different treatments varied from a low of 18.2 to a high of 21.8 leaves per palm.

Data on total uptake of NPK by the palm (Table 28) showed that these nutrients were absorbed in proportion to the quantity applied and the uptake pattern showed that F_2 was significantly superior to F_0 and F_1 for N and P and in the case of K, F_3 was significantly superior to other levels. N uptake increased significantly at F_2 level and N being the key element in promoting vegetative growth, better uptake of this nutrient at F_2 level must have resulted in higher rate of leaf production. Thus NPK fertilizing at F_2 level is a must for producing sufficient number of leaves. Significant superiority of F_2 level in NPK uptake by leaflets were also observed (Table 19).

Nitrogen is an important nutrient deciding vegetative growth and the number of leaves constitute the most important growth attribute which determine photosynthetic efficiency of the palm. Corley (1983) confirmed that in oil palm, the leaves remain photosynthetically active throughout their life and this esulted in higher yields obtained from oil palm having more number of leaves. Nitrogen is also reported to be required for rapid growth of oil palm (Hartley, 1988). High amount of nutrition leads to excessive vegetative growth which is to be avoided. In the case of phosphorus, the requirement is low compared to the other nutrients and their physiological role is also less and potash by and large is absorbed in higher or equivalent quantities as nitrogen and it plays an active role in translocation of photosynthates to reproductive organs.

Increased leaf production due to better N nutrition was reported by Rosenquist (1962) and Corley and Mok (1972), nitrogen and phosphorus nutrition by Tan (1976b) and Singh (1989) and N, P and K nutrition by Nair (1981).

The table also indicates that the maximum leaf production was obtained in I_2 level of irrigation eventhough the difference was not significantly higher than that of I_1.

Adult palms in Nigeria, where a definite dry season exists, produced 22-24 leaves annually (Hartley, 1988) as against 25-35 leaves in Malaysia (Williams and Hsu, 1970) where there is a well distributed rainfall. Significant improvement in leaf production due to irrigation was also reported by Henson and Chang (1989).

4.1.2 Number of functional leaves on the crown

The data on average number of leaves on the crown observed at a time during the three years are given in Table 2. Number of functional leaves on the crown at a time determine the photosynthetic efficiency of the palm as a whole for better growth and yield performance of the crop. This together with mean leaf area of a single leaf determines the functional area available for photosynthesis by a palm.

Both fertilizer and irrigation treatments were found to have significant influence on the number of leaves on the crown. Fertilizer application at F_2 level was found to be significantly superior to F_0 and F_1 levels of fertilizer application. F_3 level was on par with F_2 level. The same effect and trend was also observed on annual rate of leaf production due to fertilizer and irrigation treatments. This explains the reason for more number of leaves due to F_2 level of fertilizer application over F_0 and F_1 levels.

Irrigation at I_2 level though recorded more number of leaves, was on a par with I_1 level and was significantly superior to I_0 level. Irrigation at I_1 level was found sufficient to encourage vegetative growth of the palm. Hence leaf production has not significantly increased beyond the I_1 level of irrigation application. Significant improvement in soil moisture status of the root zone of palms at I_1 and I_2 levels over I_0 had encouraged more leaf production and vegetative growth of palms of these treatments.

4.1.3 and 4.1.4 Length of petiole and rachis

The data on mean length of petiole and of rachis for three years are furnished in Table 2. Neither the main effects of fertilizers and irrigation nor their interaction were found to have any significant influence. These characters do not have much physiological significance with reference to production of oil palm. The influence of the treatments were also not significant. The probable reason is that these characters are genetically controlled and the management practices have less impact.

4.1.5 Number of leaflets

The data on average number of leaflets produced per leaf are given in Table 2.

Effect of irrigation treatment alone was found significant. Irrigation at I_2 level produced significantly more leaflets per leaf than the two lower levels of I_1 and I_0. This may be due to better uptake of nitrogen and higher moisture availability at I_2 level of irrigation (Table 9).

4.1.6 Length of leaflets

Average length of leaflets for the three year period has failed to show any significant response due to fertilizer application or irrigation treatments (Table 2).

4.1.7 Width of leaflets

The data on mean width of leaflets for the three years are given in Table 2. Increase in leaflet width increases the functional leaf area available for photosynthesis.

Effect of fertilizer treatment alone was found significant. Eventhough there was an increase in leaflet width upto F_2 level of fertilizer application, there was no significant increase beyond F_1 level. F_1, F_2 and F_3 were significantly superior to F_0 level, while they themselves were onapar. Higher leaf nutrient contents and its uptake by palms under these treatments might have resulted in the increased width of leaflets.

4.1.8 Annual height increment

The data on mean height increment of palms as influenced by fertilizer and irrigation over the three years are presented in Table 3. The main effects of fertilizer and irrigation were not significant. However their interaction was found significant (Table 4).

Table 3. Effect of fertilizer and irrigation on height increment, trunk diameter, leaf area and net assimilation rate

Characters / Treatment	Annual height increment of trunk (cm palm-1)	Wood diameter of trunk	Leaf area of a single leaf (m^2)	Leaf area per palm (m^2)	Leaf area index	Net assimilation rate (g dm^2 $week^{-1}$)
Fertilizer						
F_0	50.1	53.5	7.85	257.2	3.68	0.09
F_1	50.9	57.1	9.59	327.9	4.69	0.09
F_2	53.7	55.5	9.60	341.1	4.88	0.10
F_3	54.6	56.1	9.16	325.4	4.65	0.10
F test	NS	NS	S**	S**	S**	NS
SEM	1.3	1.2	0.26	10.4	0.15	.005
CD (.05)	..	..	0.76	30.4	0.44	..
Irrigation						
I_0	50.7	53.7	8.75	286.5	4.10	0.10
I_1	52.7	56.9	8.80	311.1	4.45	0.10
I_2	53.5	56.2	9.61	341.1	4.88	0.10
F test	NS	NS	S*	S**	S**	NS
SEM	1.1	1.1	0.22	9.04	0.13	.004
CD (.05)	..	..	0.65	26.3	0.38	..

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

NS – Not significant

Table 4. Effect of fertilizers irrigation and interaction on annual height increment of trunk (cm $palm^{-1}$)

	I_0	I_1	I_2
F_0	44.33	52.90	53.10
F_1	54.97	49.70	47.90
F_2	49.67	54.57	56.80
F_3	53.77	53.57	56.33

SEM = 2.21 CD (.05) = 6.51

The I_2F_2 combination has given maximum height increment followed by I_2F_3. The I_0F_0 treatment recorded the least value. The height is not a character of agronomic importance in oil palm. However the increase in height is a resultant of the rate of leaf production and number of leaves. The effect of treatments on these two characters were already discussed and a further discussion is not attempted.

4.1.9 Wood diameter of the trunk

The mean wood diameter values of the trunk are given in Table 3.

None of the treatments or their interaction was found to influence the wood diameter significantly. As there is no secondary thickening, the trunk of oil palm grows to its full width below the apex (Corley et al. 1976). Hence the effect of treatments were found not significant on adult palms.

4.1.10 Leaf area of a single leaf

The data on leaf area of a single leaf are presented in Table 3. Leaf area is a parameter that contribute both to growth and yield by its function and efficiency in synthesising carbohydrates for vegetative growth and yield of oil palm.

It was observed that both fertilizer and irrigation treatments had significantly increased the leaf area. There was no significant improvement in leaf area beyond the F_1 level of fertilizer application. F_1, F_2 and F_3 treatments which were on par were found significantly superior to F_0 level. Leaf area of a leaf was mainly decided by number of leaflets produced and length and width of the leaflets (Corley et al., 1971b). It may be recalled that there was no significant difference due to fertilizer application in the number of leaflets produced and length of leaflets. Response upto F_1 level was obtained for the width of the leaflet (Table 2) and naturally the trend in single leaf area followed the same response as that of the width of the leaflet.

Increase in leaf area due to nitrogen nutrition was reported by Hartley (1988), Singh (1989) and Wilkie and Foster (1989). Increase in leaf area due to potassium nutrition was reported by Corley and Mok (1972) Corley (1976b) and Hartley (1988). The significantly high exchangeable soil K level (Table 14) as well as the leaf K status (Table 19) in F_2 treatment ensured better potassium nutrition of these palms which might have increased leaf area of palm in this treatment.

Studies conducted by Singh (1989) showed that P and K nutrition enhanced leaf area.

Among the irrigation treatments, the I_2 treatment had given the maximum leaf area of 9.61m^2 which was significantly superior to I_0 and I_1. Number of leaflets wer also significantly higher in I_2 treatment (Table 2) and this might have contributed to the larger leaf area at I_2 level. However leaflet length was not found affected by the treatment. Corley et al. (1976) reported that better soil moisture conditions caused increase in leaf area of oil palm which is in confirmity with this finding. The magnitude of reduction in leaf area was in direct relation with intensity of stress as reported by Villalobos et al. (1990b).

4.1.11 Leaf area per palm

The data on total leaf area per palm is given in Table 3.

There was a progressive increase in leaf area of a palm up to F_2 level of fertilizer application even though it was onapar with F_3 and F_1.

Leaf area is an important character in oil palm that determines photosynthetic efficiency of the palm. Leaf area of palm depends both on the leaf area of a single leaf and the number of leaves on the crown. It was observed that F_2 level of fertilizer application has produced significantly larger number of leaves on the crown (Table 2). Also area of a single leaf increased proportionately up to F_2 level

(Table 3), even though it was at par with F_3 and F_1. The combined effect of number of leaves on crown as well as single leaf area is exhibited in the leaf area of a palm. In this case the F_2 had recorded the maximum leaf area per palm. This is probably because both the number of leaves and the area per leaf was fairly high in the F_2 level of fertilization. This being a vegetative character a fairly high level of fertilizer is also a must for producing maximum leaf area.

The effect of K was to increase mean leaf area whereas N caused increase in number of leaves per palm so as to increase the mean leaf area per palm at higher fertilizer levels (Corley and Mok, 1972). Increase in leaf area due t fertilizer nutrient application was reported by Squire (1986). The uptake of NPK per palm presented in Table 28 showed significantly higher uptake of these nutrients which might have increased the leaf area per palm. Singh (1989) and Wilkie and Foster (1989) had reported that nitrogen uptake had significantly increased leaf area.

Irrigation at I_2 level produced significantly larger leaf area per palm over that of lower levels. Thus irrigating palm with 90 litres of water per day produced more leaf area per crown by increasing single leaf area (Table 3) which in turn was due to larger number of leaflets produced in I_2 treatment (Table 2). This indicates that I_2 level of irrigation is required for improving photosynthetic function of leaf by increasing leaf area.

The data on the uptake of nutrients presented in Table 28 showed that maximum uptake of N, P and K was at I_2 level of irrigation. This has resulted in a higher leaf area per palm. Increased leaf area due to better moisture conditions were also reported by Van der Vossen (1974) and Corley et al. (1976). The magnitude of reduction in leaf area at lower levels is related to the intensity of stress. Leaf area might have been decreased to reduce the transpiration rate. Similar results were reported by Villalobos et al. (1990b).

4.1.12 Leaf Area Index (LAI)

The data or leaf area index values of oil palm in different treatments are given in Table 3.

The F_2 level had given the maximum LAI. The irrigation at I_2 level also has given the maximum index. Thus it could be seen that LAI is following the same trend as that of total leaf area per palm.

4.1.13 Net Assimilation Rate (NAR)

The data on NAR for various treatments are presented in Table 3.

NAR is a function of the total photosynthesis as influenced by LAI or leaf area per palm. However the dry matter in the trunk act as a negative factor by prohibiting an increase in NAR. During night time the trunk respiration probably wastes some of the photosynthates produced during day time. This can be substantiated by the higher rate of trunk dry matter especially in the treatment I_2F_2 in which the leaf area per palm was maximum. Such a report of trunk respiration was also made by Corley et al. (1976).

4.1.14 Important morphological parameters

Of the different morphological growth characters observed, the annual rate of leaf production, number of leaves on the crown at a time, width of leaflet and leaf area were found significantly influenced by fertilizer application. It is noted that F2 level is optimum for most of the growth parameters measured.

Influence of irrigation was also maximum at I_2 level on growth characters such as leaf production, number of leaves on the crown at a time, number of leaflets per leaf and also the leaf area per palm. It was thus observed that fertilizer application at F_2 level with 1200 g N + 600 g P_2O_5 + 1200 g K_2O palm^{-1} year^{-1} and irrigation at I_2 level with 90 l palm^{-1} day^{-1} ensured better growth of the palm.

4.2 Effect on dry matter production

Results of the effect of fertilizer and irrigation on dry matter production of leaf, trunk, male flower, bunch and their components are discussed in detail.

4.2.1a Dry matter production of leaflets

The data on dry matter production of leaflets are presented in Table 5.

Table 5. Effect of fertilizer and irrigation on components of vegetative dry matter of palm parts (kg palm^{-1} year^{-1})

Character / Treatment	Leaf-lets	Petiole with rachis	Total leaf	Trunk	Male inflor-escence	VDM including male infl-orescences
Fertilizer						
F_0	18.11	39.37	57.48	26.07	1.21	84.76
F_1	21.18	46.06	67.25	29.48	1.92	98.65
F_2	22.12	48.09	70.21	30.64	2.09	106.39
F_3	24.42	53.11	77.53	31.69	1.86	111.08
F test	S^{**}	S^{**}	S^{**}	S^{*}	S^{**}	S^{**}
SEM	1.01	2.19	3.20	1.36	0.11	4.58
CD (.05)	2.96	6.44	9.40	3.98	0.31	13.45
Irrigation						
I_0	19.41	42.21	61.62	26.64	1.99	90.25
I_1	21.31	46.34	67.65	31.08	1.72	101.04
I_2	23.65	51.43	75.08	30.68	1.60	107.37
F test	S^{**}	S^{**}	S^{**}	S^{*}	S^{*}	S^{*}
SEM	0.87	1.90	2.78	1.18	0.09	3.97
CD (.05)	2.56	5.58	8.14	3.45	0.27	11.65

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

F_2 level of fertilizer has recorded significantly larger dry matter over F_0. F_3 level of fertilizer application has resulted in significantly large dry matter production of leaflets over both F_1 and F_0 levels. However the maximum value observed at F_3 was onapar with F2 level.

Leaflet characters as maximum leaflet width recorded at F_2 level and absence of significant difference on the number of leaflets produced (Table 2) might have resulted in a significant increase by F_2 only over F_0. The significant difference of F_3 over F_1 also indicates that F_1 level was insufficient. Lack of nitrogen, phosphorus and potassium at F_0 level must have inhibited chlorophyll formation and synthesis of food in leaflets.

Irrigation at I_2 level has significantly improved dry matter accumulation in leaflets over I_0 whereas I_1 was on par with I_0 and I_2.

The results indicated that I_2 level is required to show the merit of irrigation whereas I_1 level is insufficient. Increased leaflet production coupled with better moisture and nutrient availability helped the leaflets to synthesize and accumulate more photosynthates at I_2 level increasing the dry matter production at this level of irrigation.

4.2.1b **Dry matter production in petiole and rachis**

Results of dry matter production of the petiole and rachis together are presented in Table 5.

There was significant increase in dry weight upto the highest dose of F_3 level of fertilizer application which was superior to F_1 and F_0 levels. However F_3 was at par with F_2 level.

Progressive increase in dry weight of petiole and rachis upto F_3 level indicated that the increased supply of nutrients has resulted in continuous accumulatiion of vegetative dry matter even though the production requirement was met at the lower level. This shows that even after meeting the production requirement in bunch dry matter, if nutrient supply is continued it will be taken in excess and will be used only for dry matter accumulation of vegetative parts. This happens especially when adequate bunches are not produced by the palm.

I_2 level of irrigation was found superior to I_0 level whereas I_1 was not superior to I_0 level. I_1 level was thus inadequate to show the full expression or impact on dry matter accumulation.

4.2.1c Leaf dry matter production

The data on leaf dry matter production are given in Table 5.

The results showed that fertilizer application up to F_1 level has significantly increased the leaf dry matter production over F_0 level and was on a par with F_2. Eventhough F_3 has recorded maximum leaf dry matter, it remained on a par with F_2 level.

Significant superiority of F_3 over F_0 and F_1 levels and its parity with F_2 level indicated that F_2 level is required for sufficient leaf dry matter production. The lack of significance of F_2 over F_1 may be because at F_2 level most of the photosynthates might have been utilised for more bunch production. However a further increase in leaf dry matter production at F_3 over the F_1 level indicates inefficient consumption of nitrogen as also noted for the numerical increase in total uptake of nitrogen (Table 28) by palm. Potassium uptake also had increased upto F_3 level of application (Table 28).

Significant effect of fertilizer in increasing annual leaf production and maximum leaf area in the fertilized treatment (Table 2) have resulted in increased leaf dry matter in these plots. Corley and Mok (1972) reported increase in leaf dry weight due to nitrogen fertilizer applicaton. Increase in leaf dry weight due to N, P and K nutrition was also reported by Singh (1989).

Better moisture condition at I_2 level of irrigation might have helped the palms to be photosynthetically active during dry periods which resulted in more synthesis and accumulation of dry matter in palm leaves. Increase in frond dry matter production due to irrigation was reported by Henson and Chang (1989). Reduction in bunch dry matter production and bunch index due to moisture stress was reported by Corley et al. (1971a).

4.2.2 Annual trunk dry matter production

Data on annual trunk dry matter production are furnished in Table 5. Effect of fertilizer and irrigation as well as their interaction were found to be significant.

F_2 level of fertilizer application increased the annual trunk dry matter production significantly over F_0 level whereas F_1 level was inadequate to express its impact on this character. Most of the leaf characters were better for F_2 treatment which resulted in synthesis of more food by the palm. Increase in annual rate of leaf production might have resulted in increased height of the trunk in F_2 treatment. Annual height increment followed a similar pattern of response which too might have influenced the volume of trunk and therefore its dry matter production.

Here again significant increase in trunk dry matter at F_2 level over the F_0 level indicates that better influence of F_2 level on trunk dry matter is due to the improved photosynthetic activity of these palms at F_2 level by virtue of more number of leaves at this level (Table 2). This has resulted in improving the growth and volume of the trunk which serves also as a storage organ in oil palm. Thus accumulation of dry matter was greater at F_2 level of fertilizer application. The stored food in oil palm trunk is utilised at the time of peak production to meet the immediate demand for nutrients by the developing bunches. Thus maintaining the fertilizer dose at F_2 level is important as it can contribute to the seasonal heavy bunch production.

Irrigation at I_1 level has significantly increased the trunk dry matter production. Increased uptake of nutrients over that of unirrigated plots is responsible for such improvement.

When irrigation at I_2 level was combined with fertilizer at F_2 level or I_1 with F_3 level it resulted in maximum trunk dry matter production (Table 6). Annual trunk dry matter production is an important character as it contributes towards the vegetative dry matter production in oil palm. The poor dry matter accumulation of control plot of no irrigation and no fertilizer gives an idea on lack of supply of nutrients in these treatment for the proper growth and development of trunk.

Table 6. Effect of fertilizer and irrigation interaction on trunk dry matter production (kg palm^{-1} year^{-1})

	I_0	I_1	I_2
F_0	19.27	28.00	30.93
F_1	31.73	30.00	26.70
F_2	26.63	31.27	34.03
F_3	28.93	35.07	31.09

SEM = 2.35 CD (0.05) = 6.89

4.2.3 Male inflorescence dry matter production

Mean annual dry matter production of male inflorescences are given in Table 5.

A progressive increase was observed upto F_2 level though there was no significance beyond F_1 level of fertilizer application.

Male inflorescences dry matter is the product of average dry weight of a male inflorescence and the total male inflorescences produced. Though there was significant increase in average dry weight of a male inflorescence upto F_2 level, it remained non significant in the case of number of male inflorescences produced. This has resulted in confining the significance of male inflorescence dry matter production at F_1 level.

I_2 level of irrigation had significantly reduced the male inflorescence dry matter production than I_0 level. This is because the plots with I_0 treatment, which were unirrigated, produced significantly more number of male inflorescences and I_2 plots with higher level of irrigation produced more female inflorescences.

Effect of irrigation on dry matter production was mainly due to the reduction in male inflorescence production in irrigated treatments as revealed by a high sex ratio. Irrigation at I_2 regime thus has significantly reduced the male inflorescences and increased female inflorescences production. More dry matter production in male inflorescences thus contribute only towards uneconomic returns.

4.2.4 Vegetative dry matter (VDM) production

The mean annual vegetative dry matter production of oil palm in different treatments are given in Table 5.

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The vegetative dry matter production increased progressively upto F_3 level of fertilizer application even though it was not significant beyond F_1 level of application.

The annual vegetative dry matter presented is the sum total of the above ground portions of the palm namely, the trunk, the leaf and the male inflorescences. Both trunk dry weight and leaf dry weight also increased upto F_3 level of fertilizer application as noticed for vegetative dry matter production. In the case of trunk dry weight and leaf dry weight F_3 had given maximum nutrient uptake. Uptake of N, P and K were also uniformly higher in these components at F_3 level.

This shows that better nutrition as indicated by nutrient content of leaves for N and P (Table 19) was ensured at higher levels of fertilizer application. Both N and P uptake which are synergetic might have resulted in increasing vegetative dry matter production.

Increase in vegetative dry matter production due to N and K application was reported by Corley and Mok (1972) and Wilkie and Foster (1989). Response to fertilizer application by vegetative dry matter production to the extent of 5 per cent in coastal soils and 20 per cent in inland soils were reported by Squire (1986). In the present study a response of 24 per cent at F_2 level and 16 per cent at F_1 level over control was obtained. Breure (1982) also reported similar results. Von Uexkull and Fairhurst (1991) reported that palms deficient in P had a slow growth rate and produced short fronds as noticed for F_0 treatment.

Irrigation levels resulted in progressive increase in VDM upto I_2 level though the difference was not significant above I_1 level. Superiority of I_2 level of irrigation over I_1 and I_0 levels was noted for all the components of VDM namely leaf dry matter, trunk dry matter and male flower dry matter production. N, P and K uptake was also maximum at I_2 level of irrigation. Irrigation at I_2 level had thus ensured better nutrition and health of the palm producing more vegetative dry matter. Van der Vossen (1974) reported that vegetative growth is adversely affected by water stress.

4.2.5 Bunch dry matter

Bunch dry matter has two major components namely dry matter of the bunch refuse and dry matter of fruit. The fruit dry matter is further partitioned to mesocrap dry matter, shell dry matter and the kernel dry matter.

4.2.5 a. Dry matter of bunch refuse

Dry matter production of bunch refuse is furnished in Table 7.

Only fertilizer treatments were found to influence the bunch dry matter production. Eventhough the dry matter of bunch refuse continued to increase with increasing levels of fertilizers, its significance was limited upto F_1 level of application.

Importance of bunch refuse as an organic source of fertilizer is important in this context and is yet to be exploited in palm plantations of India.

The lack of significance between F_1, F_2 and F_3 levels of fertilizers on dry matter production of bunch waste and the significant superiority of F_2 level over F_1 on total bunch dry matter (Table 7) indicated that a good proportion of the bunch dry matter is used in the production of fruit

Table 7. Effect of fertilizer and irrigation on dry matter of bunch components and total dry matter (kg $palm^{-1}$ $year^{-1}$)

Character / Treatment	Dry matter production (kg $palm^{-1}$ $year^{-1}$) of							
	Bunch refuse	Meso-carp	Shell	Kernel	Bunch	Total	crop growth rate t ha^{-1} $year^{-1}$	Bunch index
Fertilizer								
F_0	6.83	27.49	4.38	2.61	42.91	127.68	18.23	0.34
F_1	8.46	40.61	5.19	3.10	57.67	156.33	22.36	0.37
F_2	8.78	47.75	5.64	4.20	65.92	172.31	24.64	0.39
F_3	9.57	42.93	5.50	3.55	63.42	174.50	24.95	0.37
F test	S^{**}	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{**}	NS
SEM	0.41	1.83	0.38	0.29	2.27	5.41	0.77	0.01
CD (.05)	1.20	5.38	..	0.87	6.64	15.90	2.27	..
Irrigation								
I_0	8.32	33.53	5.08	3.04	52.00	142.26	20.34	0.36
I_1	8.33	39.17	5.14	3.41	56.63	159.67	22.83	0.36
I_2	8.58	46.39	5.31	3.56	63.81	171.18	24.48	0.37
F test	NS	S^{**}	NS	NS	S^{**}	S^{**}	S^{**}	NS
SEM	0.36	1.58	0.33	0.26	1.96	4.69	0.67	0.01
CD (.05)	..	4.66	..	..	5.76	13.76	1.97	..

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

dry matter at F_2 level of fertilizer supply. Thus heavy bunch production with a major share of fruit dry matter is obtained with F_2 level of fertilizer application.

4.2.5 b Mesocarp dry matter production

Effect of different treatments on mesocarp dry matter production is given in Table 7.

Fertilizer application had significantly increased the mesocarp dry matter up to F_2 level which was on a par with F_3 level.

Mesocarp production depends on number of fruits and mesocarp content. Increase in single fruit weight (Table 10) and consequently the weight of fruits per palm per year at F_2 level had resulted in more mesocarp dry matter production at F_2 level over the other treatments. Among the nutrients supplied at F_2 level, potassium might be the key nutrient that has improved this quality character of the palm.

Irrigation at I_2 level had significantly improved the mesocarp dry matter over its lower levels of application.

I_2 level had also increased the fruit weight per palm due to more fruits produced per bunch and also due to increased single fruit weight (Table 11). Influence of I_2 level of irrigation in increasing the total uptake of nutrients (Table 28) has resulted in more mesocarp dry matter production at I_2 level.

4.2.5 c Shell dry matter production

Table 7 gives the effect of treatments on shell dry matter production.

Neither the fertilizer treatments nor the irrigation treatments could significantly influence this character. Shell dry matter appeares to be a character not influenced by agronomic practices.

4.2.5 d Kernel dry matter production

Mean dry matter production of kernel as influenced by different treatments are given in Table 7.

Fertilizer treatments had significantly increased kernel dry matter production up to F_2 level of application. F_3 level was on a par with F_2.

As reported from the study, total uptake of nitrogen was significantly high in F_2 level of fertilizer application (Table 28). Hence kernel dry matter which contains both amino acids as well as protein was also significantly influenced by the total uptake of nitrogen at F_2 level of fertilizer application. Production of kernel dry matter contributes to kernel oil and kernel oil cake which is rich in protein.

Irrigation had failed to show any significant influence on this character.

4.2.5e Bunch dry matter (BDM) production

The bunch dry matter production of oil palm is presented in Table 7.

Both fertilizer and irrigation treatments were found to have a significant role on bunch dry matter production.

Superiority of F_2 level of fertilizer application in increasing bunch dry matter production over the two lower levels has been brought out. F_3 level has not recorded any further improvement over F_2 level.

Bunch dry matter is the total sum of dry matter of bunch refuse, mesocarp, shell and kernel for all of which, F_2 level of fertilizer application had produced higher dry matter than the lower levels. Because of these improved fruit characteristics and the resultant significant increase in FFB production per palm at F_2 level of fertilizer application (Table 12) bunch dry matter production also showed significant increase in this treatment over others.

Irrigation at I_2 level also had significantly increased the bunch dry matter production per palm over I_1 and I_0 levels which did not differ between each other. Significant influence of I_2 level of irrigation was due to the increased number of bunches produced (Table 12), fruit to bunch ratio (Table 11), single fruit weight (Table 10) and the consequent increase in FFB production at I_2 level (Table 12). Thus the bunch yield varied due to variation in moisture stress. Reduction in bunch dry matter production due to moisture stress was reported by Sparnaaij et al. (1963) and Corley et al. (1971a). More detailed discussion is given under FFB production.

4.2.6 Total dry matter (TDM) production and Crop growth rate (CGR)

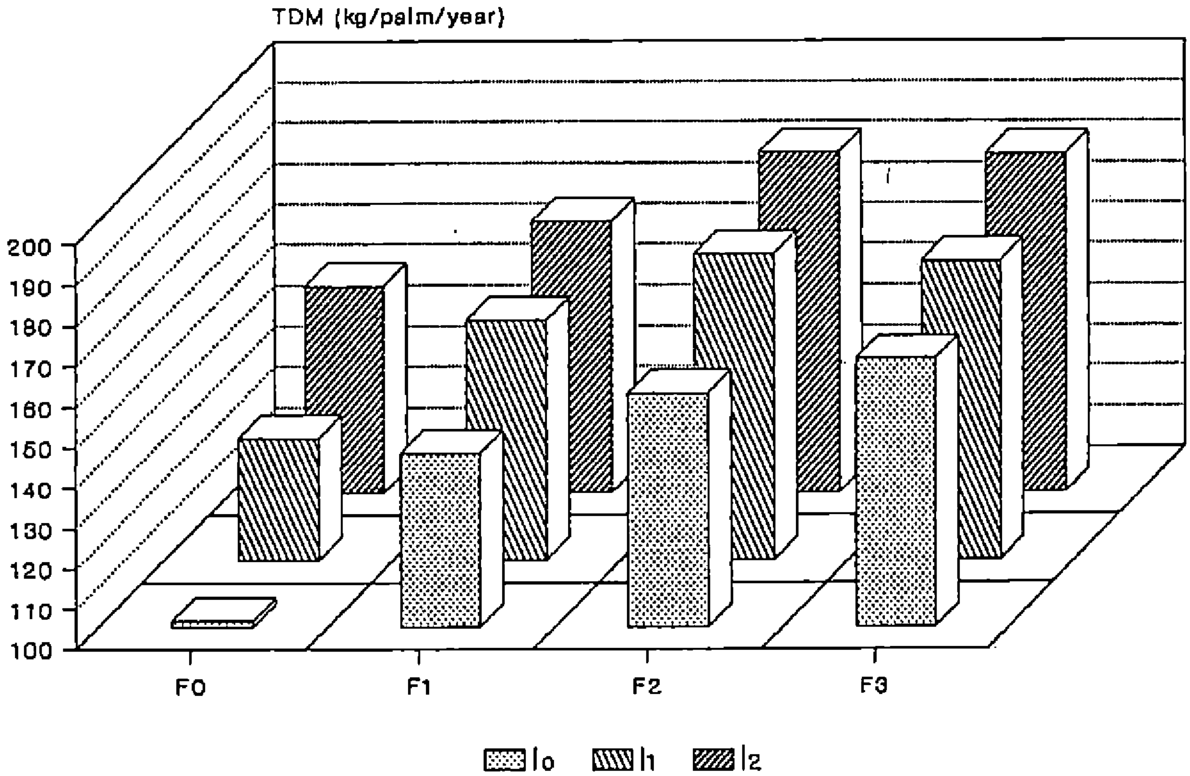
The data on total dry matter production expressed in per palm basis and the crop growth rate expressed in per hectare basis are given in Table 7. The TDM produced in various treatments are depicted in Fig. 4.

Fertilizer application as well as irrigation were found to significantly influence the total dry matter production and therefore the crop growth rate of the palm.

F_2 and F_3 levels of fertilizer application has produced significantly higher TDM and hence higher CGR than lower levels of F_0 and F_1.

Total dry matter (TDM) and therefore CGR (TDM $year^{-1}$) is the sum total of vegetative dry matter (VDM) and bunch dry matter (BDM). Corley et al. (1971b) reported that

Fig. 4. Effect of fertilizer and irrigation on total dry matter production (kg palm^{-1} year^{-1})



leaf, trunk and bunch production together constituted over 96% of total annual dry matter production of oil palm. The favourable response obtained both of BDM and VDM at F_2 level of fertilizer together resulted in a significant improvement in total dry matter at F_2 level.

At F_2 level of fertilizer supply a greater proportion of the total dry matter produced could be utilized for bunch dry matter production. In otherwords the requirements of bunch sink could be met only at F_2 level of fertilizer application when there was sufficient total dry matter production after meeting the requirement for vegetative growth especially the frond sink. Corley and Mok (1972) and Wilkie and Foster (1989) reported that the TDM production and CGR were increased by application of nitrogen and potassium. At F_2 level of fertilizer application K content of leaflet was maximum (Table 19) and to maintain an optimal rate of photosynthesis, leaflet K content is considered very important (Foster, 1989).

I_2 level of irrigation has recorded more total dry matter production though the improvement over I_1 level was marginal as was noticed in the case of VDM. Since VDM constituted the major component of TDM the same trend was observed. The bunch dry matter (BDM) production at I_2 level also showed the same trend. Thus it became clear that only with I_2 level of irrigation, a major share of the dry matter could be diverted for bunch dry matter production as indicated both by increase in number of bunches produced (Table 12) as well as bunch dry matter production (Table 7). Caliman et al. (1987) observed growth improvement of oil palm by improving the moisture availability of the soil.

4.2.7 Bunch Index (BI)

Mean bunch index values are given in Table 7.

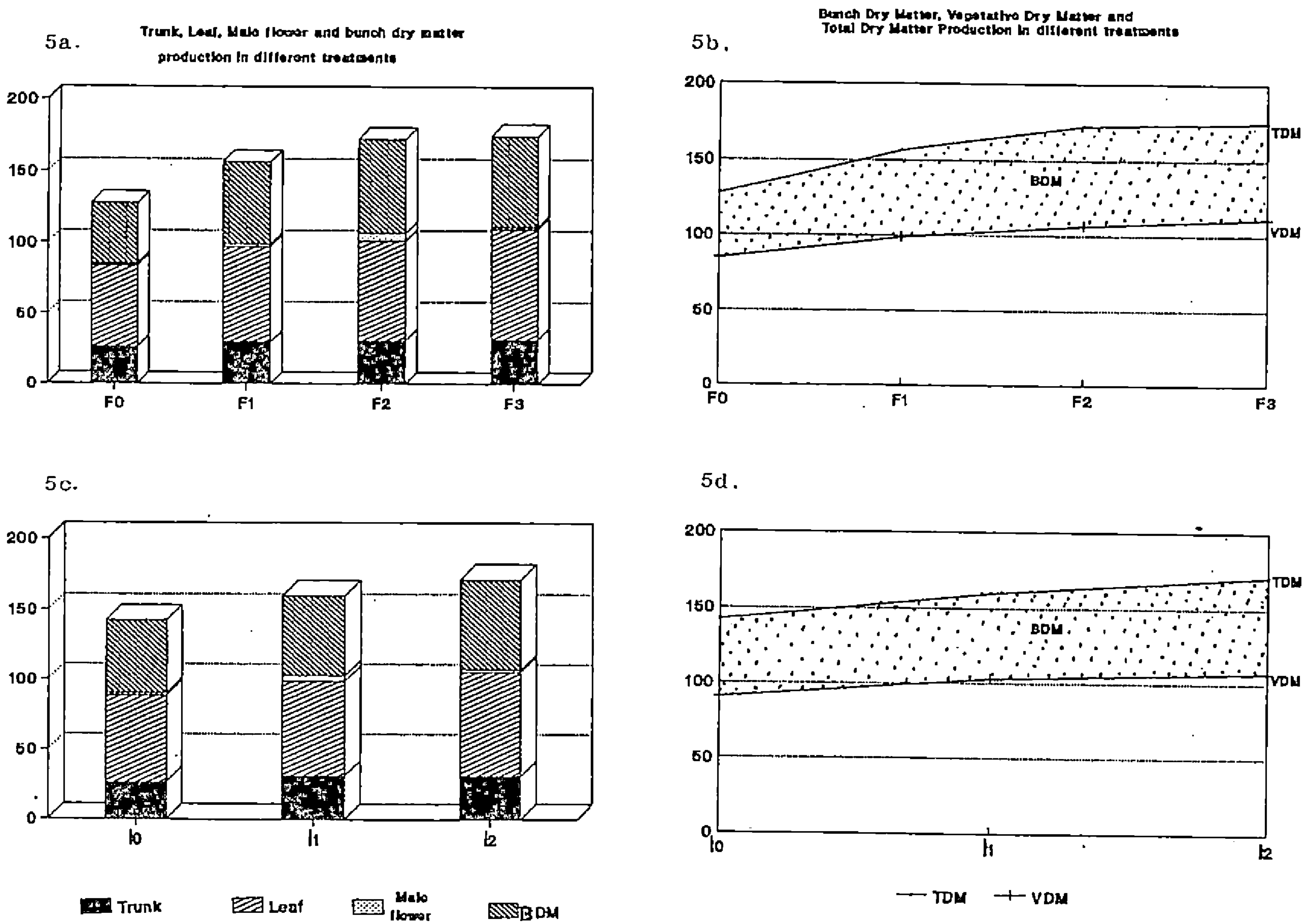
Bunch index was found to be not influenced significantly by fertilizer and irrigation treatments.

Corley and Mok (1972) also reported that bunch index was hardly affected by fertilizers. This was also confirmed by few agronomy trials conducted in Malaysia by Squire (1986). So when total dry matter production could be increased by fertilizer, bunch yield was also increased proportionately. However numerical improvement in bunch index observed up to F_2 level of fertilizer application indicated that at this level more of the assimilates were diverted to bunches than vegetative growth. Bunch index was also not influenced by irrigation treatments.

4.2.8 Importance of dry matter production

The total dry matter production which is partitioned into different components as influenced by fertilizer treatment are illustrated in Fig. 5a and 5b. It was observed that with increase in doses of fertilizers trunk dry matter, leaf dry matter, vegetative dry matter and total dry matter increased progressively upto the highest dose of fertilizers. However in the case of bunch dry matter (TDM-VDM) it was observed that beyond F_2 level a slight reduction was manifested. This indicates that for optimum bunch production, fertilizer application beyond F_2 level is inefficient as it contributed only towards vegetative dry matter production. The percentages of dry matter utilized for bunch production were 33.6, 36.8 38.4 and 36.3 per cent of TDM in F_0, F_1, F_2 and F_3 plots respectively. Up to F_2 level there was a progressive increase in BDM as seen in Fig. 5b and proportionately more dry matter was utilized for bunch production.

Fig. 5. Effect of fertilizer and irrigation on components of TDM (kg $palm^{-1}$ $year^{-1}$)



Influence of irrigation on components of dry matter are shown in Fig. 5c and 5d. It was observed that vegetative dry matter, total dry matter and bunch dry matter were all maximum at I_2 level of irrigation. The bunch dry matter production went on increasing upto the highest level of irrigation i.e. 90 l $palm^{-1}$ day^{-1}. With increase in vegetative and total dry matter, bunch dry matter also was found to increase at I_2 level of irrigation. Therefore, for optimum growth and yield as indicated through vegetative, total and bunch dry matter production, fertilizer at F_2 and irrigation at I_2 level are found optimum for oil palm.

4.3 Physiological parameters

The physiological parameters namely (a) the relative water content of leaf (per cent) (b) leaf water potential (-MPa) (c) stomatal resistance (s cm^{-1}) (d) leaf temperature (^oC) and (e) net photosynthesis (micromoles m^{-2} s^{-1}) were studied in different treatments and are summarised in Table 8.

Irrigation at I_0, I_1 and I_2 levels were found to significantly differ in their influence on all the characters

Table 8. Effect of fertilizer and irrigation on physiological parameters of palm

Characters / Treatment	Relative leaf water content (per cent)	Leaf water potential (-M Pa)	Stomatal resistance (s cm^{-1})	Leaf temperature (^{o}C)	Net photosynthesis (micromoles m^{-2} sec^{-1})
Fertilizer					
F_0	90.2	0.68	3.78	36.7	4.99
F_1	90.4	0.65	4.16	36.7	5.15
F_2	90.6	0.71	4.41	35.7	6.03
F_3	90.7	0.67	4.04	35.5	4.82
F test	NS	NS	NS	NS	NS
SEM	0.82	0.04	0.31	0.51	0.40
CD (.05)	..	..	..	..	..
Irrigation					
I_0	87.7	0.86	5.85	39.8	3.68
I_1	90.4	0.72	3.70	34.9	5.34
I_2	92.6	0.46	2.75	33.8	6.73
F test	S**	S**	S**	S**	S**
SEM	0.71	0.038	0.27	0.45	0.35
CD (.05)	2.0	0.11	0.78	1.3	1.03

S* - Significant at P = 0.05 level

S** - Significant at P = 0.01 level

NS - Not significant

studied whereas fertilizer levels manifested no difference. The highest level of application of water (I_2) at the rate of 90l $palm^{-1}$ day^{-1} recorded maximum relative water content, high water potential, minimum stomatal resistance, lowest leaf temperature and highest net photosynthesis. The favourable influence of I_2 level of irrigation on these parameters is discussed.

4.3a Relative water content (RWC)

The average relative water content in leaf of the different treatments as influenced by fertilizer and irrigation are summarised in Table 8.

Irrigation treatment alone was found to influence the relative water content of leaves. There was significant difference between the irrigation levels tested. A maximum RWC of 92.57% recorded in I_2 level was significantly superior to 90.47% recorded in I_1 and 87.66% in I_0 treatment. I_1 and I_0 also differed significantly. Irrigation at I_2 level has significantly increased water uptake by the palm. I_2 level has also recorded significantly high water content in soil (Table 9) and also showed better distribution of water in the soil (Fig. 7b). This is also indicated by the significantly low stomatal resistance (Table 8) in I_2 treatment. Lack of availability of moisture in the unirrigated plots kept the stomata closed most of the time due to high stomatal resistance. The leaves lost its turgidity both due to non-availability of water and potassium resulting in a low RWC in I_0 treatment. Importance of adequate water supply to keep stomata open in enhancing the leaf activity was reported by Caliman (1992). Potassium nutrition as noticed by its improved uptake at I_2 level (Table 28) also played a key role in maintaining high RWC. Potassium has been reported to improve the water relations of oil palm. An increase in RWC due to potassium application was reported by Villalobos et al. (1990a).

4.3b Leaf water potential (LWP)

Irrigation at I_2 level has recorded high water potential than I_1 and I_0 levels. The predawn water potentials are indicative of the water availability to the roots. Predawn water potential recorded lowest values of -0.85 MPa in I_0 treatment and highest of -0.459 MPa in I_2 treatment. The higher values indicate more water availability to these palms in I_2 treatment. Lower values in I_0 and I_1 indicate that these palms are subjected to more stress due to lack of sufficient water. Non availability of sufficient moisture has been reported to reduce photosynthesis. (Hardon et al. (1969). At lowered water potential, activity of stomata was reduced and remain closed due to turgor loss which reduce both transpiration and CO_2 assimilation. This might have been the situation existing in I_0 and I_1 plots.

4.3.c Stomatal resistance

Irrigation at I_2 level which has recorded the least stomatal resistance might have guaranteed adequate supply of water to the palms for transpiration. Potassium uptake by the leaflets (Table 19) was also significantly higher in I_2 treatment than I_0 treatment. Potassium also has the role in keeping the stomata open or closed. Relative water content and leaf water potential were also significantly high in I_2 treatment over I_0 and I_1 levels (Table 8). Increased moisture content in soil in I_2 treatment (Tables 9) also might have ensured adequate moisture availability. All these parameters lead to least stomatal resistance in I_2, more in I_1 and the most in I_0. Closure of stomata as a common response to water deficit during summer months were reported by Wormer and Ochs (1959), Rees (1961) from Africa and Corley (1976b) from Malaysia. With water deficit the leaves maintain their stomata closed during most part of the day. (Caliman et al. 1987). Photosynthetic activity was found reduced due to stomatal closing by Dufrene (1989) and might be the reason for poor performance of palms in I_1 and I_0 treatments. Villalobos et al. (1990b and 1992) observed higher conductivity and lesser stomatal resistance in irrigated palms compared to unirrigated ones.

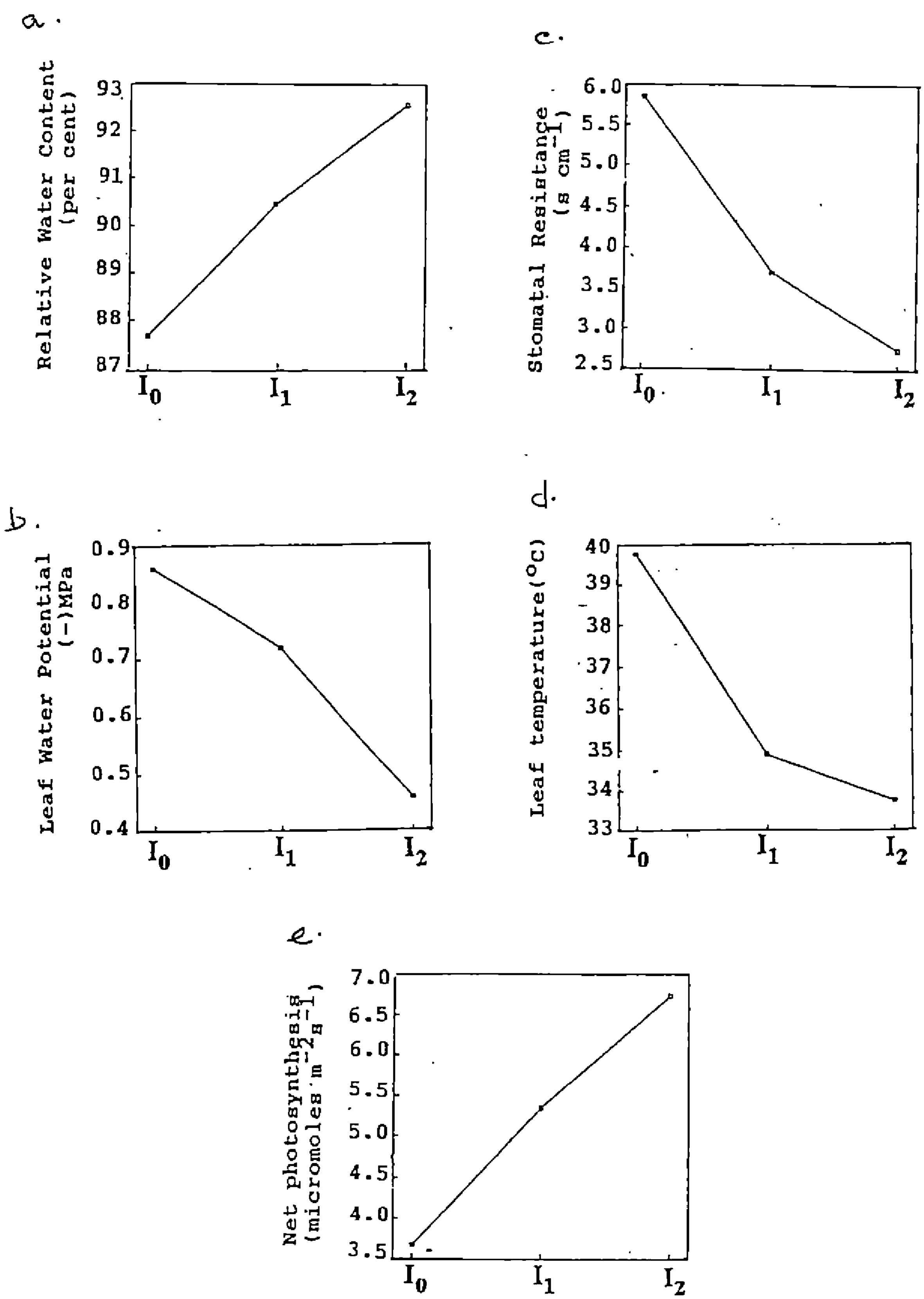
4.3d Leaf temperature

The I_0 treatment palms which were unirrigated recorded significantly higher leaf temperature of 39.8°C than those of irrigated palms. The temperature recorded in I_1 and I_2 treatments were 34.9°C and 33.8°C respectively which were on par. The stomata might have remained closed most of the time in I_0 treatment as indicated through high stomatal resistance as a result of which, the leaves got heated up and increased the leaf temperature. In the irrigated plots especially in I_2, the stomata of palms might have remained open and allowed free movement of water. The liberation of water from leaves as water vapour cools the leaf and the water is replaced immediately by higher intake of water due to better water availability in irrigated treatments. This process has kept the leaves of palms in I_2 treatment cooler than those in the other treatments. Rees (1961) observed stomatal closure in oil palm due to high leaf temperature.

4.3e. **Net photosynthesis (Pn)**

Significant improvement in net photosynthesis in I_2 treatment could be attributed to the increased photosynthetic activity of palms in this treatment. Irrigation has ensured sufficient water and nutrients to the leaf that helped the leaves to remain in an active state of photosynthesis. In I_0 plots the photosynthesis was reduced due to insufficiency of water and at the same time, respiration continued keeping the net photosynthesis at reduced levels. In otherwords the CO_2 fixed through photosynthesis was comparatively more than that lost through respiration in I_2 treatment than in I_1 and I_0 treatments. To continue the photosynthetic process the stomata have to remain open for which the main requirement of water and nutrition especially potassium were ensured at I_2 level of irrigation. Sunlight could be fully exploited for photosynthesis only under adequate supply of moisture (Hardon

Fig. 6. Effect of irrigation on physiological parameters



et al. 1969). Photosynthesis might have been reduced as a result of lowered water potential (Table 8) and consequent reduction in transpiration at I_0 level. Dufrene (1989) and Henson and Chang (1989) also reported that photosynthetic activity was adversely affected due to high stomatal resistance and closing of stomata in adult oil palms.

All the physiological parameters indicated that irrigation at I_2 level had kept the leaf cells more turgid and the photosynthetic processes more active. The favourable influence of irrigation on these parameters as seen in Fig. 6a to 6c has helped the palm to synthesise and translocate more food during summer months. Thus there was an optimum moisture supply at I_2 level of irrigation which also had contributed towards growth and yield of palms.

4.4 Soil moisture (per cent), extent of wetting zone (cm) and root distribution (g m^{-2})

4.4a Soil moisture

Mean soil moisture content of soil at different depths namely 0-25, 25-50, 50-75 and 75-100 cm layer of soil are summarised in Table 9.

Table 9. Mean soil moisture content (per cent) at different depths and root concentration in top 30 cm layer ($g\ m^{-2}$)

Characters / Treatment	Moisture content (per cent) at depth 0-25 cm	25-50 cm	50-75 cm	75-100 cm	Root dry weight in top 30 cm layer ($g\ m^{-2}$)
Fertilizer					
F_0	13.11	14.78	10.49	9.94	11.84
F_1	13.16	14.55	10.71	9.67	13.50
F_2	13.28	14.62	10.53	9.99	13.96
F_3	13.29	14.59	10.61	9.90	13.64
F test	NS	NS	NS	NS	NS
SEM	0.09	0.15	0.10	0.14	0.92
CD (.05)	..	..	..	..	..
Irrigation					
I_0	9.83	10.02	9.57	9.35	11.74
I_1	14.57	16.73	9.93	9.89	12.92
I_2	15.23	17.16	12.26	10.39	15.06
F test	S^{**}	S^{**}	S^{**}	S^{**}	S^{*}
SEM	0.08	0.13	0.09	0.12	0.80
CD (.05)	0.23	0.38	0.26	0.35	2.34

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

Fig. 7. Extent of wetting zone (cm) of a dripper as influenced by irrigation levels

a. I_1 level – 45 l $palm^{-1}day^{-1}$

Soil depth (cm) \ Lateral distance (cm)	0	15	30	45	60	75	90	105
0–15	17.3	16.6	16.1	14.0	10.7	10.4	10.2	10.0
15–30	18.3	18.0	17.7	13.9	11.8	10.2	10.0	10.0
30–45	16.0	15.8	14.9	13.0	11.2	9.9	10.1	10.2
45–60	13.9	15.6	13.3	11.7	10.0	10.2	9.8	9.9
60–75	11.0	11.4	10.5	10.5	9.9	10.1	9.9	10.2
75–90	11.3	10.1	10.4	10.5	10.1	10.0	10.1	10.1
90–105	10.4	10.1	10.3	10.4	10.0	9.8	10.2	10.0

b. I_2 level – 90 l $palm^{-1}day^{-1}$

Soil depth (cm) \ Lateral distance (cm)	0	15	30	45	60	75	90	105
0–15	17.7	15.6	16.4	13.0	13.0	12.4	10.4	10.0
15–30	18.3	17.7	19.0	19.7	14.4	13.0	11.6	9.8
30–45	15.1	15.5	15.4	14.8	12.4	10.7	10.1	10.2
45–60	15.2	14.7	14.4	15.0	13.4	10.4	10.5	10.0
60–75	14.5	11.7	14.5	11.0	10.4	10.3	10.0	10.2
75–90	11.4	10.3	12.2	11.0	10.3	10.0	10.1	10.0
90–105	10.0	10.1	9.9	10.4	10.2	10.0	10.2	10.1

Irrigation was found to significantly influence the soil moisture content of the root zone at all depths. All the three irrigation treatments differed significantly and I_2 recorded the maximum moisture content. Irrigation at I_2 level has increased the soil moisture content in the root zone of oil palm at all depths. It was observed that at I_1 level FFB yield was significantly lower than I_2. This has indicated that I_1 level of water is inadequate and I_2 level ensure more water available to the crop. Thus both soil and plant environment were kept more optimum at I_2 level of irrigation.

4.4b Wetting zone

The data on moisture content of soil at various lateral and vertical distances determined to study the wetting zone of the drippers under I_1 and I_2 treatments are presented in Fig. 7a and 7b. The field capacity of the soil of the experimental area is 18 per cent and wilting point is 10.5 per cent. Figure shows vertical and lateral distribution of moisture (per cent) content. The demarkation line is drawn at the wilting percentage for determining the wetting zone.

From the data and figure presented stimulataneously it was observed that the vertical distribution of water extended upto a depth of 90 cm and the lateral distribution up to 60 cm from the point of discharge of water through the drippers in I_1 treatment. In I_2 treatment the vertical distribution of water extended up to 90 cm and the horizontal distribution also extended up to 90 cm from the point of its application. The hard subsoil might have resulted in uniform vertical distribution of water to a depth of 90 cm in both I_1 and I_2 level of irrigation. However as the quantity of water supplied and the time of discharge were more with I_2 level, it could distribute to more lateral distance.

Thus the area wetted by the four drippers placed around the palm were 4.52 m^2 and 10.18 m^2 in I_1 and I_2 respectively especially in the top soil. The active root zone of the palm being 2.5 m radius around the base of the palm, the total area effectively utilized by a palm is 19.64 m^2. Thus the area wetted corresponds to 23% and 51.8% of the active root zone of a palm in I_1 and I_2 treatments respectively. Thus in I_2 treatment the moisture content is near field capacity especially in top 30 cm layer of the soil where majority of the feeding roots are confined. Since fertilizers are also applied to this area, better absorption is expected when larger area is wetted. Observations by

Taffin and Daniel (1976) showed that water requirement was adequate when 39-45% of the root zone was wetted. Benami and Ofen (1983) also reported advantage of drip irrigation when 25-30% of the area was wetted. Increased distribution of both water and roots enabled the palms to absorb sufficient quantity of water as indicated through low stomatal resistance (Table 8). Thus it is observed that the wetting zone in I_2 regime in the present study is sufficient to exert all possible benefits for attaining maximum production.

4.4c Root distribution

Concentration of roots in top 30 cm layer of the soil to a lateral distance of 4.5 m from the base of the palm was excavated and is expressed as dry weight (g m^{-2}) in Table 9. Of the treatments, the effect of irrigation alone was found significant. I_2 level of irrigation has recorded significantly denser roots than I_0 treatment. Adequate supply of moisture at I_2 level during summer months encouraged more root growth for absorbing the nutrients applied. This availability of adequate moisture (Table 9) has accelerated root growth of palms under I_2 treatment. Dufrene (1989) reported that concentration of tertiary roots were mainly confined to top 30 cm layer. Irrigation encouraged more root concentration and increased absorption of nutrients (Taffin and Daniel, 1976).

4.5 Yield attributes

4.5.1 Sex ratio

The sex ratio is the ratio of female inflorescences to the total inflorescences produced. Data on female inflorescences produced and the sex ratio are presented in Table 10.

Both fertilizer and irrigation treatments were found to significantly influence the sex ratio. F_2 level of fertilizer application has significantly increased female inflorescence production than other levels tested. This has resulted in significantly improved sex ratio in F_2 treatment over other treatments. F_3 level has given a lesser sex ratio. At F_3 level the quantity of NPK are given in higher doses. Higher levels of N leads to lesser carbon assimilation and this must be the possible reason for lesser female flower production in F_3 than in F_2. The significant reduction in sex ratio at F_3 level might be due to excess nitrogen uptake.

Table 10. **Effect of fertilizer and irrigation on female flower production, sex ratio, bunch characters and fruit characters**

Characters / Treatment	Annual female inflorescence production per plam	Sex ratio	Bunch characters: Bunch length (cm)	Bunch breadth (cm)	Polar circum-ference (cm)	Non polar circum-ference (cm)	Fruit characters: Mean fruit length (cm)	Mean fruit breadth (cm)	Single fruit weight (g $fruit^{-1}$)
Fertilizer									
F_0	4.01	29.01	46.8	42.7	106.4	111.8	3.3	2.5	13.05
F_1	4.84	31.62	51.1	42.8	103.3	116.4	3.9	2.5	13.92
F_2	5.42	36.23	50.4	44.1	117.7	119.6	3.8	2.6	15.28
F_3	4.84	32.02	49.6	45.5	118.2	110.2	3.6	2.6	13.07
F test	S^{**}	S^{**}	NS	NS	NS	NS	S^{**}	NS	S^{**}
SEM	0.19	1.25	2.5	2.5	7.98	4.33	0.10	0.08	0.46
CD (.05)	0.57	3.68	..	..	..	..	0.31	..	1.35
Irrigation									
I_0	3.84	27.00	50.2	43.44	112.2	118.7	3.6	2.5	13.20
I_1	4.79	32.53	51.7	44.67	113.7	117.4	3.8	2.5	13.51
I_2	5.71	37.13	46.5	43.44	108.4	107.4	3.7	2.6	14.78
F test	S^{**}	S^{**}	NS	NS	NS	NS	NS	NS	S^{**}
SEM	0.16	1.08	2.1	2.17	6.91	3.75	0.09	0.07	0.40
CD (.05)	0.49	3.18	..	..	..	..	..	..	1.17

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

Excess nitrogen reduces the C/N ratic which in turn reduces sex ratio (Sparnaaij, 1960).

Irrigation at I_2 level has produced significantly more female inflorescences compared to the lower levels of I_1 and I_0. This has also significantly increased the sex ratio in I_2 treatment. Irrigation has thus resulted in exploiting the inherent nature of the palms to produce female flowers which is often prevented by drought (Corley, 1976c). Ollagnier et al. (1970) found out that insufficient water supply has adversely affected sex ratio. Von Uexkull and Fairhurst (1991) also reported similar reduction in sex ratio due to water stress.

The poor sex ratio observed in I_0 plot is mainly due to the effect of drought on these palms. It has been reported that continuous drought for a longer period produced more male inflorescences (IRHO, 1970). Irrigation also prevented the female flower bud abortion as abortion is related to drought (Desmarest, 1967 and Corley, 1973). It has also been reported that adequate moisture supply during sex differentiation results in more number of female inflorescence production (IRHO, 1970).

Irrigating palms at I_2 level has resulted in more leaf production (Table 2) and therefore more flower production as reported by Tan (1973). Since being irrigated the better moisture conditions during sex differentiation influenced more flowers to differentiate into female and also reduced the female flower abortion rate and increased the sex ratio. (IRHO, 1970. Von Uexkull and Fairhurst, 1991).

4.5.2 Bunch characters

The average values of bunch measurements namely bunch length, breadth as well as non polar and polar circumference in different treatment are given in Table 10.

Neither the effect of fertilizer, irrigation nor their interaction was seen to influence these bunch measurements.

4.5.3 Fruit characters

Data on fruit measurements namely single fruit weight, mean fruit length and fruit diameter are furnished in Table 10.

Single fruit weight and fruit length were found to be significantly different whereas the data on fruit diameter was not significant. The single fruit weight was maximum in F_2 treatment and significantly superior to the rest. As observed in many other yield characteristics, the doses of fertilizer as given in F_2 seems to be optimum for this character also.

Fruit length was also found to be influenced by fertilizer application. Fruits from all the fertilized plots with treatments F_1, F_2 and F_3 were seen significantly longer than the unfertilized F_0 treatment. Fruit diameter was seen not influenced by fertilizer treatments.

Irrigation at I_2 level had also produced heavy fruits. This might be due to the adequate supply of water throughout the fruit development stage to produce more fleshy and bold fruits through proper translocation of food and nutrients to the developing fruit. This has resulted in increasing individual fruit weight in I_2 treatment. Fruit length and diameter were not seen significantly influenced by irrigation.

4.5.4a Fruit to bunch ratio (F/B)

The mean fruit to bunch ratio is given in Table 11.

This is the ratio of weight of fruit to total bunch weight. After removal of fruits, the waste material is called bunch refuse. The weight of this uneconomic part also is a deciding factor in the fruit to bunch ratio. In other words if F/B ratio is more the higher will be the oil yield and hence this is an important character.

Effect of fertilizer and irrigation was found to significantly influence the fruit to bunch ratio. F_2 level of fertilizer application has recorded the maximum fruit to bunch ratio and was significantly superior to F_3 and F_0 levels. However the increase above F_1 level was not found significant. The progressive increase up to F_2 level and a significant reduction at F_3 level indicate that fertilizer above F_2 level is not required. At F_3 level excess nitrogen increased more vegetative growth and this in turn reduced fruit production. Also this might be due to the influence of excess potassium uptake in reducing the fruit to bunch ratio. Corley and Mok (1972) reported reduction in fruit to bunch ratio due to high levels of potassium application.

Table 11. Effect of fertilizer and irrigation on oil components

Characters / Treatment	F/B ratio	M/F ratio	O/B ratio	K/F ratio	O/M ratio	O/K ratio
Fertilizer						
F_0	62.2	80.0	24.67	7.49	49.49	47.13
F_1	65.8	83.2	26.98	6.09	49.17	47.22
F_2	68.3	83.2	27.16	7.07	47.76	44.33
F_3	64.2	83.4	24.94	6.78	46.35	41.79
F test	S^{**}	NS	S^{*}	NS	S^{**}	S^{**}
SEM	1.08	1.09	0.65	0.50	0.23	1.14
CD (.05)	3.1	..	1.93	..	0.67	3.34
Irrigation						
I_0	62.1	81.1	24.16	7.28	47.96	44.07
I_1	65.5	82.1	26.07	7.00	48.47	46.34
I_2	68.0	84.2	27.58	6.28	48.15	44.94
F test	S^{**}	NS	S^{**}	NS	NS	NS
SEM	0.94	0.94	0.56	0.43	0.20	0.99
CD (.05)	2.75	..	1.67	..	..	..

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

Irrigation also recorded the maximum F/B ratio at I_2 level though the increase beyond I_1 level was not found significant. The significant increase in fruits in irrigated plots was because of the proper development of fruits on the spikelet due to adequate supply of water. Lack of sufficient moisture produced underdeveloped and undeveloped fruits. Most of the fruits failed to develop to full size in the absence of adequate water.

4.5.4b Mesocarp to fruit ratio (M/F)

The effect of fertilizer and irrigation treatments on mesocarp to fruit ratio are summarised in Table 11.

None of the treatments were found to influence the mesocarp content. It is mostly an inherited character which is not often changed with environmental treatments.

4.5.4c Oil to mesocarp ratio (O/M)

The mean percent oil content in the mesocarp on wet basis is given in Table 11.

Effect of fertilizer treatment alone was found to significantly influence the oil content of mesocarp. With increased doses of fertilizers there was a significant reduction in mesocarp oil content. F_3 level has recorded the least mesocarp oil content which was significantly lower than the other levels tested including control plot. F_0 and F_1 levels were on par. Effect of higher levels of nitrogen in reducing oil content of oil yielding crops as sunflower was reported by Varghese (1973). Effect of higher doses of fertilizer especially potassium in reducing the oil content was reported by Ochs and Ollagnier (1977) and Breure (1982). Application of potassium as KCl was reported to increase moisture content of mesocrap stimulated by marked uptake of chlorine by Green (1976) and Breure (1982). Ochs and Ollagnier (1977) observed that the depressive effect of KCl is also partly due to reduction in Mg uptake.

Appreciable reduction in oil content of mesocarp due to increased doses of fertilizer application was also reported by Foster <u>et al</u>. (1987).

4.5.4d Oil to bunch ratio (O/B)

The influence of fertilizers and irrigation on oil to bunch ratio in oil palm is given in Table 11.

Fertilizer and irrigation treatments were found to influence the oil to bunch ratio of the palm. Fertilizer application at F_2 level has recorded the maximum oil to bunch ratio which progressively increased from F_0 to F_2 level. However the increase at F_2 level failed to show significant increase over F_1. Oil to bunch ratio is determined by the components as fruit to bunch ratio, mesocarp to fruit ratio and the oil to mesocarp ratio. It is noticed that since mesocarp to fruit ratio remained nonsignificant, the O/B ratio followed the same trend as that of fruit to bunch ratio. The highest level of F_3 had significantly reduced the oil to bunch ratio. The highest rate of KCl application at F_3 level might have reduced the O/B ratio as reported by many workers. Ollagnier and Ochs (1977) reported reduction in Mg due to K-Mg antagonism and consequent reduction in oil to bunch ratio. Increase in moisture content accelerated by the chlorine absorption from KCl is also reported to reduce the oil to bunch ratio by Breure (1982).

Effect of irrigation also followed the same trend as that of F/B ratio. Here again there was an increase in oil to bunch ratio up to I_2 but the difference between I_1 and I_2 was not found significant. This again is attributed to the proper filling and proper development of fruits in bunches of irrigated plot. In I_0 plot the plants were stressed (Table 8) and produced mostly underdeveloped fruits or abnormal fruits.

4.5.4e Kernel to fruit ratio (K/F)

Table 11 shows that the K/F ratio remains unaffected by fertilizer and irrigation treatments. Being mostly a genetic character, for *tenera* palms this ratio remain unchanged due to management practice.

4.5.4f. Oil to kernel ratio (O/K)

The ratio of oil to kernel is given in table 11.

Effect of fertilizer treatment alone was found significant. As the fertilizer levels increased from F_1 level there was a corresponding decrease in kernel oil content. There was a significant reduction in oil content at F_3 level compared to F_0 and F_1 levels. F_2 remained on par with F_0 and F_1 levels. A progressive increase in nitrogen uptake by palm (Table 28) was noted with higher levels of fertilizer application. This increase in nitrogen uptake increased the protein content and reduced oil content at F_3 level to a significantly lower value than in F_0 and F_1 plots.

4.5.5 Number of bunches produced

Number of bunches produced is one of the main yield components of oil palm and are presented in Table 12 and Fig. 8. Both irrigation and fertilizer treatments were found to significantly influence the bunch production. Number of bunches produced were maximum at F_2 level which was significantly superior to the F_0 level of fertilizer application and F_2 was on a par with F_1 and F_3. Number of bunches were high in this treatment mainly due to the significantly higher sex ratio (Table 10). It is also seen from correlation studies that number of leaves were positively and significantly correlated with the number of bunches produced (r=0.495). Also the significant uptake of nitrogen, phosphorous and potassium (Table 28) ensured better nutrition of the palm and increased bunch production. Increase in number of bunches due to nitrogen application was reported by Wilkie and Foster (1989), due to phosphorus by Foster and Chang (1977), and due to potassium by Foo and Omar (1987) and Foster et al. (1987).

Table 12. Effect of fertilizers and irrigation on yield attributes, FFB, palm oil and kernel oil yield

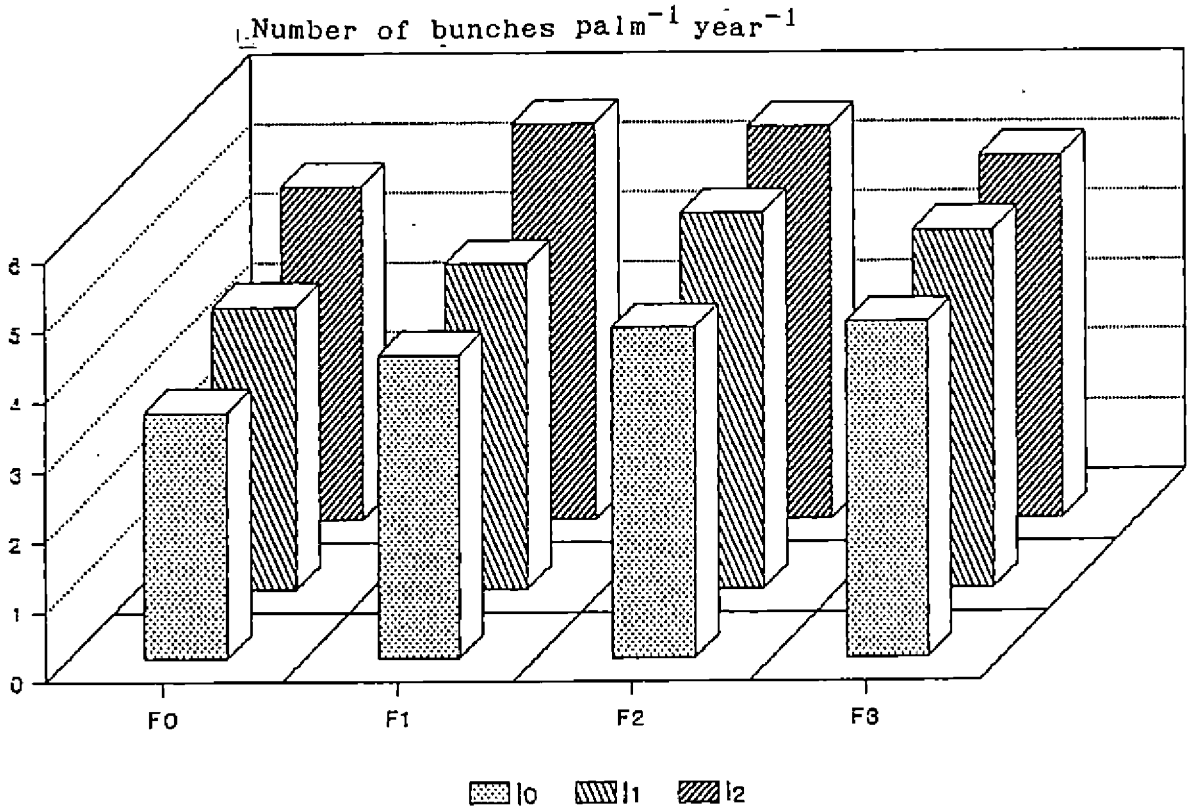
Characters / Treatment	Number of bunches produced (bunches $palm^{-1}$)	Average bunch weight (kg $bunch^{-1}$)	FFB yield (t ha^{-1} $year^{-1}$)	Palm oil yield (t ha^{-1} $year^{-1}$)	Kernel oil yield (kg ha^{-1} $year^{-1}$)
Fertilizer					
F_0	4.10	19.24	11.31	2.81	246
F_1	4.87	21.75	15.18	4.14	281
F_2	5.23	23.25	17.33	4.72	373
F_3	5.02	23.34	16.68	4.15	300
F test	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SEM	0.167	0.72	0.59	0.19	23.4
CD (.05)	0.49	2.14	1.73	0.56	60.0
Irrigation					
I_0	4.34	21.92	13.69	3.31	265
I_1	4.78	21.66	14.90	3.91	316
I_2	5.29	22.11	16.78	4.64	319
F test	S^{**}	NS	S^{**}	S^{**}	S^{**}
SEM	0.144	0.63	0.51	0.17	20.3
CD (.05)	0.42	3.70	1.50	0.49	

S^{*} - Significant at P = 0.05 level

S^{**} - Significant at P = 0.01 level

NS - Not significant

Fig. 8. Effect of fertilizer and irrigation on number of bunches produced per annum



Irrigation at I_2 level has significantly increased the number of bunches produced over I_1 level which in turn was significantly superior to I_0 level. This indicated that irrigation ensured adequate water supply to oil palm as expressed through better sex ratio (Table 10). Significant response at I_2 over I_1 level showed that application of water at the rate of 45 l $palm^{-1}$ day^{-1} was inadequate and 90 l $palm^{-1}$ day^{-1} was required for oil palm. Deleterious effect of drought on bunch production has been reported by many workers as Chan et al. (1985) and Foster and Chang (1989).

Irrigation has resulted in better soil moisture content (Table 9), more leaf area (Table 3), enhanced uptake of N, P and K (Table 28) and improved sex ratio (Table 10). All these characters contributed to significantly higher bunch production at I_2 level. Good vegetative growth and resultant increase in bunch number with adequate water supply was reported by Hartley (1988). Increase in bunch number in irrigated over unirrigated treatment was also reported by Henson and Chang (1989).

4.5.6 Bunch weight

Fertilizer application at F_3 level had produced maximum bunch weight which was on par with F_2 and F_1

(Table 12). Quality characters of bunch such as single fruit weight (Table 10), mesocarp dry matter and kernel dry matter (Table 7) were also seen influenced by fertilizer application. Potassium uptake by bunches (Table 27) and total K uptake (Table 28) were also significantly higher in F_2 and F_3 treatments. Increase in bunch weight due to better uptake of nitrogen was reported by Cheopte et al. (1988), phosphorus by Pachecho et al. (1985) and potassium by Foo and Omar (1987) and Wilkie and Foster (1989).

Irrigation levels were not found to influence the bunch weight significantly.

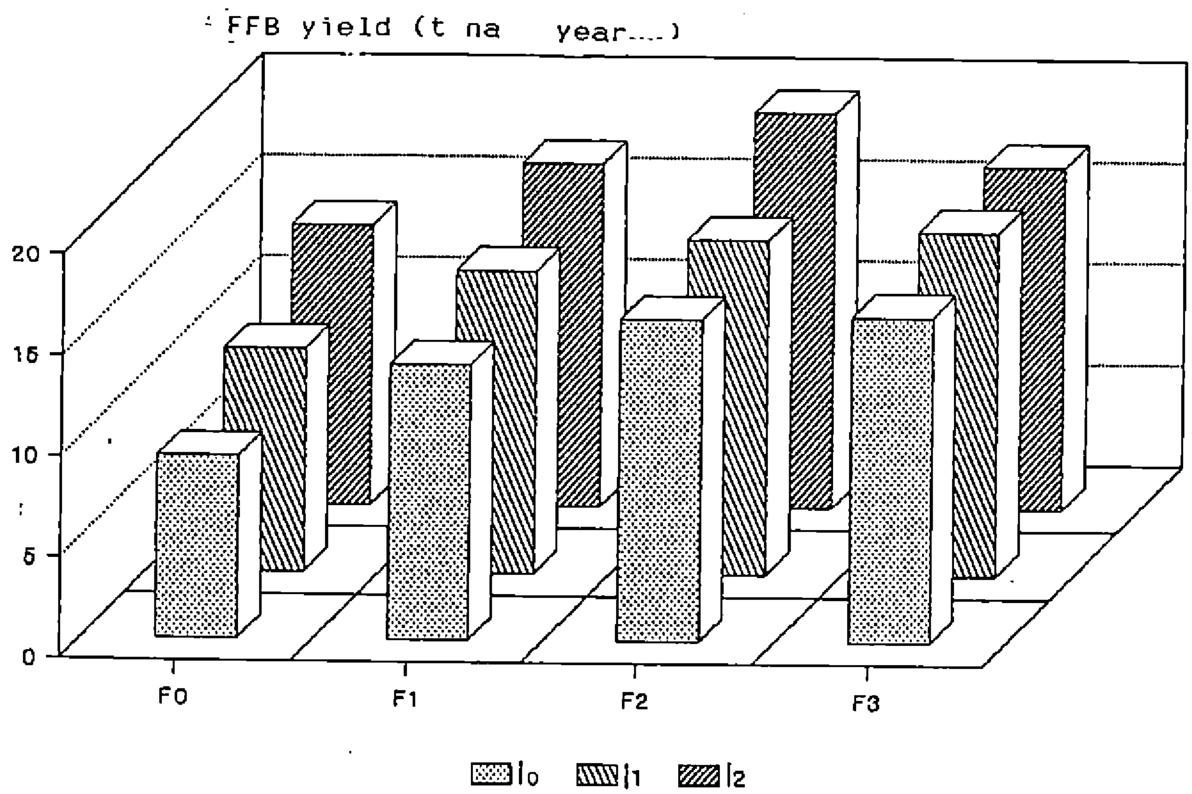
4.5.7 Yield of fresh fruit bunches (FFB ha^{-1} $year^{-1}$)

Yield of FFB (Table 12) revealed that both fetilizer application and irrigation had significantly influenced this character in oil palm. FFB production in different treatments are depicted in Fig. 9. Fertilizer application at F_2 level had given maximum FFB yield which was significantly higher than those of F_0 and F_1 levels and was on a par with F_3. F_1 level has recorded significantly more yield than the F_0 level. Average FFB yield at F_2 level was 17.33 t ha^{-1} $year^{-1}$ compared to 15.18 t ha^{-1} $year^{-1}$ in F_1, 11.33 t ha^{-1} $year^{-1}$ in F_0 and 16.68 t ha^{-1} $year^{-1}$ in F_3 level of application.

Irrigation treatments also have influenced the yield significantly. I_2 level has produced significantly more yield than I_0 and I_1 levels. The later two were on par. The average FFB yield recorded in these treatments were I_2- 16.78 t ha^{-1} $year^{-1}$, I_1 - 14.90 t ha^{-1} $year^{-1}$ and I_0-13.69 t ha^{-1} $year^{-1}$.

It may be recalled that the vegetative growth characters especially the annual leaf production, and the number of leaves on crown (Table 2) were found significantly more in F_2 treatment. Width of individual leaflets (Table 2) and the leaf area of palm (Table 3) were also found maximum at this level of fertilizer application. The correlations worked out (Table 29) showed that annual leaf production, leaf area per palm, trunk growth and vegetative dry matter were positively and significantly correlated with FFB yield. These characters were favourably increased by fertilizer application as seen in the respective tables. Significant improvement in all these leaf characters over its lower levels has enabled these palms to be photosynthetically more active and the enhanced photosynthetic production might have contributed to the increased FFB yield at F_2 level of fertilizer application.

Fig. 9. Effect of fertilizer and irrigation on FFB yield
(t ha^{-1} $year^{-1}$)



Increase in vegetative growth characters and corresponding yield improvement had been reported by many workers. Rosenquist (1962), Corley and Mok (1972) and Singh (1989) reported increase in leaf production by nitrogen fertilizers and consequent yield increase. Von Uexkull and Fairhurst (1991) reported growth and yield improvement due to phosphorus application. Tan (1976a), Ollagnier and Olivin (1984) reported that K nutrition has improved leaf production, vegetative growth and the yield of oil palm. Increase in yield due to leaf area improvement as a consequent effect of nitrogen, potassium and phosphorus application has been reported by Pacheco et al. (1985) and by Singh (1989).

Total dry matter production and therefore crop growth rate (Table 7) were also found significantly more in F_2 and F_3 treatments than the lower levels. Net assimilation rate, net photosynthesis and total dry matter which were more in these treatments were also seen positively and significantly correlated with yield (Table 29).

Yield attributes such as single fruit weight, number of bunches produced and average bunch weight were also seen influenced by fertilizer application (Tables 10 and 12).

This has produced the cumulative effect in increasing the FFB yield. These characters were also seen correlated with FFB yield (Table 29).

The soil nutrient availability also showed that the available nutrient status in the fertilizer applied plots were higher which might have helped the plant to absorb more nutrients. This is substantiated by the uptake studies which had manifested a higher uptake of nitrogen, phosphorus, and potassium (Table 28). The uptake of all these nutrients were also found positively and significantly correlated with the yield.

Positive response of nitrogen on FFB yield was reported by Agamuthu and Broughton (1985), Cheopte et al. (1988), phosphorus by Foster and Chang (1977), Pachecho et al. (1985) and potassium by Ollagnier and Olivin (1984) Foo and Omar (1987), Fallavier and Olivin (1988) and Mutert (1993).

Thus it could be seen that both the source and sink were favourably influenced by fertilizer application especially at F_2 level. It is concluded that from the economic point of view and farmers point of view, F_2 level of fertilizers which supplies 1200 g N + 600 g P_2O_5 + 1200 g K_2O $palm^{-1}$ $year^{-1}$ is to be applied for the maximum production of oil palm.

Response of oil palm yield to fertilizer application had been reported by many workers namely Hew et al. (1973), Tan (1976b), Chan (1981a and b), Yeow et al. (1981), Teoh and Chew (1984), Foster et al. (1985a) and Dolmat et al. (1989).

Among irrigation
has recorded maximum FFB yield and is found significantly superior to the lower levels ie. I_0 and I_1 which themselves were on par.

Growth characters such as leaf production, leaf area, leaf dry matter, vegetative dry matter and total dry matter were also maximum at I_2 level of irrigation.

Physiological investigations on water relations of the palm has revealed that all the characters were significantly more favourable at I_2 level of irrigation. I_2 level of irrigation to the palms has recorded more relative leaf water content (RWC), leaf water potential (LWP), low stomatal resistance and reduced leaf temperature (Table 8). The significant improvement in net photosynthesis also indicated that favourable conditions due to adequate water supply at I_2 level has resulted in the increased bunch production and FFB yield.

I_2 level of irrigation has increased root concentration in top 30 cm layer of a soil (Table 9). Total uptake of all nutrients (Table 28) were also found increased with irrigation up to this level. Foster et al. (1987) reported that increased N and P uptake due to greater water availability through rainfall has enhanced yield of oil palm. Foster (1989) has also observed that uptake of N, P and K were limited by the availability of moisture.

The yield attributes such as female inflorescence production, sex ratio and single fruit weight were significantly higher at I_2 level of irrigation.

The total number of bunches produced and the average bunch weight recorded (Table 12) were also found to be maximum at I_2 level of irrigation. The number of bunches produced and the FFB yield were found highly correlated (Table 29). Increase in FFB yield due to irrigation had been reported from Africa by Taffin and Daniel (1976) and from Malaysia by Chan et al. (1985). Henson and Chang (1989) also reported that in laterite soils maximum yield was limited by inadequate moisture.

4.5.8 Palm oil yield

The palm oil production (t ha^{-1} $year^{-1}$) of different treatments are given in Table 12 and depicted in Fig. 10. Fertilizer and irrigation treatments were found to significantly influence the palm oil yield.

Among the fertilizer treatments F_2 level which has produced the maximum palm oil was found significantly superior to the other three fertilizer levels. The increased FFB production at F_2 level as discussed earlier had resulted in maximum oil production at this level. Though the oil content of mesocarp was found decreased with increased fertilizer levels (Table 11), this was more than compensated by the increased FFB production at F_2 level. Similar results were obtained by Foster et al. (1987). However at F_3 level the oil yield was found significantly reduced. This might be due to the significant reduction in oil content in mesocarp at this level of fertilizer application. So it is confirmed that both for FFB production and oil yield F_2 level of fertilizer is optimum.

Irrigation at every level has significantly increased the oil production and maximum oil yield was recorded at I_2 level of irrigation. Merits of this level of irrigation in increasing both number of bunches and FFB production has already been discussed and need no further elaboration. Thus I_2 level of 90 litres of water supplied daily through drip system of irrigation is found to increase both FFB yield and oil yield of palm.

4.5.9 Kernel oil

The palm kernel oil production in different treatments are given in Table 12.

Fertilizer alone was found to significantly influence kernel oil yield (Fig. 11). F_2 level of fertilizer application has given significantly more kernel oil yield than other fertilizer treatments. Increased FFB yield obtained in F_2 has also produced proportionately larger quantity of kernel and consequent increase in kernel oil.

Fig. 10. Effect of fertilizer and irrigation on yield of palm oil (t ha^{-1} $year^{-1}$)

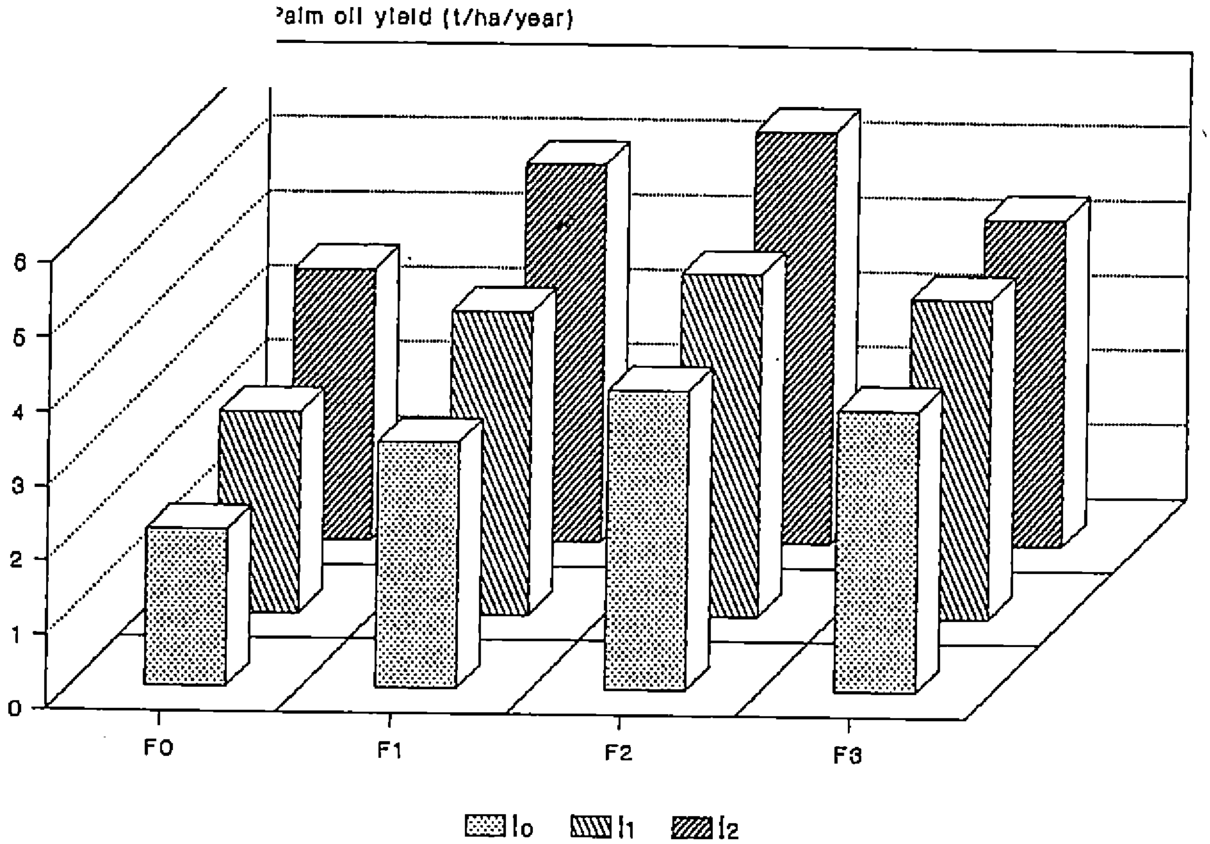
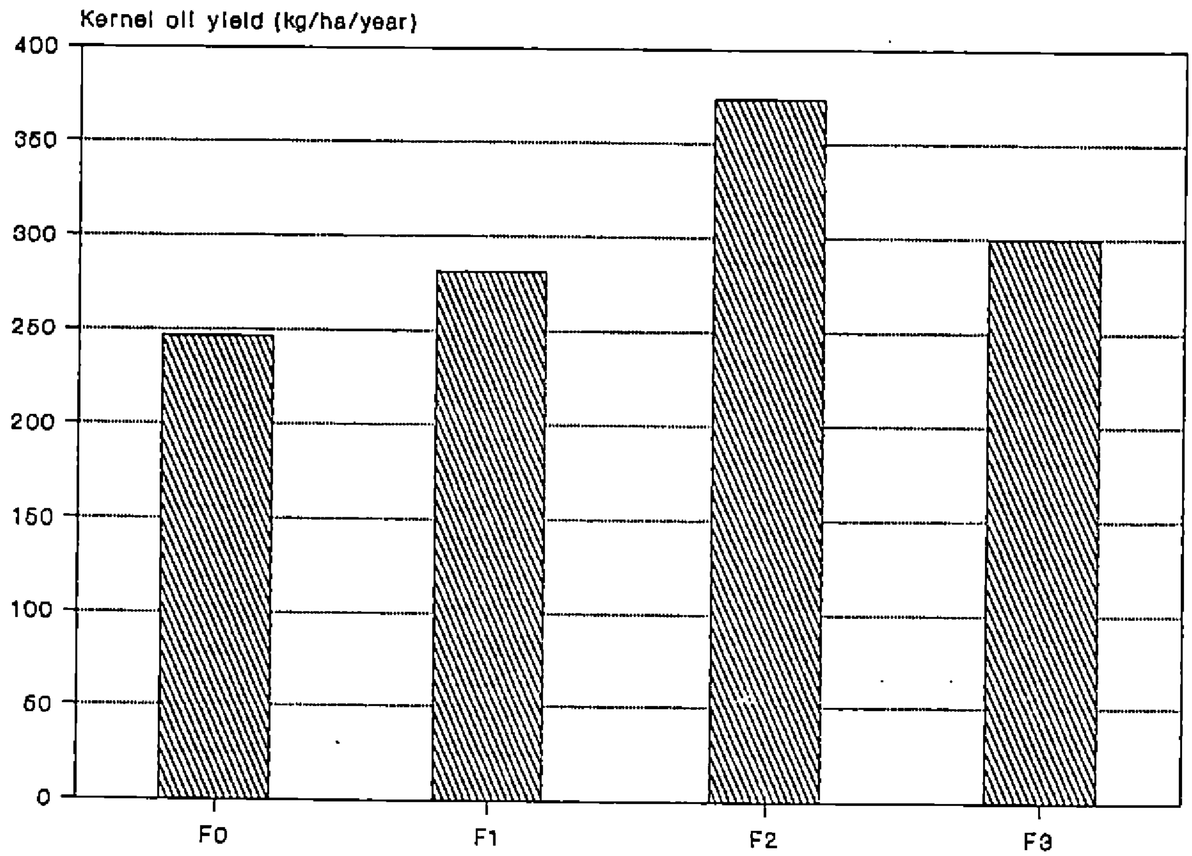


Fig. 11. Effect of fertilizer on yield of kernel oil (kg ha^{-1} $year^{-1}$)



4.6 Soil pH and nutrient status

4.6.1 Soil pH

The data on average soil pH at different depths namely 0-25cm, 25-50cm and 50-75cm in various treatments are given in Table 13.

None of the irrigation, and fertilizer treatments or their interactions was found to significantly influence the pH of the soil at any depth. The mean pH recorded at different depths were: 5.32 at 0-25 cm, 4.4 at 25-50 cm and 4.2 at 50-75 cm depth.

4.6.2 Organic carbon

The data on average soil organic carbon content (per cent) at 0-25, 25-50 and 50-75 cm depths in different treatments are given in Table 13.

Effect of fertilizers, irrigation and their interactions failed to show any significant influence on organic carbon content of soil at any depth.

Table 13. Effect of fertilizer and irrigation on soil pH and oragnic carbon (per cent) at different soil depths

Characters	Soil pH at depth			Organic carbon (per cent)		
Treatment	0-25 cm	25-50 cm	50-75 cm	0-25 cm	25-50 cm	50-75 cm
Fertilizer						
F_0	5.31	4.50	4.2	2.4	1.6	0.8
F_1	5.34	4.58	4.2	2.3	1.8	0.9
F_2	5.34	4.35	4.3	2.4	1.7	0.8
F_3	5.29	4.18	4.1	2.5	1.6	0.9
F test	NS	NS	NS	NS	NS	NS
SEM	0.06	0.13	0.09	0.12	0.13	0.04
CD (.05)	..	..	..	..	..	..
Irrigation						
I_0	5.36	4.31	4.2	2.4	1.7	0.9
I_1	5.33	4.37	4.2	2.3	1.7	0.8
I_2	5.26	4.53	4.3	2.5	1.6	0.9
F test	NS	NS	NS	NS	NS	NS
SEM	.05	0.11	0.08	0.11	0.11	0.03
CD (.05)	..	..	..	..	..	..

NS - Not significant

4.6.3 Available nitrogen content

The data on available nitrogen content of the soil at different depths of 0-25, 25-50, 50-75cm are given in Table 14.

Fertilizer application was found to significantly influence the available N at 0-25 cm depth. F_2 level has recorded significantly high available N content than that of lower levels. F_3 level was on par with F_2 level. Significantly high N content in top soil with higher levels of fertilizers was both due to more mineralisation of nitrogen at F_2 level and also due to higher level of applied nitrogen which contributed to an increased soil N status. All these have naturally resulted in a higher uptake of nitrogen. The available N status of top soil ranged between 147 and 210 ppm in different treatments.

At 25-50 and 50-75 cm depths irrigation treatment alone was found significant. It is probable that in the irrigated treatment the roots were more which would have absorbed more N from soil thereby irrigated plots recorded a significantly low available N content. This is substantiated by root growth as furnished in Table 9 wherein in the irrigated plot root growth was more.

Table 14. Effect of fertilizer and irrigation on soil available nitrogen (ppm), available phosphorus (ppm) and exchangeable potassium (C mol (p^+) kg^{-1})

Characters	Available N (ppm)			Available P (ppm)			Exchangeable K (C mol (p^+) kg^{-1})		
Treatment	0–25 cm	25–50 cm	50–75 cm	0–25 cm	25–50 cm	50–75 cm	0–25 cm	25–50 cm	50–75 cm
Fertilizer									
F_0	154	124	101	7.2	8.3	3.3	0.12	0.09	0.08
F_1	165	120	105	11.1	9.8	4.8	0.25	0.13	0.11
F_2	181	126	110	12.9	9.8	4.9	0.36	0.21	0.15
F_3	172	125	113	13.4	10.2	5.5	0.36	0.24	0.20
F test	S^{**}	NS	NS	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{**}
SEM	5.3	1.9	3.5	0.58	0.58	0.36	0.01	0.01	0.01
CD (.05)	15	..	..	1.7	..	1.0	.05	0.05	0.04
Irrigation									
I_0	172	128	115	10.7	7.7	3.9	0.27	0.18	0.13
I_1	170	121	104	10.6	9.3	4.3	0.27	0.16	0.14
I_2	163	123	102	12.1	11.5	5.7	0.27	0.17	0.13
F test	NS	S^{**}	S^{**}	NS	S^{**}	S^{**}	NS	NS	NS
SEM	4.6	1.6	9	0.50	0.49	0.31	0.15	0.01	0.01
CD (.05)	..	5	3.0	..	1.7	0.91	..	..	..

S^* – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

The interaction of irrigation and ferilizer was also significant (Table 15). At F_2 level of fertilizer, there was significantly higher N content in I_0 plots which were not irrigated. This can probably be attributed to the fact that in the plots fertilized with higher levels but were not irrigated the abundant quantity of available N present was not properly absorbed by the plant due to poor root growth. N being mainly absorbed by mass flow, moisture content is a determining factor in N uptake.

4.6.4 Available phosphorus in soil

The data on available phosphorus content of soil at different depths of 0-25 cm, 25-50 cm and 50-75 cm are furnished in Table 14.

Available P was found significantly influenced except at 25-50 cm by fertilizer while irrigation showed significant difference at lower depths.

As the fertilizer increased, there was an increase in available P content. This is naturally expected. Bosshart et al. (1989) prescribed an available P concentration of

Table 15. Effect of fertilizer and irrigation interaction on soil available N (ppm) at 0-25 cm depth

Irrigation / Fertilizer	I_0	I_1	I_2
F_0	143.8	157.8	158.7
F_1	158.3	176.7	160.3
F_2	205.5	164.5	168.5
F_3	172.7	179.0	163.7

CD (.05) - 27.1 SE 9.2

10-15 ppm in top soil to meet peak crop demand by oil palm. The available P content in top soil at F_2 and F_3 levels were 12.9 and 13.4 and it was only 7.2 in F_0 and 11.1 in F_1. Zaharah et al. (1985) also obtained similar results when Christmas Island rock phosphate was used as phosphate fertilizer.

In the irrigated plots there was more available P left in the soil at lower depths. When compared to nitrogen, absorption of P by the crop was lesser, at the same time the applied P must have contributed to more phosphorus status. In the dry soil the available P content was naturally less than in a wet soil. Moreover in irrigated plots, the root activity was more which would have helped to increase the available P content of native and applied phosphorus due to root exudations and increased microbial activity.

4.6.5 Exchangeable K

Data on exchangeable K content of soil at depths 0-25, 25-50 and 50-75cm as influenced by fertilizer and irrigation treatments are summarised in Table 14.

Fertilizer treatment alone was found to significantly influence the exchangeable K status of soil.

At 0-25 and 25-50 cm depths F_2 level of fertilizer application was found significantly superior to F_1 and F_0 levels and was at par with F_3 level. At 50-75 cm depth, F_3 was superior to all three levels and F_2 was superior to F_0. K concentration in soil was found to decrease with depth as reported by Bosshart et al. (1989). The fertilizer application has shown an increase in exchangeable K along with increase in doses at all depths. Since fertilizer application is done continuously, an increase in exchangeable K is expected. Exchangeable K in the top soil as well as subsoil were found increased due to fertilizer application in Malaysia by Ng (1977) and in Papua New Guinea by Breure and Rosenquist (1977). Singh (1989) also reported similar results.

4.6.6 Soil exchangeable calcium

The exchangeable calcium of soil at depths 0-25 cm and 50-75 cm as influenced by fertilizer and irrigation treatments are given in Table 16.

No significant effect was noticed due to fertilizer treatments. Since the Ca content of soil was relatively

Table 16. Effect of fertilizer and irrigation on soil exchangeable Ca and Mg (C mol (p^{+}) kg^{-1})

Characters Treatment	Exchangeable Ca (C mol (p^{+}) kg^{-1}) 0-25 cm	25-50 cm	50-75 cm	Exchangeable Mg (C mol (p^{+}) kg^{-1}) 0-25 cm	25-50 cm	50-75 cm
Fertilizer						
F_0	0.23	0.10	0.10	0.23	0.19	0.11
F_1	0.27	0.15	0.12	0.22	0.21	0.09
F_2	0.26	0.13	0.11	0.21	0.19	0.05
F_3	0.28	0.12	0.13	0.22	0.19	0.08
F test	NS	NS	NS	NS	NS	S^{*}
SEM	0.02	0.01	.008	0.017	0.019	0.013
CD (.05)	..	..	..	..	..	0.04
Irrigation						
OI_0	0.23	0.12	0.10	0.23	0.18	0.09
I_1	0.27	0.14	0.12	0.21	0.19	0.06
I_2	0.29	0.14	0.12	0.23	0.21	0.09
F test	s^{*}	NS	NS	NS	NS	NS
SEM	0.015	0.01	.006	0.014	0.016	0:01
CD (.05)	0.04	..	..	..	..	..

S^{*} - Significant at P = 0.05 level

S^{**} - Significant at P = 0.01 level

NS - Not significant

lesser and also there was no appreciable addition of calcium there was no significance.

However irrigation was found significantly influencing Ca at 0-25 cm depth. A progressive increase in calcium availability was noticed with increasing levels of irrigation. Irrigation at I_2 level has significantly increased exchangeable Ca over I_0 plot. As already observed in the case of phosphorus, this increased availability might be related to the increased root activity in the irrigated treatment where the dissolution of calcium also takes place from the rock phosphate applied. Similar results were obtained by Singh (1989).

4.6.7 Soil exchangeable magnesium

The data on exchangeable magnesium status of the soil at depths 0-25, 25-50 and 50-75 cm are furnished in Table 16.

The results showed that exchangeable Mg has not been appreciably influenced by fertilizer and irrigation treatments except at 50 to 75 cm depth.

4.7 Nutrient concentration (per cent) and uptake of nutrients (g $palm^{-1}$ $year^{-1}$) by palm parts

The oil palm has four major components of above ground portion namely the trunk, leaves, male flower and the bunches. Nutrient content in each of these components was determined separately to know the nutrient removal and immobilization in various palm parts. Nutrient uptake study is important to know the annual removal of nutrients for planning fertilization programme in oil palm. Influence of fertilizer and irrigation is discussed for each nutrient in different palm parts.

4.7.1 Nutrient contents and uptake of trunk

N, P, K, Ca and Mg (per cent) and their uptake by trunk (g $palm^{-1}$ $year^{-1}$) in different treatments are given in Table 17.

4.7.1a Nitrogen

Effect of fertilizer treatment was found significant both on nitrogen content and nitrogen uptake by

Table 17. Nutrient content (per cent) and nutrient uptake (g palm^{-1} year^{-1}) by trunk

Characters / Treatment	Nitrogen Content	Nitrogen Uptake	Phosphorus Content	Phosphorus Uptake	Potassium Content	Potassium Uptake	Calcium Content	Calcium Uptake	Magnesium Content	Magnesium Uptake
Fertilizer										
F_0	0.41	110.27	0.05	12.39	0.43	114.91	0.09	24.14	0.24	62.95
F_1	0.51	148.16	0.05	13.90	0.59	173.45	0.10	30.04	0.26	76.70
F_2	0.76	234.05	0.06	17.63	0.74	226.33	0.13	39.10	0.31	95.14
F_3	0.75	235.95	0.06	17.90	0.80	251.37	0.12	37.99	0.26	81.74
F test	S**	S**	NS	S*	S**	S**	S*	S**	NS	NS
SEM	0.04	13.29	0.005	1.51	0.05	14.90	0.008	2.17	0.03	8.46
CD (.05)	0.11	38.99	..	4.43	0.14	43.70	0.02	6.36	..	..
Irrigation										
I_0	0.54	148.79	0.05	12.24	0.58	156.91	0.10	25.19	0.26	70.62
I_1	0.61	191.23	0.06	17.68	0.68	215.74	0.12	36.57	0.26	80.88
I_2	0.67	206.30	0.05	16.43	0.66	201.89	0.12	36.70	0.28	85.90
F test	S*	S**	NS	S*	NS	S*	NS	S**	NS	NS
SEM	0.03	11.51	0.004	1.31	0.04	12.90	0.007	1.88	0.02	7.32
CD (.05)	0.09	33.76	..	3.83	..	37.84	..	5.51	..	..

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

NS – Not significant

trunk. F_2 and F_3 treatments which remained on par were found significantly superior to F_0 and F_1 for N content and uptake. Increased nitrogen content of leaf (Table 19) and total uptake of nitrogen (Table 28) in F_2 and F_3 treatments illustrates the necessity of absorption and translocation of nitrogen in the trunk. Increased photsynthesis due to nitrogen supply has thus necessitated increased uptake of nitrogen content in the trunk at F_2 and F_3 levels over F_0 and F_1 levels. Thus increase in nitrogen content (Table 17) along with increased trunk dry matter production (Table 5) and increased soil nitrogen availability in top 0-25 cm layer of soil (Table 14) have favoured more uptake of N by trunk at F_2 and F_3 levels. Also trunk being a storage organ in oil palm, to meet any immediate requirement due to heavy bunch production, nitrogen is stored in trunk as reported by Corley (1976b).

Irrigation at I_2 level has increased N content and the uptake of N by trunk significantly over I_0 level. Lack of significance at I_1 level for N content indicated that for proper nitrogen nutrition of the palm I_2 level is required. Increased nitrogen content (Table 17) and dry matter production (Table 5) of trunk at I_2 level has thus resulted in significant increase in uptake of N by trunk. Better availability of moisture might have encouraged the nitrogen uptake.

4.7.1b Phosphorus

Eventhough P content did not vary with fertilizer treatment, F_2 and F_3 levels of fertilizer application was found to increase uptake of phosphorus significantly over F_0 level. The parity of F_1 with F_0 indicated that F_1 was inadequate to supply the P requirement needs of the trunk. Available phosphorus content in top 0-25cm layer of the soil was also found significantly high in F_2 and F_3 treatments (Table 14). Thus the increased availability of phosphorus coupled with increased dry matter production of trunk has resulted in significantly large uptake of phosphorus by trunk at F_2 and F_3 levels.

Inspite of the observed nonsignificance in P content, irrigation at I_2 level has recorded maximum P uptake by trunk. Availability of phosphorus in soil was also more in I_2 level especially in the lower depths of 25-50 cm and 50-75cm (Table 14).

4.7.1c Potassium

The effect of fertilizer treatment was found significant in increasing the K content and K uptake by trunk. The K content and uptake by trunk has increased up to the highest level of F_3, but was not significantly different beyond F_2 level. The F_1 and F_0 treatments recorded a significantly low K content. This again showed that for sufficient K nutrient content of the trunk, application of fertilizer at F_2 level is required. K uptake by trunk was also significantly more in F_2 treatment than lower levels. Uptake in F_3 treatment was found on a par with F_2 level. Since both potassium content and dry matter of trunk were more in F_2 and F_3 treatments potassium uptake also recorded significantly higher values. Potassium is usually found in large quantities in storage organs. Trunk being a storage organ in oil palm, accumulation of sizable amount of potassium in trunk is expected. Large quantity of potassium accumulation in the trunk has also been reported by Corley et al. (1976). Exchangeable K content in top 0-25 cm layer of soil has also significantly increased at the higher levels of fertilizer application (Table 14). This increased availability of K in soil has thus resulted in a continuous supply and increased uptake by trunk in F_2 and F_3 treatments.

Irrigation has increased the uptake over unirrigated plot. Improved vegetative growth especially of trunk dry matter production (Table 5) has significantly increased the K uptake in irrigated plots. Increased K supply due to irrigation might have enhanced the photosynthesis due to its role in stomatal opening and translocation of the synthesised food. This increased demand of potassium forced the palm to absorb and conserve more K in the trunk.

4.7.1d Calcium

F_2 level of fertilizer has recorded significantly high calcium content in trunk over F_0 and F_1 levels and was at par with F_3 level. Uptake of calcium also followed exactly the same trend.

Calcium is required for proper development of meristamatic tissues, and for fibre formation of the trunk. Calcium is also present as calcium pectate in cell walls. These explain the need for a high requirement of calcium by oil palm. The increased availability of calcium due to better root activity in irrigated plot has already been explained. Application of more calcium through rock phosphate in F_2 and

F_3 plots also contributed to the increase in Ca upake by trunk.

Irrigation at I_2 level which has recorded maximum calcium content and calcium uptake was found significantly superior to I_0 level and was on par with I_1 level. Increased soil exchangeable calcium in irrigated plot (Table 16) might have resulted in more uptake of this element.

Interaction of irrigation and fertilizer was found significant for calcium uptake which is given in Table 18.

Table 18 Effect of fertilizer and irrigation interaction on uptake of calcium by trunk (g $palm^{-1}$ $year^{-1}$)

Irrigation / Fertilizer	0	1	2
0	16.33	23.24	32.85
1	31.77	32.79	25.57
2	28.49	47.74	41.08
3	24.16	42.51	43.71

CD (0.05) = 11 SEM - 3.8

With I_1 level of irrigation, F_2 recorded significantly higher uptake over F_0 and with I_2, F_3 level has recorded maximum Ca uptake. Both the irrigated treatments of I_1 and I_2 recorded maximum uptake with fertilizer supply at F_2 and F_3 levels. Ca uptake was least in the control plot I_0F_0.

4.7.1c Magnesium

Neither the fertilizer nor irrigation treatments has influenced the magnesium content and magnesium uptake by trunk.

4.7.2 Content and uptake of nutrient by leaflets, petiole with rachis and total leaf

The leaf consists of two main components namely the leaflets and petiole with rachis. The nutrient content and uptake of both these components were determined separately (Tables 19 and 20) to estimate the total uptake by leaf (Table 21). The influence of fertilizer and irrigation treatments are discussed nutrient wise on these components and the total uptake by leaf.

Table 19. Nutrient content (per cent) and nutrient uptake (g $palm^{-1}$ $year^{-1}$) by leaflets

Characters Treatment	Nitrogen Content	Nitrogen Uptake	Phosphorus Content	Phosphorus Uptake	Potassium Content	Potassium Uptake	Calcium Content	Calcium Uptake	Magnesium Content	Magnesium Uptake
Fertilizer										
F_0	2.16	391	0.14	25	0.55	100	0.72	129	0.38	69
F_1	2.31	487	0.14	30	0.69	147	0.74	156	0.34	71
F_2	2.53	560	0.15	33	0.84	188	0.63	139	0.31	68
F_3	2.49	609	0.14	35	0.81	198	0.64	154	0.30	73
F test	S**	S**	NS	S**	S**	S**	NS	NS	S**	NS
SEM	0.03	25	0.003	1.7	0.03	9.3	0.04	11	0.02	3.6
CD (.05)	0.10	72	..	5	.06	27	..	..	0.05	..
Irrigation										
I_0	2.43	478	0.14	28	0.70	139	0.69	133	0.34	64
I_1	2.36	504	0.14	31	0.74	161	0.67	140	0.34	71
I_2	2.33	554	0.14	33	0.72	175	0.69	160	0.33	76
F test	S*	NS	NS	S*	NS	S*	NS	NS	NS	S*
SEM	0.03	22	0.002	1.4	0.023	8.0	0.03	9.5	0.01	3.1
CD (.05)	0.08	..	..	4	..	23	..	..	..	9

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

NS – Not significant

4.7.2a Nitrogen

From the results presented in Table 19, it is noticed that fertilizer treatments have significantly influenced the per cent content and uptake of nitrogen by leaflets. Fertilizer at F_2 level was found significantly superior to F_1 and F_0 levels of application and remained on par with F_3 level for both N content and N uptake. Significant increase in leaf N content at F_2 level of fertilizer application was due to the better uptake of nitrogen by the palm (Table 28). The higher leaf nitrogen status is also related to the enhanced available soil N due to fertilizer application (Table 14). At F_2 level, the N content of leaf was 2.53 per cent. Wilkie and Foster (1989) reported that leaf nitrogen levels of 2.5 to 2.6 per cent is required for optimum yield and found reduced when it fell below 2.5 per cent. Increase in nitrogen content of leaves consequent to fertilizer application has been reported by Ollagnier et al. (1970), Foo and Omar (1987) and Singh (1989).

Significant N uptake was also observed at F_2 level of fertilizer application beyond which it remained nonsignificant. Being a product of dry weight of leaflets and

Table 20. Nutrient content (per cent) and nutrient uptake (g $palm^{-1}$ $year^{-1}$) by petiole and rachis

Characters / Treatment	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake
Fertilizer										
F_0	0.22	88.5	0.03	11.6	0.27	108.5	0.78	305.9	0.53	206.2
F_1	0.28	128.8	0.03	15.0	0.69	327.2	1.03	468.5	0.40	182.3
O_2	0.27	129.4	0.03	15.5	1.12	529.9	0.93	447.3	0.25	117.8
F_3	0.28	151.1	0.03	16.1	1.21	656.4	0.83	447.5	0.17	93.8
F test	S^{**}	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{*}	S^{**}	S^{**}	S^{**}
SEM	0.01	7.8	0.001	0.87	0.07	39.0	0.06	31.7	0.03	12.5
CD (.05)	0.03	22.9	..	2.5	0.21	114.4	0.17	93.1	0.08	36.6
Irrigation										
I_0	0.27	116.3	0.03	13.0	0.72	331.5	0.89	38.2	0.36	144.9
I_1	0.26	118.2	0.03	14.7	0.83	387.6	0.91	42.5	0.33	151.2
I_2	0.27	138.8	0.03	16.0	0.92	497.4	0.86	44.5	0.31	153.9
F test	NS	NS	NS	S^{*}	NS	S^{**}	NS	NS	NS	NS
SEM	0.007	6.7	0.001	0.76	0.06	33.8	0.05	27.5	0.02	10.8
CD (.05)	..	..	..	2.2	..	99.1	..	..	..	..

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

its nitrogen content, these have direct bearing on nutrient uptake. Leaflet production and therefore its dry weight was found significantly increased due to fertilizer application at F_2 level over the unfertilized plots and also there was a significant increase in N content at F_2 over F_1 together which had resulted in significant nitrogen uptake by leaflets. A significant increase in content and uptake of nitrogen at F_2 level and its lack of significance beyond F_2 indicates that nitrogen requirement of oil palm is adequately met at F_2 level of fertilizer application.

The nitrogen content and uptake of nitrogen by petiole and rachis presented in Table 20 revealed that fertilizer had significantly increased N content and N uptake.

Total annual uptake of nitrogen by whole leaves in g palm^{-1} are given in Table 21. The effect of fertilizer treatment alone was significant. Uptake of nitrogen by leaves at F_3 level was at par with F_2 and was found significantly superior to F_0 and F_1 levels. The leaf dry matter production (Table 5) also showed similar trend. This illustrates that the increased supply of nitrogen through fertilizer application has resulted in increased chlorophyll

Table 21. Nutrient uptake by leaf (g $palm^{-1}$ $year^{-1}$)

Characters Treatment	N	P	K	Ca	Mg
Fertilizer					
F_0	479.0	36.9	208.7	434.5	274.9
F_1	616.7	45.0	474.2	624.1	253.9
F_2	689.5	48.1	717.6	586.0	185.6
F_3	760.0	51.2	854.6	601.4	166.8
F test	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SEM	32.1	2.3	43.3	37.85	13.2
CD (.05)	94.2	6.8	127.0	111.1	38.7
Irrigation					
I_0	593.8	40.9	470.1	514.9	209.0
I_1	622.2	45.6	549.1	564.7	221.7
I_2	692.9	49.4	672.1	604.8	229.6
F test	NS	S^{**}	S^{**}	NS	NS
SEM	27.8	2.0	37.5	32.8	11.4
CD (.05)	..	5.9	109.9	..	..

S^{**} – Significant at P = 0.01 level

NS – Not significant

synthesis by leaves for enhanced growth which warranted relatively large uptake of nitrogen.

Irrigation treatment was found to significantly reduce N content of leaflets where as N uptake remained unaffected. The reduction in leaf N content in the irrigated treatments might be due to the translocation of this mobile nutrient to other palm parts causing a dilution effect in leaflets. Reduction in leaf N content due to irrigation had been reported by Ugbah et al. (1990). However in the case of N uptake, the effect of reduced N content was nullified by the significant increase in dry weight of leaflets thus making the N uptake nonsignificant. Similarly the N uptake by petiole and rachis and also by total leaves remained nonsignificant.

4.7.2b Phosphorus

The fertilizer levels did not influence the P content of both leaflet and petiole with rachis whereas it has significantly influenced the uptake of phosphorus by both (Tables 19 and 20). The significant difference in leaf dry weight and the lack of significant response observed in P content together made the P uptake to follow the trend as that of its dry weight. Eventhough P uptake had increased up to F_3 level of fertilizer application, its significance was confined to F_1 level. Synergistic effect of N and P on oil palm had been reported by Ummar et al. (1977). This is because both N and P are linked in cell formation and metabolic processes. Thus an increase in N uptake resulted in a corresponding increase in P uptake both by leaflets (Table 19) and petiole with rachis (Table 20).

Eventhough the uptake of phosphorus by leaf (Table 21) increased up to the highest level of F_3 followed by F_2 the significance was restricted at F_1 level. Improvement in uptake of phosphorus is due to the increased dry matter accumulation of petiole and rachis in these treatments. Supply of higher quantities of phosphorus has increased the available P in top 0-25 cm layer of soil (Table 14) which enabled the palms to absorb more phosphorus from soil. Phosphorus is also required to keep the photosynthetic mechanism active for which more phosphorus might have been taken up by the leaf. Similar increase in uptake of phosphorus without increasing its content was reported by Hartley (1988).

Irrigation at I_2 level has increased the P uptake significantly over I_0 level whereas I_1 did not improve P uptake significantly. The same trend was noted both for leaflets and for petiole with rachis. At I_2 level the dry weight of leaflets as well as that of petiole with rachis were higher which enhanced the P uptake. Irrigation at I_2 level has improved the availability of phosphorus, especially in lower layers of soil (Table 14). Because of favourable soil moisture conditions, there was continuous availability of nutrients in irrigated plots throughout, to meet the timely P requirement of the crop resulting in an increased P uptake by leaves.

4.7.2c. Potassium

Effect of fertilizer treatment was significant on the leaflet K content and its uptake by leaflets (Table 19). Fertilizer application at F_2 level which was on a par with F_3 level had significantly increased the leaf K content and K uptake over F_0 and F_1 levels. This has also resulted in an increased uptake of nutrients at F_2 and F_3 levels over their lower levels (Table 28). Foster (1989) reported leaflet K as the most relevant indicator of K status and was required to maintain the optimal rate of photosynthesis. Increase in leaf K levels due to KCl application in the fertilizer was reported by Wilkie and Foster (1989). Though the increase in leaf dry weight at F_2 was only marginal over F_1, it was significantly superior to F_0 level (Table 5). There was also a significant increase in K content at F_2 level over lower levels (Table 19). Together these effects resulted in a significant uptake of K by leaflets with higher levels of fertilizer application. Foo and Omar (1987) reported that K application has increased leaf K levels in oil palm. Uptake of nitrogen also might have influenced the uptake of potassium at F_2 level of application. Increase in leaf K level due to increase in N has been reported by Mutert (1993).

For petiole and rachis (Table 20) fertilizer application has resulted in significant increase in K content and uptake. F_2 and F_3 levels of fertilizer applications which did not differ between, was found significantly superior to F_0 and F_1 levels. Teoh and Chew (1988) reported that K content below 0.01 per cent is low in petiole. The very low values recorded in F_0 and F_1 treatments which were significantly lower than F_2 and F_3 indicated the inadequacy of potassium nutrition at lower levels of fertilizer application. Significant increase in potassium content at F_2 and F_3 levels along with the significant increase in dry matter have thus resulted in the significant difference in uptake of potassium between all levels of fertilizer treatment.

From the data on total uptake of K by leaf (Table 21) fertilizer treatments were found to significanlty influence the potassium uptake by leaf. All the fertilizer treatments differed significanlty in increasing the total uptake of potassium up to the highest level tested. Potassium contents of both leaflets and petiole also showed significant increase up to F_2 level of fertilizer application (Table 19 & 20). A very high demand of K for total dry matter production (Table 7) might have caused a significant increase in uptake of K by leaves up to the highest dose of F_3 level.

Irrigation at I_2 level was found to increase the potassium uptake by leaves significantly over I_1 and I_0 levels (Table 21). The same result was observed both for leaflets and the petiole with rachis. As the nutrient content remained not influenced by irrigation treatments, the increased uptake was mainly due to increased dry matter production at I_2 level of irrigation. Irrigation might have enhanced the release and uptake of K from soil. Ruer (1966) reported that K uptake is limited by inadequate moisture. Because of the role of potassium in stomatal opening and transpiration which was favoured through adequate supply of water at I_2 level might have also resulted in an increased uptake of K by leaf. Increase in leaf K content due to irrigation was reported by Chillard et al. (1983). Ochs et al. (1991) also reported potassium uptake as a function of water availablity.

4.7.2d. Calcium

Neither the effect of fertilizer, irrigation nor their interaction is found to have any significant influence on either the content or uptake of calcium by leaflets. However fertilizer application has significantly influenced both Ca content and Ca uptake of petiole and rachis. Ca concentration in F_1 treatment was on a par with F_2 and was superior to F_0 and F_3 levels of fertilizer application. Calcium content thus showed a decreasing trend beyond F_1

level. It is also possible that there might exist an antagonism that decreased Ca content with increase in fertilizer levels. As observed in the case of calcium content (Table 19), least Ca uptake was also noticed in the control plot.

Calcium uptake by leaves of a palm in different treatments showed that only the fertilizer treatment had significantly increased the calcium uptake by leaf. Fertilizer application at F_1 level was found to increase Ca uptake significantly over F_0 level and was at par with F_2 and F_3 levels. Calcium being a primary element, its requirement and therefore its uptake was sufficiently met by the crop only with fertilizer application at F_1 level.

4.7.2e. Magnesium

The fertilizer treatment was found to significantly influence the leaf magnesium content and Mg uptake by leaflets (Table 19). Though not supplied in the fertilizer combination, the influence of fertilizers on leaf Mg was observed. The effect of increasing supply of fertilizers in reducing the leaf magnesium content was manifested for all levels of fertilizers from F_1 to F_3. Mg content was found significantly reduced at F_2 and F_3 levels than F_0 treatment. Higher concentration of potassium at F_2 and F_3 levels might have reduced the uptake of magnesium due to K-Mg antagonism. Substantial decrease in leaf Mg levels at optimal NPK fertilizer application was reported by Dolmat <u>et al</u>. (1989). Being an oil yielding crop large quantity of Mg might have been removed through harvested bunches which has resulted in reduction of Mg content of leaf at F_2 level of fertilizer supply.. This is also supported by the lack of significant difference between F_0 and F_1 levels wherein the yield was also less. It was also observed that the total magnesium uptake was lower in F_2 and F_3 treatments (Table 28) whereas its removal through bunches were significantly large in the fertilized plots. The maximum removal was recorded in F_2 level of fertilizer application (Table 27). This continued removal reduced the leaf Mg content at higher levels of fertilizer application.

Effect of fertilizer application on Mg uptake was found nonsignificant because the general reduction in leaf Mg content at higher levels (Table 19) were compensated by increased leaflet dry matter production (Table 5) at these levels. This has resulted in more or less uniform uptake of magnesium by the palm.

The data on magnesium content and Mg uptake by petiole with rachis (Table 20) also showed that all the four level of fertilizers differed significantly between one another. Contrary to potassium content, there was a decreasing trend for Mg from F_0 to F_3. Thus higher level of fertilizer application has significantly reduced the magnesium content of petiole. Mg uptake by petiole at F_2 and F_3 treatment levels which remained on a par recorded significantly low uptake than F_0 and F_1 levels. Here again the K-Mg antagonism holds good.

Effect of irrigation treatment was not found significant on leaf Mg content but was found significant on Mg uptake by leaflets. Increasing levels of irrigation has increased the uptake of magnesium by leaflets at I_2 level over I_0 level. I_1 level was found insufficient to cause any significant difference over I_0. This trend was the same as that of leaflet dry matter production as irrigation did not influence the magnesium content.

The data on uptake of magnesium by whole leaf (g palm^{-1} year^{-1}) showed that (Table 21) there was a decreasing trend in its uptake. Thus F_0 and F_1 treatments recorded significantly high magnesium uptake than F_2 and F_3. When fertilizers were given at F_2 and F_3 levels, increased bunch yield caused a heavy removal and exhaustion of the available nutrient resulting in reduced uptake in F_2 and F_3 treatments. Hartley (1988) reported that high application rates of nitrogen reduced its uptake. In addition, the continued application of high levels of K at F_2 and F_3 levels also resulted in the reduction of magnesium content of soil at the lower depth of 50 to 75 cm as reported by Tinker and Smilde (1963).

4.7.3. Content and uptake of nutrients by male inflorescence

Content and uptake of N, P, K, Ca and Mg by male inflorescence are given in Table 22.

4.7.3a. Nitrogen

Effect of fertilizer was not found to significantly influence the N content of male inflorescence. However, the

Table 22. Nutrient content (per cent) and uptake (g $palm^{-1}$ $year^{-1}$) by male inflorescences

Characters / Treatment	Nitrogen Content	Nitrogen Uptake	Phosphorus Content	Phosphorus Uptake	Potassium Content	Potassium Uptake	Calcium Content	Calcium Uptake	Magnesium Content	Magnesium Uptake
Fertilizer										
F_0	2.23	27.00	0.48	5.77	1.28	15.39	0.52	6.36	1.24	14.99
F_1	2.38	45.36	0.51	9.81	1.47	28.22	0.51	9.85	1.06	20.34
F_2	2.47	51.61	0.51	10.64	1.59	32.57	0.57	11.70	1.05	21.99
F_3	2.38	43.81	0.50	9.21	1.35	25.21	0.54	9.74	0.93	17.33
F test	NS	S**	NS	S**	NS	S**	NS	S**	S**	S**
SEM	0.12	3.12	0.02	0.71	0.08	1.72	0.03	0.73	0.03	1.30
CD (.05)	..	9.15	..	2.08	..	5.04	..	..	..	3.82
Irrigation										
I_0	2.35	46.34	0.50	10.09	1.45	28.68	0.47	9.29	1.07	20.95
I_1	2.41	41.72	0.49	8.44	1.38	23.83	0.52	8.99	1.08	18.27
I_2	2.33	37.77	0.50	8.04	1.44	23.53	0.62	9.96	1.06	16.76
F test	NS	NS	NS	NS	NS	S**	S**	NS	NS	S*
SEM	0.11	2.70	0.02	0.62	0.07	1.49	0.02	0.64	0.03	1.12
CD (.05)	..	..	..	..	..	4.36	..	..	..	3.31

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

NS – Not significant

fertilizer treatments were found to significantly influence the nitrogen uptake by male inflorescences. F_2 treatment recorded maximum uptake and was on a par with F_1 and F_3 but superior F_0. As the N content did not vary due to influence of fertilizers, the N uptake pattern followed the same trend as that of dry matter production of male flowers. F_2 treatment which has produced maximum dry matter production of male inflorescences has recorded maximum N uptake.

Neither the N content nor its uptake was influenced by irrigation treatments.

4.7.3b. Phosphorus

Fertilizer treatments did not influence P content of male inflorescences.

Phosphorus uptake was maximum at F_2 level of fertilizer application which was significantly superior to F_0 level and remained on a par with F_1 and F_3 levels. As in the case of nitrogen, phosphorus uptake also followed the same pattern showing the physiological synergism between phosphorus and nitrogen in its uptake.

Irrigation treatments did not influence both P content and P uptake by male inflorescences.

4.7.3c Potassium

Fertilizer treatments failed to influence the per cent content of K in male inflorescences. However K uptake by male flowers was found significantly influenced by fertilizers. F_2 level recorded the maximum uptake and was significantly superior to F_0 treatment. Here again as observed for N and P, K uptake also followed the same trend as that of male flower dry matter production.

Effect of irrigation though not significant on K content, it was found to influence K uptake by male inflorescences. P uptake by male inflorescences was maximum at I_0 level and was significantly higher than both I_1 and I_2 levels. This is because of the larger number of male inflorescences produced in the unirrigated plot I_0 and consequently more dry matter production of male inflorescences (Table 5) recorded in this plot. Since I_1 and I_2 plots were irrigated they produced more of female inflorescences and less of male inflorescences thereby reducing the dry matter and uptake of potassium in these treatments.

4.7.3d Calcium

Ca content of male inflorescences was not found influenced by fertilizer treatments. However fertilizer treatments were found to significantly influence Ca uptake by male inflorescences. Eventhough maximum Ca uptake was observed in F_2 plot it was on a par with F_1 and F_3 treatments. Application of phosphorus as rock phosphate might have made more calcium available for uptake by palms in these treatments.

Irrigation is found to influence the Ca content of male inflorescences. I_2 level of irrigation has recorded significantly high Ca content compared to the lower level of irrigation. Increased uptake of calcium was due to increased availability of exchangeable Calcium in top 0-25 cm layer of soil due to irrigation treatment (Table 16). Irrigation was not found to significantly influence calcium uptake by male inflorescences.

4.7.3e Magnesium

Enhanced doses of fertilizer up to F_3 level were found to significantly reduce the magnesium content of male inflorescences. The reduction in Mg content due to heavy removal of magnesium through harvested bunches in the treatment of higher doses of fertilizers.

Fertilizer treatments has also significantly influenced the magnesium uptake by male inflorescences. Though there was a reduction in Mg content as discussed before, uptake of Mg was maximum at F_2 level. This was found on par with F_1 and significantly superior to F_0 and F_3. This increase in uptake was mainly due to the increased dry matter production of male inflorescences in fertilized treatments (Table 5). The reduction in F_3 treatment was due to the low Mg content observed in this treatment (Table 22).

Irrigation though did not influence Mg content it has influenced the Mg uptake. Irrigation at I_2 level has significantly reduced the uptake by male inflorescences because the male inflorescences were few in I_2 treatment and more in I_0 treatment. The reduction at I_1 was not found significant as the male inflorescences dry matter also was not significantly reduced at I_1 level. In otherwords Mg uptake followed the same trend as that of male inflorescences dry matter production.

4.7.4 Nutrient content and uptake by bunches

Oil palm bunch has two main components namely the bunch refuse and the fruits. The fruit has three components namely the mesocarp, the shell and the kernel. Nutrient content and uptake by each part are discussed below.

4.7.4.1 Bunch refuse

The data on nutrient content (per cent) and uptake (g $palm^{-1}$ $year^{-1}$) of N, P, K, Ca and Mg by bunch refuse are furnished in Table 23.

4.7.4.1a Nitrogen

Fertilizer treatments were found to increase the nitrogen content of bunch refuse. As the fertilizer doses increased from F_0 to F_3 level, there was a continuous increase in N content though the difference was not significant beyond the F_1 level of fertilizer application. Maximum content at F_3 level indicate that N is absorbed progressively up to the highest level of fertilizer application. Significant uptake at F_3 level by the bunch

Table 23. Nutrient content (per cent) and annual nutrient uptake (g $palm^{-1}$ $year^{-1}$) by bunch refuse

Characters	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
Treatment	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake
Fertilizer										
F_0	0.84	57.08	0.10	7.25	2.41	164.58	0.19	12.72	0.38	25.62
F_1	0.97	81.86	0.12	10.23	2.37	202.27	0.20	17.05	0.35	29.48
F_2	0.96	83.95	0.13	10.97	2.58	226.39	0.21	18.05	0.31	27.30
F_3	1.03	98.41	0.13	12.28	2.53	241.07	0.19	18.57	0.29	27.33
F test	S^{**}	S^{**}	S^{**}	S^{**}	NS	S^{**}	NS	S^{*}	S^{**}	NS
SEM	0.03	4.73	0.004	0.61	0.08	12.79	0.01	1.23	.009	1.62
CD (.05)	0.08	13.89	0.01	1.79	..	37.53	..	3.60	0.02	..
Irrigation										
I_0	0.97	80.48	0.11	9.57	2.37	197.98	0.20	16.56	0.36	29.88
I_1	0.96	80.57	0.12	10.32	2.49	207.73	0.20	16.44	0.32	26.41
I_2	0.93	79.93	0.12	10.66	2.56	220.02	0.19	16.79	0.31	26.00
F test	NS	NS	NS	NS	NS	NS	NS	NS	S^{**}	S^{**}
SEM	0.03	4.10	0.003	0.53	0.73	11.08	0.01	1.06	0.02	..
CD (.05)	..	..	..	..	..	..	..	..	0.02	..

S^{*} – Significant at $P = 0.05$ level

S^{**} – Significant at $P = 0.01$ level

NS – Not significant

refuse also indicated that nitrogen was absorbed in relation to its supply. Since fruits are formed and supported on these parts, nutrients are first taken up by this part and transported to developing fruits. This explains for the difference in N content and uptake of the bunch refuse. Irrigation treatments did not influence the N content and N uptake by the bunch refuse.

4.7.4.1b **Phosphorus**

Fertilizer treatments were found to significantly influence the P content of bunch refuse. Here again there was continuous uptake of phosphorus up to the highest dose of F_3 level of fertilizer application. The increase in the fertilized treatments were significantly superior to the unfertilized treatment.

Phosphorus uptake by the bunch refuse was also seen influenced by fertilizer treatments. Uptake of phosphorus showed a continuous increase upto the F_3 level which was found significantly superior to F_0 and F_1 levels and was on par with F_2 level. The highest bunch dry matter production (Table 7) as well as the highest P content recorded in F_3 has resulted in significant uptake of P at this level. However its parity with F_2 level indicated that application beyond F_2 level is not necessary.

Irrigation treatments failed to show any significant influence both on P content and P uptake by bunch refuse.

4.7.4.1c Potassium

Irrespective of treatment effects, the bunch refuse recorded a uniformly high potassium content of 2.47 per cent. This high content of potassium in bunch refuse indicates the high removal of potassium through harvested bunches. Uptake of potassium by bunch waste increased up to the highest dose of F_3 level of fertilizer application which was found significantly superior to F_0 and F_1 levels and was on a par with F_2. K content being nonsignificant, the increased uptake was mainly due to the higher bunch waste dry matter production (Table 7).

Irrigation treatments did not influence the potassium content and potassium uptake by bunch refuse.

4.7.4.1d Calcium

Fertilizer treatments failed to show any significant influence on Ca content. However uptake of calcium was found significantly influenced. There was a progressive increase in calcium uptake upto F_3 level of fertilizer application eventhough the increase above F_1 level was found not significant. The increase in uptake is due to the increased dry matter production and also supply of calcium in rock phosphate.

Irrigation levels failed to show any significant influence on calcium content and calcium uptake by bunch refuse.

4.7.4.1e Magnesium

Contrary to the influence of fertilizer treatments on other elements, Mg content was found decreasing with increase in levels of fertilizer application. F_3 level which recorded the least content was on a par with F_2 and significantly inferior to both F_0 and F_1 levels. This decreasing trend can be explained as a consequence of the K - Mg antagonism. With the increase in K uptake from F_0 to

F_3 there was a corresponding decrease in magnesium content, with F_3 recording the least content.

Uptake of Mg was not significantly influenced by fertilizer treatments. Though the dry matter production increased with increasing levels of fertilizers, the per cent Mg content of leaf decreased due to K - Mg antagonism. Uptake being the product of these two, their combined effect remained nonsignificant.

Irrigation treatment though influenced the Mg content, it failed to influence the Mg uptake by bunch refuse. Irrigated palms of I_1 and I_2 levels recorded a significantly lower Mg content than the I_0 treatment. This again was due to K - Mg antagonism.

4.7.4.2 Nutrient content and uptake by mesocarp of fruit

The fruit of oil palm has three major components namely fruit mesocarp, shell and kernel which are discussed separately. The data on content (per cent) and uptake (g $palm^{-1}$ $year^{-1}$) of N, P, K, Ca and Mg by mesocarp are given in Table 24.

Table 24. Nutrient Content (per cent) and nutrient uptake (g $palm^{-1}$ $year^{-1}$) by mesocarp

Characters / Treatment	Nitrogen Content	Nitrogen Uptake	Phosphorus Content	Phosphorus Uptake	Potassium Content	Potassium Uptake	Calcium Content	Calcium Uptake	Magnesium Content	Magnesium Uptake
Fertilizer										
F_0	0.32	90.03	.03	8.90	0.23	64.98	0.05	14.90	0.08	21.18
F_1	0.03	136.01	.04	14.49	0.27	111.64	0.07	28.30	0.08	31.03
F_2	0.39	189.10	.04	17.55	0.30	144.75	0.07	33.90	0.08	37.16
F_3	0.48	207.33	.04	17.12	0.39	165.12	0.08	33.58	0.09	38.33
F test	S^{**}	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	NS	S^{**}
SEM	0.01	9.91	.002	0.99	0.021	12.88	0.004	2.48	.004	2.47
CD (.05)	0.04	29.08	..	2.90	0.08	37.80	0.01	7.29	..	7.24
Irrigation										
I_0	0.35	121.52	.04	12.16	0.28	97.09	0.05	18.08	0.08	27.92
I_1	0.39	157.03	.04	13.53	0.29	115.63	0.06	26.38	0.08	30.38
I_2	0.40	188.31	.04	17.84	0.32	152.14	0.08	38.54	0.08	37.48
F test	S^{*}	S^{**}	NS	S^{**}	NS	S^{**}	S^{**}	S^{**}	NS	S^{*}
SEM	0.013	8.58	.002	0.85	0.018	11.16	0.004	2.15	0.004	2.14
CD (.05)	0.04	25.19	..	2.51	..	32.73	0.01	6.31	..	6.27

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

4.7.4.2a Nitrogen

Fertilizer treatments were found to significantly influence both nitrogen content and nitrogen uptake by mesocarp.

Nitrogen content of mesocarp was found progressively increased at all levels of fertilizer application up to the F_3 level. F_2 and F_3 recorded significantly more N content than F_0 and F_1 levels. Progressive increase in nitrogen content of mesocarp with increase at all levels of fertilizer application confirmed that nitrogen uptake by mesocarp continued up to the highest level of application.

Nitrogen uptake by mesocarp also went on increasing with increase in levels of fertilizer application up to F_3 level but was not significant beyond F_2 level. The increase in uptake at F_2 level is due to the increase in both content and dry matter at F_2 level. Eventhough content was more at F_3, uptake was not commensurate with it probably because the dry matter production was not showing any increase.

Irrigation at I_2 level has also significantly increased the N content over I_0 level. Dry matter of mesocarp was found increased with higher levels of irrigation (Table 7). Significant superiority of I_2 level of irrigation in increasing soil moisture content at all depths of soil (Table 9) has also improved growth and development of fruits and consequent increase in nitrogen uptake by mesocarp at I_2 level.

4.7.4.2b Phosphorus

Though phosphorus content of mesocarp was not seen influenced by fertilizer treatments, phosphorus uptake was found influenced. Fertilizer at F_2 level has recorded significantly high uptake of P by mesocarp over all the other levels. This is due to more bunch and mesocarp dry matter production (Table 7) in F_2 treatment. Heavy bunch yield necessitated the palms to take up more phosphorus to meet the oil formation in mesocarp. Phosphorus is an essential component of phospholipids. Increased nitrogen uptake also necessitated more P uptake due to N-P synergism.

Irrigation though not influenced P content, was found to influence the P uptake. I_2 level of irrigation has significantly increased P uptake over I_1 and I_0 levels. Irrigation at I_2 level has produced more bunches and fruits and also increased the P availability especially in lower layers of soil (Table 14) which has resulted in increased P uptake by the mesocarp.

4.7.4.2c. Potassium

Effect of fertilizer treatments was seen to influence both K content and K uptake by mesocarp. Significant increase in K content was observed up to F_3 level of fertilizer application over its lower levels. Increased content at F_3 level indicated that the palms continued to absorb soil K up to the maximum level of supply. K uptake was also found increased up to F_3 level. Due to the high K content and bunch dry matter production, the K uptake was maximum at F_3 level eventhough not found significant beyond F_2 level.

Irrigation though did not influence the K content, has significantly increased K uptake by mesocarp at I_2 level over I_1 and I_0. The better soil moisture availability (Table 9) and significant increase in exchangeable potassium in top soil (Table 14) have increased the dry matter and K uptake by mesocarp at I_2 level.

4.7.4.2d Calcium

Effect of fertilizer treatments were found to increase both Ca content and Ca uptake by mesocarp. There was a continuous increase in Ca content and Ca uptake up to the highest dose of F_3. However there was no significant difference beyond F_1 level. Contrary to the trend observed for calcium in other palm parts, Ca in mesocarp has increased with increased fertilizer levels. This is due to the presence of calcium in larger quantities in the mesocarp. Hagstrom (1988) also reported that calcium is present in large quantities in the mesocarp in the form of calcium oxalate and calcium phosphate. Increased uptake of phosphorus also might have influenced the uptake of calcium.

Irrigation at I_2 level was significantly superior to I_1 which in turn was found superior to I_0 level. Irrigation at I_2 level has increased calcium uptake by increasing the moisture content of soil in the root zone (Table 9) and also the exchangeable Ca is in the top 0-25cm layer of the soil. (Table 16). Application of fertilizer especially rock phosphate into this layer with adequate supply of water at I_2 level has increased the Ca content and uptake by mesocarp.

4.7.4.2e Magnesium

Magnesium content though was not influenced, its uptake was significantly influenced by fertilizer treatments. F_3 level of fertilizer has significantly increased Mg uptake over F_0 and F_1 levels but remained on a par with F_2 level. As diffences of the Mg content remained not significant, the increased Mg uptake was due to increased dry matter production in these treatments. Increased uptake at F_2 and F_3 levels indicated that large quantity of Mg is removed through harvested produce at these levels.

Irrigation at I_2 level also has significantly increased Mg uptake by mesocarp over I_0 and I_1 levels eventhough the Mg content remained unaffected. Adequate supply of water at I_2 level might have ensured uptake of Mg from soil and its translocation to bunches. Magnesium is required for oil synthesis which is necessitated by the larger bunch production at I_2 level (Table 12). This has resulted in significantly higher uptake of Mg by mesocarp at I_2 level over I_1 and I_0.

4.7.4.3 Shell

Nutrient content (per cent) and uptake (g palm^{-1} year^{-1}) by shell are given in Table 25.

4.7.4.3a Nitrogen

Fertilizer treatment failed to influence the N content of shell whereas it significantly influenced N uptake by shell. Fertilizer treatments F_2 and F_3 which were on a par were significantly superior to F_0. This shows that for proper shell formation and development, fertilizer application at F_2 level is required.

Irrigation did not influence both N content and N uptake by shell.

4.7.4.3b Phosphorus

Neither the fertilizer nor irrigation has influenced either the P content or P uptake by shell.

Table 25. Nutrient content (per cent) and nutrient uptake (g $palm^{-1}$ $year^{-1}$) by shell

	Nitrogen		Phosphorous		Potassium		Calcium		Magnesium	
	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake
Fertilizer										
F_0	0.37	16.25	0.04	1.78	0.39	17.44	0.05	2.40	0.13	5.70
F_1	0.40	20.58	0.04	2.27	0.42	21.98	0.06	3.03	0.14	7.05
F_2	0.40	22.40	0.04	2.21	0.41	23.01	0.06	3.32	0.14	7.55
F_3	0.40	22.14	0.05	2.60	0.43	23.75	0.06	3.26	0.15	8.38
Ftest	NS	S^*	NS	NS	NS	NS	NS	NS	NS	NS
SEM	0.014	1.59	.005	0.29	0.02	1.73	0.003	0.25	0.013	0.88
CD (.05)	..	4.66	..	..	..	..	..	..	..	..
Irrigation										
I_0	0.40	19.67	0.04	1.90	0.36	19.11	0.06	2.93	0.14	7.19
I_1	0.39	20.28	0.05	2.34	0.45	23.07	0.06	2.98	0.14	7.24
I_2	0.40	21.28	0.05	2.40	0.43	22.46	0.06	3.09	0.14	7.08
Ftest	NS	NS	NS	NS	S^{**}	NS	NS	NS	NS	NS
SEM	.013	1.38	0.004	0.25	0.017	1.50	0.003	.22	0.012	.76
CD (.05)	..	..	..	..	.05	..	..	..	..	..

S^* – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

NS – Not significant

4.7.4.3c. Potassium content and potassium uptake by shell

Fertilizer treatments failed to influence both K content and K uptake by shell.

Irrigation treatment has influenced the K content nd not K uptake by shell.

Irrigated palms of both I_1 and I_2 recorded significantly higher K content over I_0 level. This is because of the increased uptake of K at I_2 level. The mportance of K nutrition for shell development is also thus evealed.

4.7.4.3d Calcium

None of the treatments influenced either Ca content or Ca uptake by shell.

4.7.4.3e Magnesium

Neither the Mg content nor Mg uptake was influenced by the treatments.

4.7.4.4 Kernel

Nutrient content (per cent) and uptake (g $palm^{-1}$ $year^{-1}$) of N, P, K Ca and Mg are given in Table 26.

4.7.4.4a Nitrogen

Fertilizer treatments did not affect N content but affected the N uptake by kernel significantly. F_2 level has recorded significantly higher uptake of N over F_0 and F_1 levels whereas it remained at par with F_3 level. The kernel dry matter production (Table 7) also followed the same pattern. Though the total uptake by palm was maximum at F_3 level (Table 28), uptake by kernel was maximum at F_2 level. This means that for proper fruit and kernel development F_2 level seemed to be sufficient. Nitrogen being a constituent of the protein in the kernel, its uptake is important

Irrigation has also increased N content but not N uptake by kernel. Though irrigation at I_2 level has recorded the maximum N content it remained on a par with I_1 and significantly superior to I_0 level. Increased moisture (Table 9) and nitrogen availability (Table 14) have increased the N content of kernel at I_2 level.

Table 26. Nutrient content (per cent) and nutrient uptake (g palm^{-1} year^{-1}) by kernel

Characters / Treatment	Nitrogen Content	Nitrogen Uptake	Phosphorus Content	Phosphorus Uptake	Potassium Content	Potassium Uptake	Calcium Content	Calcium Uptake	Magnesium Content	Magnesium Uptake
Fertilizer										
F_0	1.37	35.86	0.32	8.31	0.36	9.41	0.021	0.57	0.22	5.85
F_1	1.44	43.57	0.33	9.85	0.39	11.54	0.027	0.79	0.21	6.33
F_2	1.52	64.69	0.33	14.07	0.39	16.47	0.023	1.01	0.21	8.71
F_3	1.47	51.63	0.34	12.02	0.42	14.75	0.026	0.89	0.18	6.36
F test	NS	S**	NS	S**	NS	S**	NS	S**	S**	S**
SEM	0.037	4.68	0.008	0.902	0.015	1.18	0.002	0.098	0.008	0.64
CD (.05)	..	13.74	..	2.65	..	3.48	..	0.29	0.03	1.88
Irrigation										
I_0	1.38	41.95	0.33	9.93	0.37	11.45	0.021	0.63	0.19	5.92
I_1	1.48	51.20	0.34	11.44	0.40	13.53	0.027	0.92	0.20	6.75
I_2	1.50	53.65	0.33	11.82	0.39	14.15	0.025	0.89	0.22	7.77
F test	S*	NS	NS	NS	NS	NS	S*	S*	NS	NS
SEM	0.032	4.06	0.007	0.78	0.013	1.03	0.001	0.085	0.007	0.56
CD (.05)	0.09	..	..	..	..	..	0.004	0.25	0.02	..

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

NS – Not significant

4.7.4.4b Phosphorus

Fertilizer treatments were not found to influence the per cent content of P in kernel whereas it significantly increased the P uptake by palm at F_2 level over F_0 and F_1 levels and remained on par with F_3 level. Since the phosphorus content remained unchanged, the P uptake pattern followed exactly the same trend as that of kernel dry matter production. Here again a uniformity in the uptake of N and P indicated that synergism existed between the two nutrient elements.

Irrigation treatment did not show any significant influence on P content and P uptake by kernel.

4.7.4.4c Potassium

Eventhough there was an increase in K content of kernel up to the highest level of fertilizer application, it remained non significant. However K uptake by kernel was significantly influenced by fertilizer treatments. Fertilizer at F_2 level has significantly increased K uptake over F_0 and F_1 levels and remained on par with F_3. Increased total K uptake at F_3 level (Table 28) and a maximum K uptake by kernel at F_2 level indicate that for kernel production F_2 level was sufficient. Kernel dry matter production also was maximum at F_2 level. This means that at F_3 level majority of the uptake was not used by kernel of fruits whereas it was used for vegetative build up. Similar relationship in N, P and K uptake indicated that at F_2 level, adequate supply of major nutrients were ensured for development of economic parts of the palm.

Irrigation has not influenced K content and K uptake of kernel.

4.7.7.4d Calcium

Effect of fertilizer level was found to increase calcium uptake but not calcium content of kernel. F_2 level that recorded maximum calcium uptake was found significantly superior to F_0 level but remained on a par with F_1 and F_3 levels. Application of rock phosphate might have enhanced the calcium supply and therefore uptake by kernel.

Irrigation treatments influenced both calcium content and calcium uptake by kernel. Irrigated plots I_1 and

I_2 which recorded larger uptake of calcium than unirrigated plot remained at par with each other. Increase in exchangeable Ca of soil (Table 16) in irrigated plots might have resulted in increased calcium uptake.

4.7.4.4e Magnesium

Fertilizer treatments at higher levels were found to significantly reduce the magnesium content of kernel. The least Mg content was recorded in F_3 which though remained on par with F_2 and F_1 levels, was inferior to F_0 level. Applications of higher doses of K through KCl application in fertilizers might have reduced the Mg content. Contrary to the effect on Mg content, uptake of Mg by kernel increased significantly at F_2 level of fertilizer application due to more kernel dry matter production. Increased dry matter production of kernel at F_2 level could more than compensate the reduction in Mg content of kernel, thus keeping the Mg uptake by kernel at a significantly higher level with F_2 level of fertilizer application.

Effect of irrigation treatments failed to make any impact on K content and K uptake by kernel.

4.7.4.5 Nutrient uptake by whole bunches

The data on uptake of N P K Ca and Mg by the whole bunch (g $palm^{-1}$ $year^{-1}$) are given in Table 27.

4.7.4.5a Nitrogen

When the uptake of bunches was taken as a whole the effect of fertilizer and irrigation was found significant for nitrogen uptake. Fertilizer application at F_2 level has significantly increased the uptake of nitrogen by bunches over F_0 and F_1 levels and remained on a par with F_3 level. However there was a numerical increase at F_3 level over F_2 level. The superiority of F_2 level over lower levels F_0 and F_1 on bunch components such as bunch refuse (Table 23), mesocarp (Table 24), shell (Table 25), and kernel (Table 26) when combined showed a significant increase in nitrogen at F_2 level. This finding gives the importance of fertilizer application at F_2 level for maximum uptake by bunches. For proper growth and development of bunches especially the mesocarp, uptake of nitrogen at F_2 level of fertilizer application was found optimum. Nitrogen thus was important in the synthesis of food in the palm leaves as well as its

Table 27. Annual nutrient uptake (g palm^{-1} year^{-1}) by whole bunches

Characters / Treatment	N	P	K	Ca	Mg
Fertilizer					
F_0	199.2	26.24	256.41	30.59	58.37
F_1	282.02	36.84	347.43	49.16	73.89
F_2	360.14	44.80	410.61	56.28	80.71
F_3	379.51	44.03	444.68	56.30	80.40
F test	S**	S**	S**	S**	S**
SEM	16.28	1.65	20.92	3.12	3.38
CD (.05)	47.77	4.85	61.36	9.17	11.38
Irrigation					
I_0	263.62	33.58	325.63	38.21	70.91
I_1	308.88	37.63	359.98	46.73	70.79
I_2	343.17	42.72	408.76	59.31	78.33
F test	S**	S**	S**	S**	NS
SEM	14.11	1.43	18.11	2.71	3.36
CD (.05)	41.37	4.20	53.14	7.94	..

S** – Significant at P = 0.01 level

NS – Not significant

translocation to the fruits. If not supplied in adequate quantity it affected both the bunch formation and oil yield adversely. Nitrogen also being a constituent of protein, kernel formation also has increased the uptake of nitrogen. Effect of fertilizer treatment on bunch dry matter production (Table 7) also showed that F_2 level has produced significantly more bunch weight over F_0 and F_1 levels and was found on par with F_3 level. Thus for both bunch dry matter production and for its components adequate N uptake was ensured only at F_2 level of fertilizer application.

Irrigation at I_2 level has recorded the maximum N uptake eventhough it was not significant above the I_1 level. Irrigation has thus increased N uptake by bunches. Improved soil moisture content (Table 9) and increased soil nitrogen availability (Table 14) has resulted in increased uptake of N at I_2 level. Nitrogen being a mobile element, its absorption and translocation happened only when sufficient water was supplied. Irrigation also has increased the number of bunches produced and the average bunch weight (Table 12) at I_2 level. This has resulted in significantly larger removal of nitrogen by harvested bunches in I_1 and I_2 treatments compared to the unirrigated control plot of I_0. Absence of adequate water supply to the palms resulted in the poor nitrogen uptake of bunches at I_0 level. Ollagnier (1985) reported that efficiency of fertilizers was reduced by lack of moisture availability.

4.7.4.5b Phosphorus

Both fertilizer and irrigation treatments were found to significantly influence the uptake of phosphorus by bunches. Maximum phosphorus uptake was recorded in F_2 treatment which was significantly higher than F_0 and F_1 treatments. F_3 level remained on a par with F_2 level. Effect of treatments remained the same for the nitrogen uptake also. So there might exist a strong N-P synergistic relationship for which adequate P supply was also ensured at F_2 level of fertilizer application. P availability in the soil was found significantly increased at F_2 level of fertilizer application in top 0-25 cm layer of soil (Table 14). Bunch dry matter production was also significantly higher at F_2 level over F_0 and F_1 levels and was at par with F_3 level (Table 7) . When sufficient P was ensured at adequate level of N, photosynthesis also might have improved. Significant increase in uptake of P at F_2 level by bunch refuse (Table 23), mesocarp (Table 24), and kernel (Table 26) have all thus contributed to the significant uptake by bunches at F_2 level. Phosphorus being a constituent of phospholipids, its uptake in large quantity at F_2 level, palms at which level produced the maximum bunches, is expected.

Irrigation treatments also showed significant improvement in phosphorus uptake at all levels tested. I_2 level has recorded significantly higher P uptake over I_1 level which in turn was superior to I_0 level. Irrigation at I_2 level has increased both soil moisture content in the root zone (Table 9) and soil phosphorus availability at all depths and significantly at 25-50 and 50-75 cm depth (Table 14). Thus increased availability of phosphorus in the soil along with adequate nitrogen supply which improved photosynthetic activity has produced more photosynthates for bunch production. This has resulted in significantly increased uptake of phosphorus by bunches at I_2 level of irrigation.

4.7.4.5c Potassium

Fertilizer treatments had significantly influenced the K uptake by bunches. F_2 level of fertilizer application has recorded significantly higher uptake of potassium by bunches over F_0 and F_1 levels. Even though F_3 has recorded the highest uptake, it remained on a par with F_2 level. As for nitrogen and phosphorus, potassium also recorded significantly higher uptake over F_0 and F_1 levels. This again indicates that an optimum N P K balancing was required at which uptake as well as yield were also maximum as obtained with F_2 level. Increased uptake of K by bunches at F_3 level though not significant over F_2 indicated that potassium was taken up in larger quantity than it's requirement and was removed through harvested bunches. K nutrition was important for production of fruits, kernel an bunch refuse. Significant uptake of K by bunch refuse was observed at F_3 level over the lowest levels and remained on a par with F_2 level. Thus the increased uptake of K by bunches at F_3 level was mostly utilised for the production of bunch refuse (Table 9) Exchangeable K was also high at F_2 and F_3 levels in 0-25 cm layer of the soil which also has contributed to the increased uptake of K by bunches at F_2 level.

Irrigation at I_2 level has recorded significantly larger uptake of K by bunches over I_0 level. I_1 level was found insufficient to effect any significant improvement in K uptake over I_0 level. Importance of K nutrition for transpiration and photosynthesis is well known. Water supply at I_2 level might have kept stomata open and continued the processes of transpiration and synthesis of food at optimum rate. Adequate supply of water had thus ensured proper development of bunches and uptake of potassium at I_2 level of irrigation.

4.7.4.5d Calcium

Both fertilizer and irrigation treatments were found to influence calcium uptake by bunches.

Eventhough there was a continuous increase in uptake of calcium up to F_3 level of fertilizer application, it remained non significant beyond F_1 level.

Irrigation at I_2 level has significantly improved calcium uptake by bunches over I_1 level which in turn also has increased significantly over I_0 level. Soil exchangeable Ca was significantly more at I_2 level over I_1 level in top 0-25 cm layer of the soil (Table 16). This increased supply of calcium and adequate moisture availability at I_2

level has increased the bunch dry matter production in irrigated plots which has resulted in higher calcium uptake.

4.7.4.5e Magnesium

Magnesium uptake by bunches was found to vary significantly with fertilizer treatment. Maximum uptake was recorded at F_2 level of fertilizer application eventhough it was not significant over F_1 level. Contrary to the reduction in Mg content observed in leaves (Table 19) with higher levels of application of fertilizer, removal through bunches was found more in fertilized plots especially in the F_2 treatment. This was due to higher bunch dry matter production at F_2 level (Table 7). Magnesium is reported to be easily absorbed by palms planted in laterite soils by Ollagnier and Olivin (1984). This increased uptake at F_2 level has illustrated that for high bunch production magnesium requirement was very high. This was also manifested in Mg uptake by mesocarp (Table 24) and kernel (Table 26). Magnesium is required for fatty acid synthesis and hence it was taken up in large quantity at F_2 level to meet the requirement of heavy bunch production (Table 12) recorded in this treatment. This again showed the importance of magnesium nutrition for bunch production.

4.7.5 Total uptake of nutrients by oil palm

The data on total uptake of N, P, K, Ca and Mg by oil palm (g $palm^{-1}$ $year^{-1}$) as influenced by fertilizer and irrigation treatments are presented in Table 28.

4.7.5a Total nitrogen uptake

Details on total nitrogen uptake is depicted in Fig. 12.

Fertilizer application at F_2 level has significantly increased the total nitrogen uptake over F_0 and F_1 levels. Eventhough F_3 level recorded the highest nitrogen uptake it was found to be on par with F_2 level.

Progressive increase in uptake of nitrogen by palms and the significant superiority of F_2 over lower levels and the nonsignificance beyond F_2 level indicated that application of fertilizer at F_2 level could meet the nitrogen requirement of oil palm. Uptake by the major components namely bunches (Table 27), trunk (Table 17) and leaves (Table 21) showed a similar increasing trend up to F_3 level and

Table 28. Total nutrient uptake (g $palm^{-1}$ $year^{-1}$) by palm

Characters Treatment	N	P	K	Ca	Mg
Fertilizer					
F_0	815.52	81.34	595.40	495.57	411.17
F_1	1092.24	105.54	1023.32	713.18	424.13
F_2	1335.32	121.19	1387.13	693.11	383.45
F_3	1419.60	122.32	1575.88	705.42	346.32
F test	S^{**}	S^{**}	S^{**}	S^{**}	S^{*}
SEM	36.33	3.80	60.34	38.17	18.74
CD (.05)	106.59	11.15	176.98	111.96	55.00
Irrigation					
I_0	1052.64	96.86	981.31	587.67	371.57
I_1	1164.02	109.36	1148.66	657.00	391.65
I_2	1280.14	116.57	1306.32	710.79	410.58
F test	S^{**}	S^{**}	S^{**}	S^{*}	NS
SEM	31.46	3.29	52.25	33.05	16.24
CD (.05)	92.30	9.65	153.25	96.97	

S^{*} – Significant at P = 0.05 level

S^{**} – Significant at P = 0.01 level

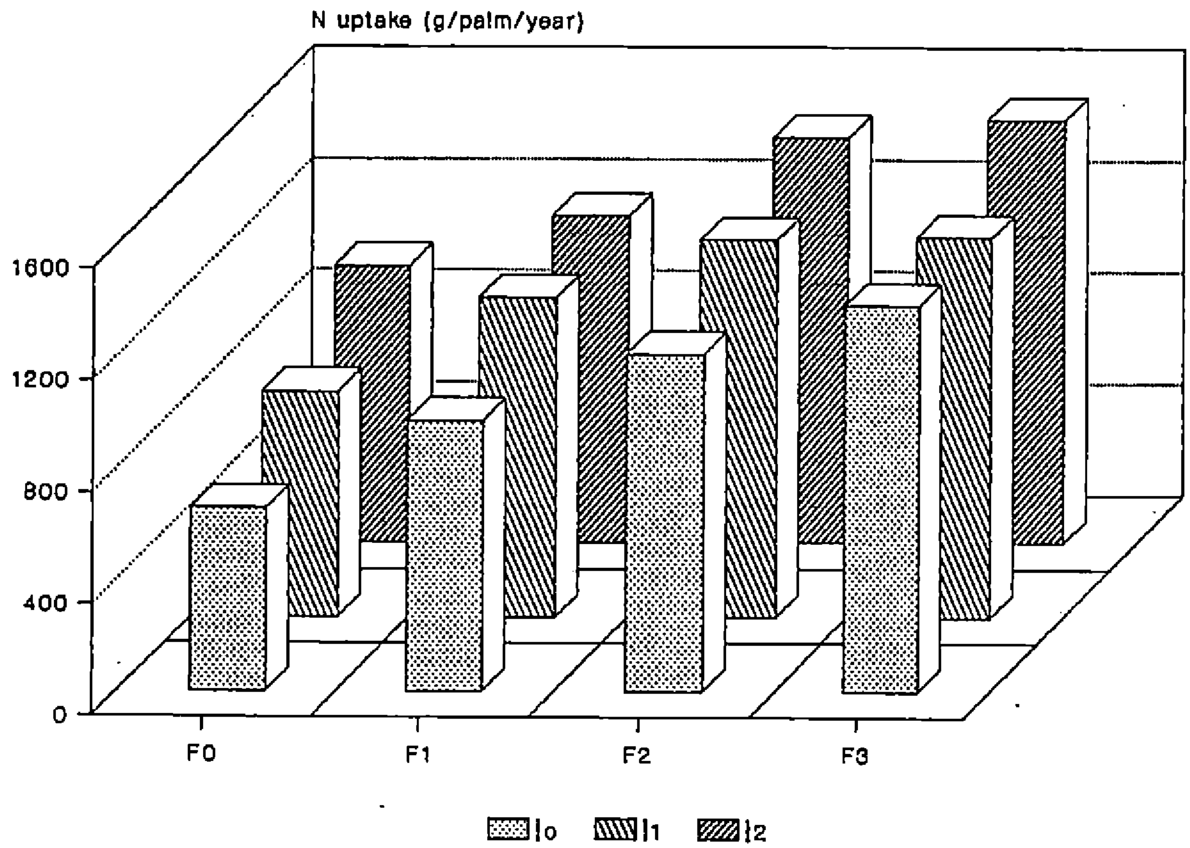
NS – Not significant

failed to show significant difference beyond F_2 level. Combined effect of all these components had contributed to the significant uptake by palm at F_2 level over lower levels.

Increased vigour of the palm as evidenced through larger leaf production and number of leaves on the crown (Table 2) were also significantly more at F_2 level than F_0 and F_1 levels. F_2 remained on par with F_3 level. Bunch dry matter production and total dry matter production (Table 7) were significantly more at F_2 level than F_0 and F_1 and remained at par with F_3 level. Thus the increased growth and dry matter production of palm at F_2 level has significantly increased nitrogen uptake at F_2 level over F_1 and F_0 levels.

Irrigation treatments were found to differ significantly on their effect on nitrogen uptake by the palm. I_2 level of irrigation has significantly increased nitrogen uptake by the palm over I_1 and I_0 levels. Foster (1989) reported increased uptake of nitrogen when availability of moisture increased. Water stress has limited the uptake of nutrients (Corley et al. 1976). Soil moisture at depths of 0-25, 25-50, 50-75 and 75-100 cm were found significantly more at I_2 level of irrigation (Table 9). A significantly

Fig. 12. Effect of fertilizer and irrigation on total N uptake (g palm^{-1} year^{-1})



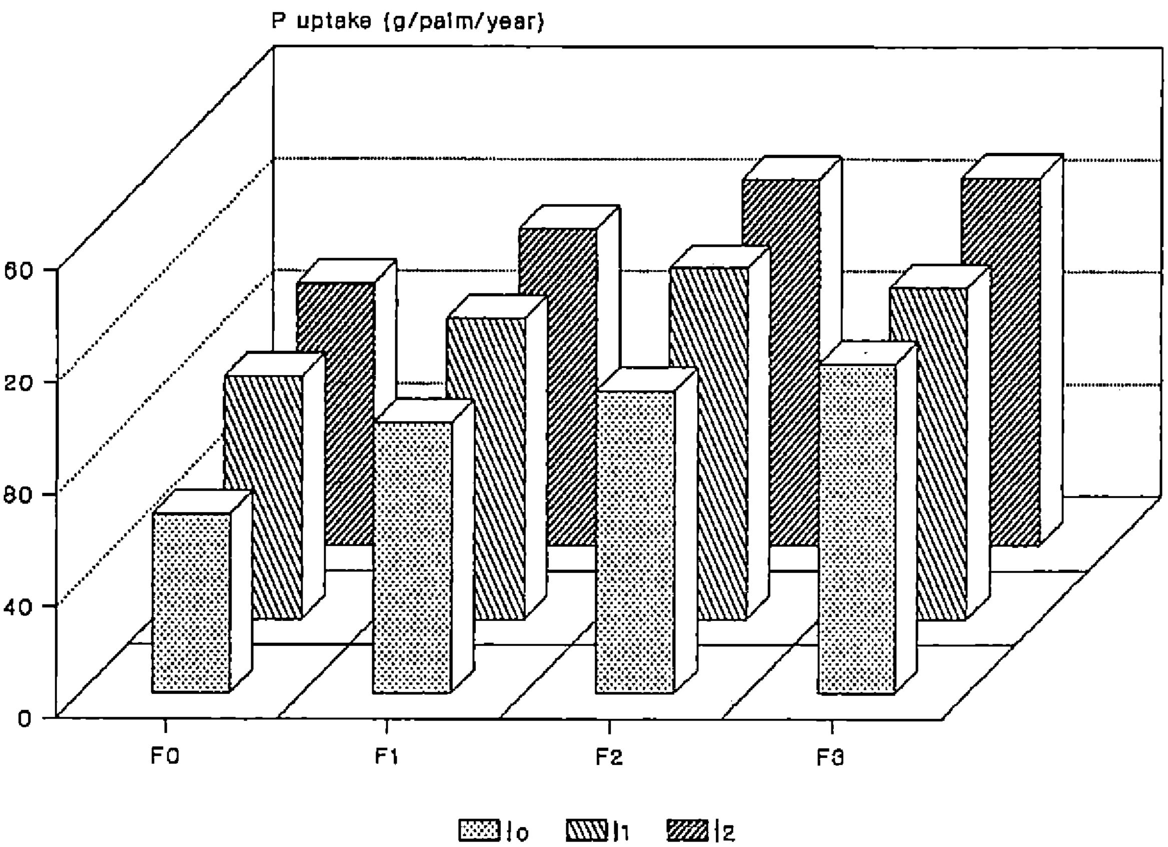
low stomatal resistance at I_2 level (Table 8) indicated continued photosynthetic activity and transpiration in these palms which also lead to more uptake of nitrogen for food synthesis. This has resulted in significantly higher vegetative dry matter production and bunch dry matter production in I_2 over I_0 (Tables 5 and 7). These merits of I_2 over lower levels has resulted in significantly higher uptake of nitrogen in I_2 over I_1 and I_0 levels.

4.7.5b Total phosphorus uptake

Fig. 13 gives details on total P uptake in different treatments.

Fertilizer treatments showed significant increase in P uptake upto F_2 level of fertilizer application. F_3 was on par with F_2. Influence of fertilizer treatments on P uptake followed the same trend as that of nitrogen uptake indicating the physiological synergism between N and P uptake. It has been reported that P uptake is correlated with N uptake in oil palm (Ollagnier and Ochs, 1981). Phosphorus is known for its role in controlling protein synthesis, flower production and absorption of other elements. Synergism

Fig. 13. Effect of fertilizer and irrigation on total P uptake (g palm^{-1} year^{-1})



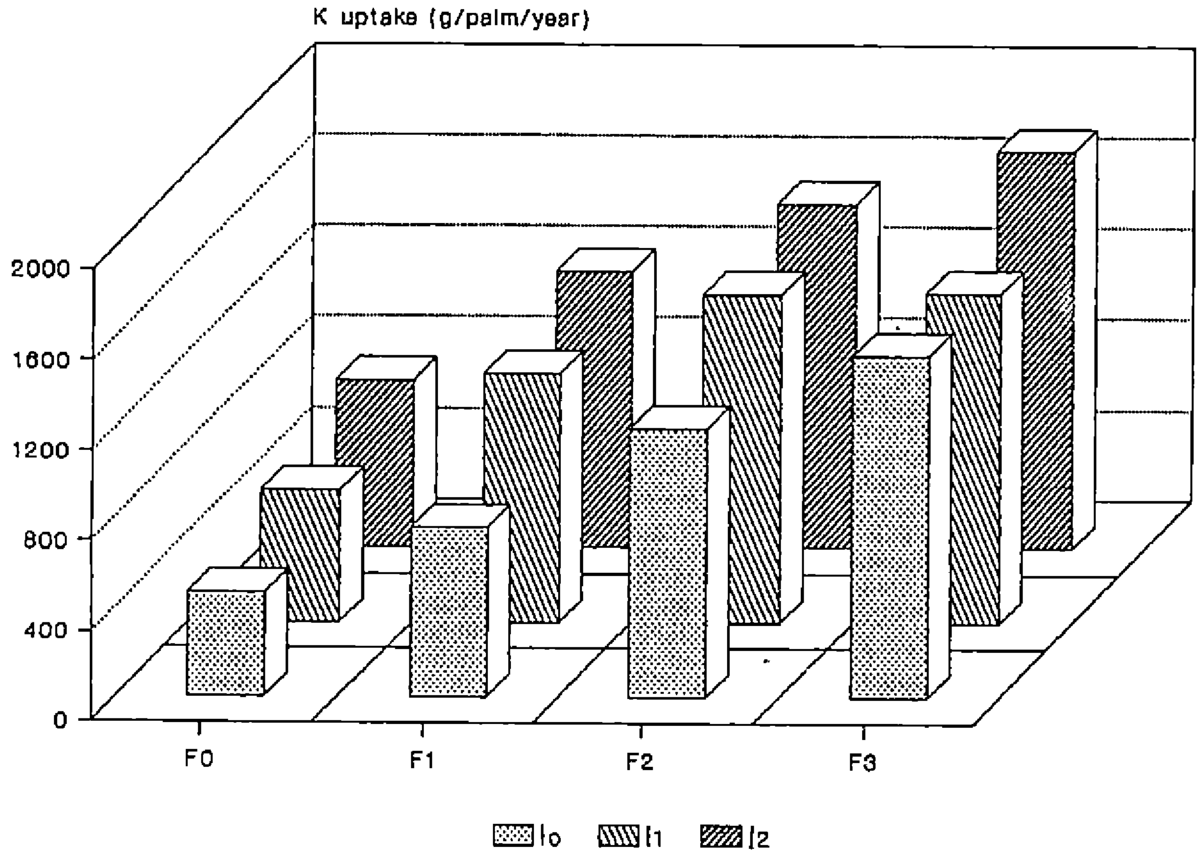
between nitrogen and phosphorus uptake has been reported by Ummar _et al_. (1977) and Ochs, (1985). Tampubolon _et al_. (1990) also observed nitrogen deficiency in palms due to insufficient phosphorus application. Significantly more available phosphorus status of soil at 0-25cm depth (Table 14) also might have contributed to the higher uptake. Increase in vegetative characters as leaf production, leaf area and leaf dry matter have resulted in better bunch dry matter production, which together contributed to the significantly high phosphorus uptake at F_2 level. Phosphorus being important for fatty acid synthesis, F_2 level which recorded maximum bunch production gave maximum uptake of phosphorus.

I_2 level of irrigation recorded maximum P uptake which was significantly superior to I_0 eventhough it remained on par with I_1 level. Irrigated plots at both I_1 and I_2 levels of irrigation significantly increased moisture content as well as P availability of soil at all depths, (Table 9 and Table 14). This condition promoted the photosynthetic activity of these irrigated palms as indicated by a low stomatal resistance (Table 8). Involvement of phosphorus in photosynthetic mechanism is well known. Immobility of phosphorus and the better root growth of palms under irrigated condition helped the palms in more uptake of phosphorus. This has resulted in more synthesis of food, improved growth and vigour of palm and increased bunch production which resulted in higher P uptake in I_2 level of irrigation.

4.7.5c Total potassium uptake

Total potassium uptake as influenced by various treatments is presented in Fig. 14. The fertilizer treatments were found to significantly influence potassium uptake by the palm. Application of fertilizer up to the highest level of F_3 continued to increase K uptake and all tested levels varied significantly between each other. Increased uptake of potassium was due to the role of K in carbohydrate metabolism, aminoacid and protein synthesis and also in stomatal opening. Stomatal resistance increased when K was deficient. Because of these improved metabolic activities, vegetative and yield characters were better in F_2 and F_3 treatments. A significant increase at the highest level of F_3 indicated the very high demand of K to meet the requirement of enhanced dry matter production. Since bunch

Fig. 14. Effect of fertilizer and irrigation on total K uptake (g $palm^{-1}$ $year^{-1}$)



production was found maximum at F_2 level, the increased uptake at F_3 level might have resulted in a luxury consumption which in turn was utilized for the build up of uneconomic parts reducing the efficiency of applied potassium. Exchangeable K at different depths 0-25, 25-50 and 50-75 cm were also seen higher at F_2 and F_3 levels compared to F_0 and F_1 levels (Table 14). Both soil conditions and plant environment which were more favourable at higher levels of fertilizer application increased vegetative and bunch dry matter production resulting in increased uptake of K at F_3 level of fertilizer supply. Overall K uptake was found significantly increased due to KCl fertilizer application by Wilkie and Foster (1989). Mutert (1993) reported that potassium together with nitrogen improved uptake of these nutrients and the vegetative growth, dry matter yield and oil yield.

Irrigation was found to significantly influence the total K uptake. I_2 level of irrigation has significantly enhanced the potassium uptake than the lower levels of I_0 and I_1. Ruer (1966) reported that potassium uptake is limited by inadequate moisture. Corley (1976b) reported that water deficit limited the assimilation of potassium. Under such conditions potassium will not even reach the critical level inspite of heavy K application. Better moisture condition in I_2 level (Table 9) ensured better availability of water to the palms as evidenced by more carbohydrate synthesis and therefore better growth and yield of palm at I_2 level. Quencez and Taffin (1981) reported K deficiency due to low water availability. Improvement in K nutrition and K uptake due to irrigation has also been reported on oil palm by many workers as Taffin and Daniel (1976), Ollagnier et al. (1987) and Foster (1989).

4.7.5d Total uptake of calcium

Total uptake of calcium in different treatments are given in Table 28.

Fertilizer treatment was found to significantly influence calcium uptake by oil palm. The fertilized treatments F_1, F_2 and F_3 remained on a par and were significantly superior to the unfertilized F_0 plot. Application of potassium chloride in the fertilizer treatments has resulted in the absorption of chlorine which is also an essential element of oil palm. Because of Ca-Cl synergism, more calcium also got absorbed by the plant along with the uptake of chlorine. Larger Ca uptake with KCl application has been reported by Turner and Gillbanks (1988). Application of muriate of potash raised the Cl levels, which is ascribed to an active uptake of chlorine accompanied by an uptake of cations other than K as calcium, as was reported by Taffin and Quencez (1980). Such a reasoning may explain for the significantly low Ca uptake recorded in F_0 treatment plots compared to the F_1, F_2 and F_3 treatments.

Irrigation was also seen to have significantly increased the Ca uptake at I_2 level over I_0 level. The I_1 level though recorded higher uptake over I_0 level, was not significant as this level might have been insufficient to effect any change over I_0. Increase in exchangeable calcium at 0-25 cm layer of soil (Table 16) also followed the same trend. So also due to the increased uptake of chlorine from KCl as explained for fertilizer treatments, larger availability of calcium in irrigated plots might have encouraged its uptake.

4.7.5e Total uptake of magnesium

Total magnesium uptake of oil palm is given in Table 28. Uptake of magnesium was found reduced with increasing levels of fertilizer application. Fertilizer at F_3 level has recorded significantly lower uptake than F_1 and F_0 levels and was on a par with F_2 level. This reduction in Mg uptake at higher levels of fertilizers was due to the K-Mg antagonism. As the K uptake has significantly increased in F_2 and F_3 treatments, there was a corresponding decrease in Mg uptake in these treatments. Singh (1989) reported that increase in N, P and K levels depressed the Mg levels in oil palm. Continuous application of higher levels of fertilizers over the years has also resulted in the removal of a large quantity of magnesium through bunch production due to the role of Mg in fatty acid synthesis. Magnesium also being a component of chlorophyll molecule, it might have been utilized for the high rate of photosynthesis in these treatments. Thus exhaustion of magnesium in fertilized plots over the years also might have reduced its uptake in these plots. Tinker and Smilde (1963) reported that palms which received heavy doses of potassium has recorded Mg deficiency symptoms on oil palm. They reported that K and Mg exerted an antagonistic relationship at soil exchange sites thus reducing uptake of Mg by palms. Hagstrom (1988) reported that Mg deficiency was noticed especially in coarse textured soils in humid climates and was affected by the level of other cations in the soil. Potassium has a strong antagonistic effect on absorption of magnesium. So the negative response of leaf Mg to fertilizer treatments at F_2 level was due to K - Mg antagonism which is in agreement with the findings was Foo and Omar (1987).

4.7.6a Uptake of nutrients by palm parts

Uptake of nutrients by palm parts as percentage of its total uptake in the best fertilizer treatments of F_2 and irrigation treatment of I_2 is depicted in Fig. 15 and 16 respectively.

It was observed that the uptake through leaves was maximum for all nutrients followed by bunches. This trend remained the same in both F_2 and I_2 treatments.

Of the total N uptake 18% was found immobilised in the trunk, 4% recycled through male flowers, 52% removed

Fig. 15. Nutrient uptake (per cent) by palm parts at F_2 level of fertilizer application

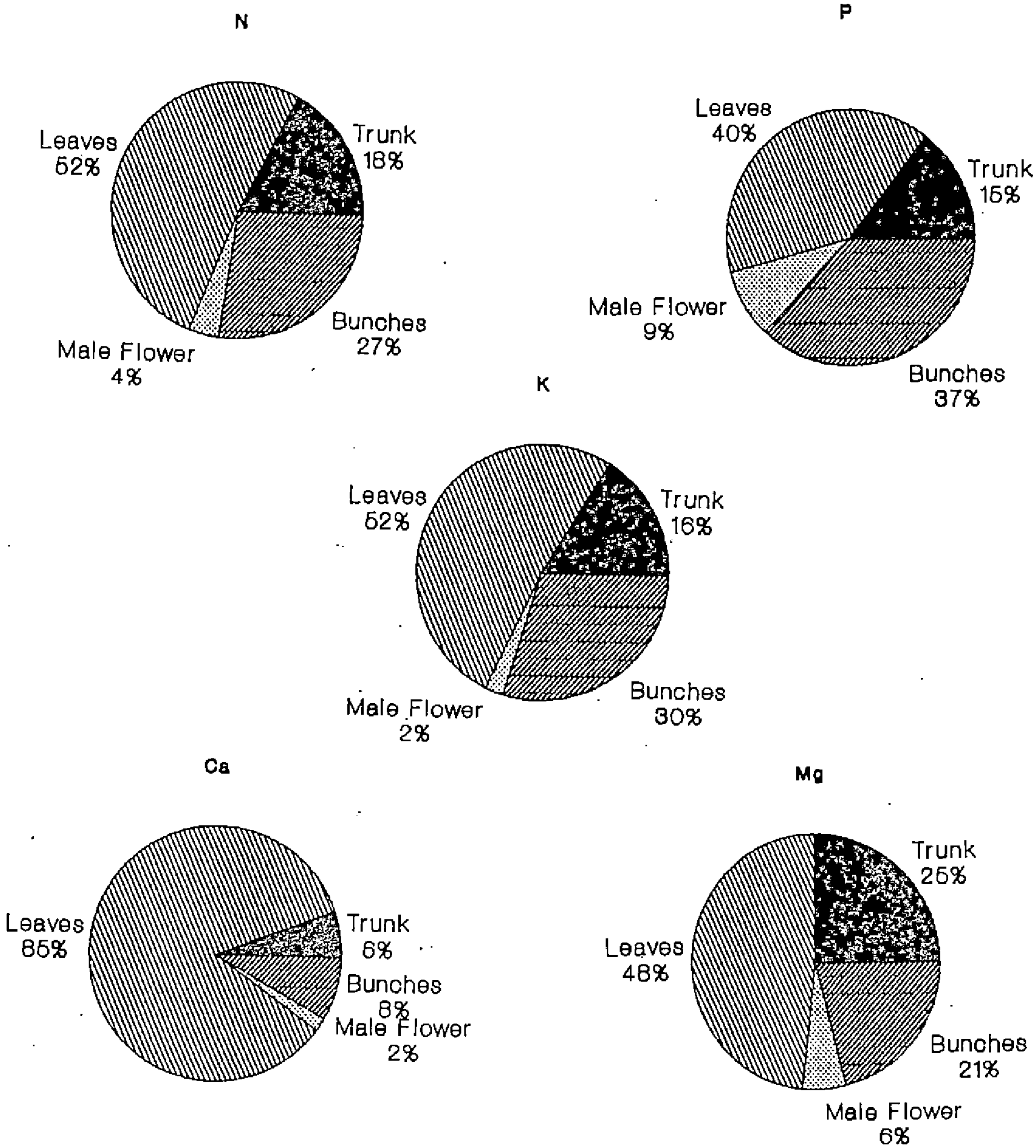
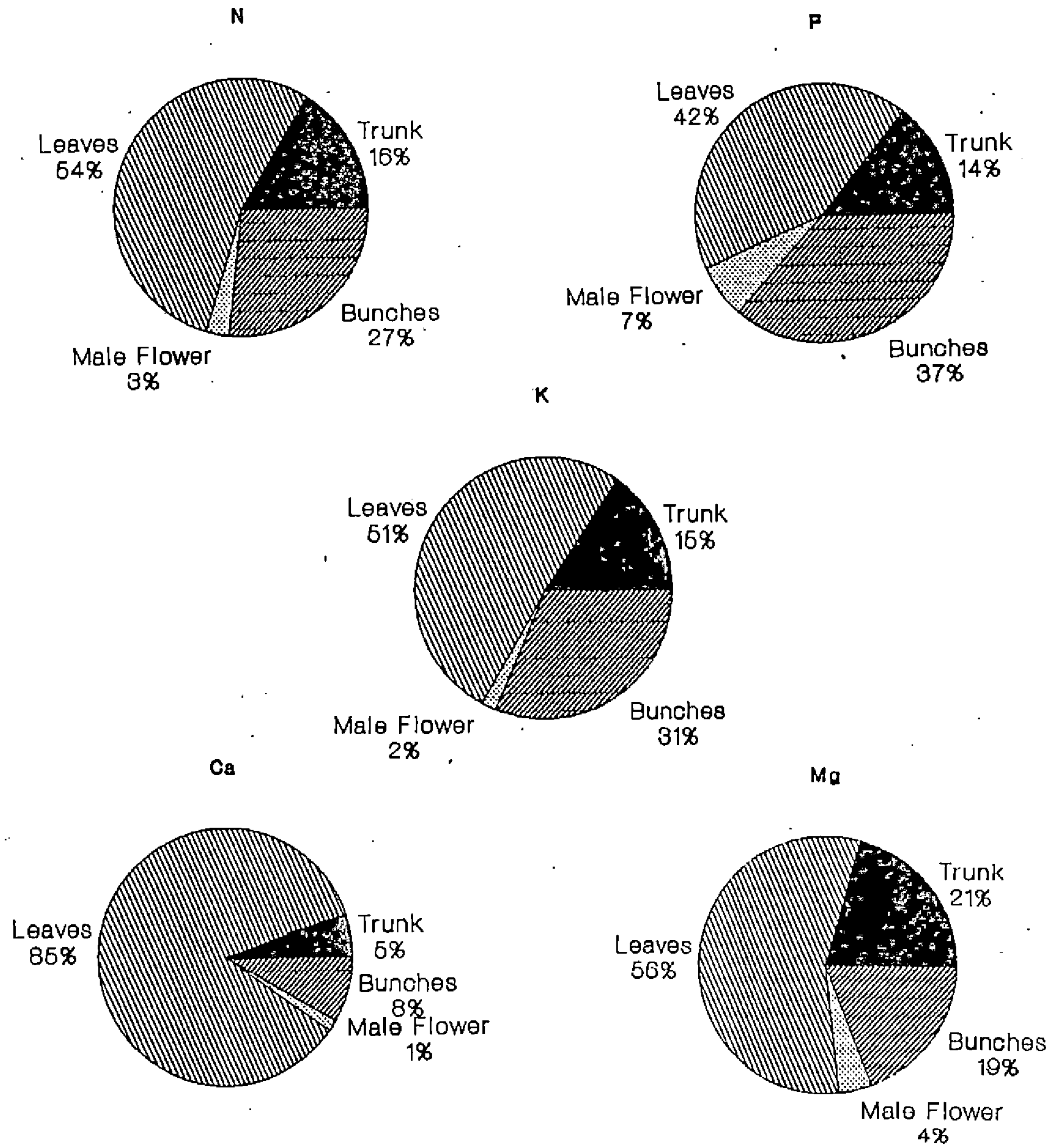


Fig. 16. Nutrient uptake (per cent) by palm parts at I_2 level of irrigation



through leaves and 27% removed through bunches. Thus a total of 79% is removed from the system every year through leaves and bunches.

With regard to phosphorus, a good share of 37% went to bunches, 40% to leaves and thus a total of 77% was removed from the system. Trunk immobilised 16% and 9% was recycled through male flowers.

In the case of potassium 30% of uptake was utilized in bunches, 54% by leaves, 2% by male flowers and 10% by trunk.

For calcium, a major share of 85% was removed through leaves, 8% through bunches, 6% by trunk and 2% by male inflorescences.

With regard to magnesium 25% was immobilised in the trunk, 21% removed through bunches, 48% through leaves and 6% was recycled through male flowers. The comparatively larger proportion of Mg stored in the trunk might be for its utilization during peak production period. This general pattern did not vary in the irrigated I_2 treatment also.

Thus a good proportion (70-80%) of N, P, K, Ca and Mg uptake was removed from the system annually through leaves and bunches. This offers the scope to recycle leaves and bunch refuse to the system which also can serve as organic source of nutrients in oil palm plantations. Bunch refuse contain 1% N 0.13% P and 2.6% K. It was also observed that comparatively larger proportion of P and K was removed in bunches and recycling of bunch refuse can compensate the removal to a certain extent.

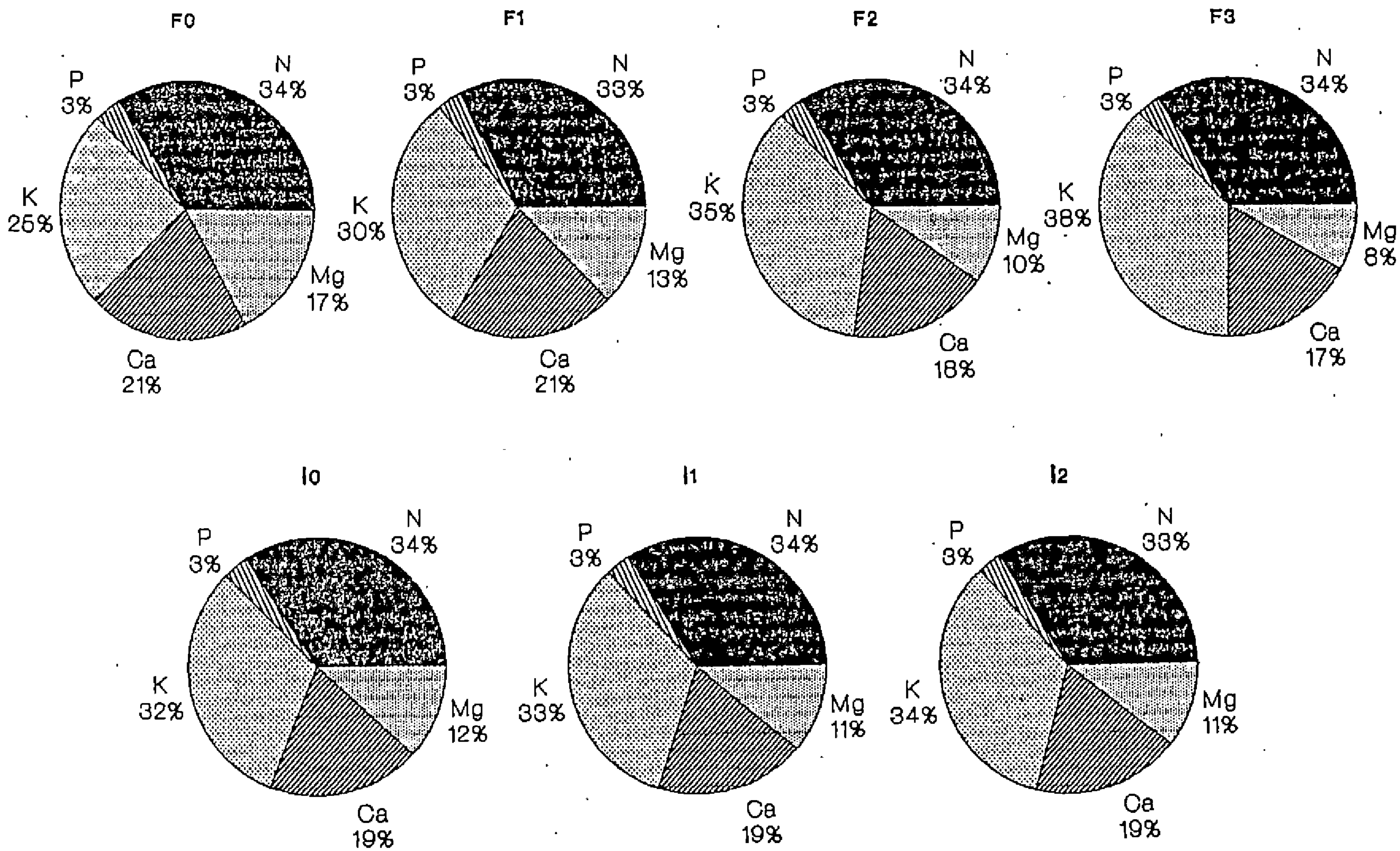
4.7.6b Uptake of individual nutrients as percentage of total N P K Ca and Mg uptake

Uptake of individual nutrients (per cent) in different treatments are furnished in Fig. 17.

Of the total uptake of N, P, K, Ca and Mg, uptake of nitrogen was 33 to 34%, P remained uniformly at 3%, K varied from 25 - 38%, Ca 17-21% and Mg 8-17%. Thus the proportionate percentage of N and P uptake remained almost uniform in all the fertilizer treatments.

The main observation made was that by increasing fertilizer levels from F_0 to F_3, the percentage K uptake to

Fig. 17. Uptake of individual nutrients as percentage of total uptake of N, P, K, Ca and Mg in different fertilizer and irrigation treatments



the total nutrient uptake went on increasing proportionately constituting 25%, 30%, 35% and 38% in F_0, F_1, F_2 and F_3 treatments respectively. So with higher doses of fertilizer application, a comparatively larger proportion of K uptake was observed. This might be due to the larger demand of potassium for bunch production and total dry matter production.

In the case of magnesium, there was a proportianate decrease in uptake recording 17% in F_0, 13% in F_1, 10% in F_2 and 8% in F_3 treatments. The K-Mg antagonism has thus become evident. The heavy demand of Mg by bunches (21%) in F_2 treatment (Fig. 15) and a comparatively lower proportion of supply of Mg (10%) at F_2 level (Fig. 17) compared to F_0 level (17%) indicate the need for magnesium nutrition at higher levels of NPK fertilizer application to oil palm.

In the case of calcium uptake there was a reduction as fertilizer doses increased from F_0 to F_3 as observed for Mg uptake. Thus K-Ca antagonism was also observed.

Irrigation treatments remained uniform with regard to uptake of nutrients but for the slight improvement noticed in K uptake at I_2 level of irrigation.

4.8 Correlation studies

Correlation studies were conducted to explain the relationship between the important characters associated with growth, yield and nutrition of oil palm. All correlations have been worked out. However only the relevant and important correlations are presented and discussed.

Many of the growth characters and the yield attributes were found to be positively correlated with yield. As such any improvement in these attributes due to better nutrition or irrigation as indicated by the leaf nutrient status and total nutrient uptake by palm are bound to influence the yield of the crop. Since fertilizers are applied to the soil, the relationship between soil nutrient and leaf nutrient status and the uptake of nutrients are also important aspects for correlation studies.

4.8.1. Correlation between growth parameters and FFB yield

The correlation coefficient values (r) between growth or yield parameters and yield are given in Table 29. Among the various growth parameters affecting yield of oil

Table 29. Correlation coefficient (r) between growth parameters and FFB yield

Character		Correlation coefficient (r)
Annual leaf poduction	=	0.6192**
Length of petiole	=	0.0030
Length of rachis	=	0.4417**
Number of leaflets	=	0.4586**
Length of leaflets	=	0.4342**
Width of leaflets	=	0.4247**
Petiole cross section area	=	0.2937
Dry weight of leaf	=	0.3081
Leaf area per palm / LAI	=	0.6949**
Annual trunk height increment	=	0.4966**
Vegetative dry matter production	=	0.6266**
Total dry matter production	=	0.8496**
Bunch length	=	0.0843
Bunch width	=	0.1411
Bunch depth	=	0.2277
Single fruit weight	=	0.4100**
Fruit length	=	0.4238**
Fruit breadth	=	0.1738
Net assimilation rate	=	0.3943*
Relative water content of leaf	=	0.1650
Stomatal resistence	=	-0.2351
Net photosynthesis	=	0.3558**
Number of bunches produced	=	0.8390**
Average bunch weight	=	0.7280**

* Significant at P = 0.05 level

** Significant at P = 0.01 level

palm, the characters found to be significantly and positively correlated with FFB yield from this study are annual leaf production, length of rachis, number of leaflets per leaf, length and width of leaflets, leaf area, annual trunk increment, net assimilation rate, net photosynthesis, vegetative dry matter production and the total dry matter production of the palm. Positive correlation between leaf area and bunch yield was reported by Hardon et al. (1969). It may be remembered that the yield as well as the above growth characters were positively influenced by application of fertilizer and irrigation treatments. So the increase in yield might have been the result of the enhanced growth of the tree. Annual leaf production is found positively and significantly correlated with female flower production (r = 0.526**). So the maximum leaf production obtained due to increased levels of fertilizer and irrigation have manifested in enhanced female inflorescence production and therefore on FFB yield. Among fruit characters the fruit length and individual fruit weight were seen to have positive relationship with FFB yield. The FFB yield is also found highly correlated positively with the number of bunches produced by the palm (r = 0.839**). This needs no further explanation since the FFB yield is very much dependent on the number of bunches produced. Squire (1986) and Mathew et al. (1993) also reported that the number of bunches and FFB yields were strongly correlated positively.

The growth characters found positively and significantly correlated with the most important yield attribute namely the number of bunches produced were annual leaf production (r = 0.495*), vegetative dry matter production (r =0.377*) and total dry matter production (0.612**). Leaf production is important for increased food synthesis which resulted in more female inflorescence production and more bunches. Better vegetative and total dry matter production indicates the health and vigour which also might have resulted in the increased bunch production of oil palm.

The average bunch weight was found positively and significantly correlated with FFB yield (r = 0.728**). It was observed that there was a progressive increase in average bunch weight due to fertilizer application (Table 12). Correlation studies revealed that the average bunch weight contributes in a significant way to FFB yield. Here again the influence of fertilizer on FFB yield is brought out.

Among other growth character relationships studied, the stomatal resistance was found significantly and negatively correlated with net photosynthesis (r = -0.6706**). Lack of adequate moisture that increased stomatal resistance might have thus reduced net photosynthesis and yield of palms in unirrigated treatments.

4.8.2a Correlation between leaf nutrient levels and growth characters

The relationship of leaf nutrient status of NPK Ca and Mg with other growth characters of the palm as revealed through correlation studies are given in Table 30.

It is seen that the leaf nitrogen content and the growth characters viz., leaf dry matter, vegetative dry matter, total dry matter, crop growth rate and FFB yield were significantly and positively correlated.

Significant and positive correlation between Leaf phosphorus content and growth characters such as leaf dry matter, total dry matter production and net assimilation rate was recorded.

Table 30. Correlation coefficient (r) between leaf nutrient content and growth or yield characters

Growth characters	Leaf nutrient content N	P	K	Ca	Mg
Leaf dry matter production	0.3587*	0.4741**	0.4748**	-0.3157	0.5419**
Vegetative Dry matter production	0.3882*	0.4674**	0.5464**	-0.3400*	-0.5464**
Bunch dry matter production	0.4969**	0.2848	0.5871**	-0.1626	-0.4420**
Total dry matter production	0.4742**	0.4375**	0.6196**	-0.2993	-0.5579**
Bunch index	0.1956	-0.1679	0.1438	0.1846	0.0601
Female inflorescence production	0.1440	-0.0097	0.3543*	-0.0751	-0.2282
F/B ratio	0.1083	0.0259	0.4214*	-0.1760	-0.1385
LAI	0.3612*	0.0999	0.4202*	-0.0618	-0.3332*
NAR	0.2414	0.4433**	0.3457*	-0.2581	-0.3980*
Number of bunches	0.2951	0.0910	0.4142*	-0.1342	-0.2063
Average bunch weight	0.5226**	0.3695*	0.4886**	-0.0771	-0.4982**
FFB	0.4970**	0.2848	0.5871**	-0.1627	-0.4419**
Mesocarp oil (%)	-0.7643**	-0.2506	-0.6089**	0.2883	0.4184*
Kernel oil(%)	-0.3735*	0.0100	0.2543	0.0825	0.1491

* Significant at P = 0.05 level   ** Significant at P = 0.01 level

More growth characters were correlated with leaf K in a positive manner. The growth characters were the leaf area index, leaf dry weight, vegetative dry matter, bunch dry matter, total dry matter, crop growth rate and net assimilation rate.

Calcium in leaf and the vegetative dry matter production was seen negatively correlated. Magnesium content also recorded negative correlation with leaf dry matter, vegetative dry matter, total dry matter production and crop growth rate. Higher growth rate and heavy demand by bunches might have exhausted and reduced the availability of magnesium resulting in such negative relationship.

4.8.2b Correlation between leaf nutrient levels and yield characters

Table 30 gives correlation coefficient values of the relationship between leaf nutrient level and yield characters. Average bunch weight and FFB yield were found positively correlated with leaf nitrogen. However oil content of both mesocarp and kernel was negatively correlated with leaf nitrogen content. Average bunch weight was positively correlated with leaf P. The female inflorescence production, number of bunches produced, average bunch weight and the FFB yield were significantly and positively correlated with leaf K. The positive correlation of fruit to bunch ratio with leaf K revealed the importance of K nutrition on FFB production and oil yield. Leaf N and leaf K were reported to be correlated with FFB yield by Wilkie and Foster (1989).

Importance of maintaining a high N, P and K leaf nutrient status for better yield of oil palm is thus revealed. Number of bunches produced, average bunch weight and the FFB yield were all better at F_2 level of fertilizer application wherein the leaf nutrient status of N and K were significantly more.

However the average bunch weight and FFB yield were negatively correlated with leaf Mg content. This was due to the increased K content and due to K-Mg antagonism.

Oil content of mesocarp was negatively correlated with N and K content and positively correlated with leaf Mg. Similar positive correlation between leaf Mg and oil to bunch ratio was obtained by Ochs and Ollagnier (1977). Hagstrom (1988) based on work conducted in New Britain reported a very good correlation between leaf Mg levels and oil yield. The positive role of Mg in oil production is thus confirmed from this study.

4.8.3. Correlation between soil nutrient status and leaf nutrient contents

Correlation studies were conducted between soil nutrient status at different soil depths and leaf nutrient levels. The correlation coefficient (r) values are given in Table 31. Leaf N content was significantly and positively correlated with available nitrogen of 0-25 cm layer of soil.

Leaf N and K were positively correlated with P content of top soil whereas Mg content of leaf was negatively correlated with soil P.

Leaf N and K status were significantly and positively correlated with soil K at all depths.

Leaf nutrient content of N, P and K were thus found positively correlated with nutrient status of the topsoil

Table 31. Correlation coefficient (r) between soil nutrient status and leaf nutrient content

Soil Nutrient	Soil depth (cm)	Leaf nutrient content				
		Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg
Av. N	0–25	0.3887*	0.1000	0.3164	–0.0893	–0.0866
	25–50	0.2158	0.0820	–0.1093	0.1176	0.0599
	50–75	0.2768	0.4182*	0.3759*	–0.4613**	–0.2598
Av. P	0–25	0.5474**	0.1456	0.5943**	–0.2098	–0.4445**
	25–50	0.0851	0.1853	0.1152	0.1485	–0.0067
	50–75	0.1413	0.2690	0.1940	0.0842	–0.1515
Ex. K	0–25	0.6663**	0.1218	0.6502**	0.1981	–0.2700
	25–50	0.5670**	0.0150	0.4648**	–0.0732	–0.1225
	50–75	0.4834**	0.0050	0.3648*	–0.0861	–0.0998
Ex. Ca	0–25	0.0794	0.1170	0.2821	–0.0895	–0.0988
	25–50	0.1487	0.0809	0.3510**	–0.2860	–0.3150
	50–75	0.1795	0.0348	0.1952	–0.1382	–0.2021
Ex. Mg	0–25	–0.0951	–0.2752	–0.0640	0.0794	–0.1030
	25–50	–0.2556	–0.1537	–0.1458	–0.0303	0.0820
	50–75	–0.4617**	–0.4288**	–0.3793*	0.1974	0.1654

* Significant at P = 0.05 level

** Significant at P = 0.01 level

which explains the response of the palm to fertilizers application.

4.8.4 Correlation between soil nutrient status and uptake of nutrients

The correlation between soil nutrient and uptake of nutrients by the palm is given in Table 32. Uptake of nutrients did not show any significant correlation with available soil N status. However N, P and K uptakes were significantly and positively correlated with the soil available P at all depths. Ca uptake was also found significantly increased when available P of top soil increased.

N uptake and K uptake were found positively correlated with K status of soil at all depths and P uptake with K status of top soil. Mg uptake by palm was negatively correlated with the soil exchangeable K at all soil depths.

Increase in K uptake due to more K availability reduced Mg uptake due to K-Mg antagonism. Uptake of NPK and Ca were also found positively correlated with Ca content of top soil.

Table 32. Correlation coefficient (r) between soil nutrient status and total nutrient uptake by palm

Soil nutrient		Soil depth (cm)	Total nutrient uptake				
			N	P	K	Ca	Mg
Av.	N	0–25	0.2592	0.2054	0.2399	0.1652	–0.1365
		25–50	–0.0110	0.0177	0.0114	0.1423	–0.1550
		50–75	0.2991	0.1940	0.3219	0.2674	–0.1441
Av.	P	0–25	0.6994**	0.6162**	0.7255**	0.4656**	–0.0866
		25–50	0.3961*	0.3931*	0.3276*	0.3013	–0.0836
		50–75	0.4818**	0.5201**	0.4775**	0.2283	–0.2224
Ex.	K	0–25	0.6120**	0.5313**	0.6759**	0.2073	–0.4019*
		25–50	0.4700**	0.3192	0.4910**	0.0887	–0.4405**
		50–75	0.4437**	0.2425	0.4835**	0.1513	–0.3559*
Ex.	Ca	0–25	0.4252**	0.3987*	0.4272**	0.4437**	0.2158
		25–50	0.3123	0.4116*	0.2738	0.5356**	–0.1724
		50–75	0.2406	0.1650	0.2693	0.0896	–0.1191
Ex.	Mg	0–25	–0.0603	0.0265	0.0416	–0.0879	–0.1914
		25–50	–0.1976	–0.1727	0.2039	–0.1869	0.0321
		50–75	–0.3644*	0.3621*	–0.3762*	–0.1739	0.0595

* Significant at P = 0.05 level

** Significant at P = 0.01 level

Magnesium at lower depth of 50-75 cm was found negatively correlated with the uptake of N, P and K by the palm. To strike a balance with the heavy removal of other nutrients through bunches, magnesium from lower depths might have been absorbed in larger quantity by the crop thus reducing its content at lower depths of the soil.

4.8.5 Correlation between soil moisture and nutrient uptake

It was observed that the soil moisture at 0-25 cm layer was significantly and positively correlated with total nitrogen uptake (r = 0.3253) and also with the total P uptake (r = 0.3805). The positive influence of irrigation in increasing the uptake of N, P and K are thus illustrated. Wormer and Ochs (1959) obtained positive correlation between soil moisture content and leaf nitrogen and phosphorus contents. Increased leaf N and P due to improvement in soil moisture due to rainfall has also been reported by Foster et al. (1987).

4.8.6 Correlation between soil nutrient status and FFB yield

The correlation coefficient values between soil nutrient content and FFB yield are given in Table 33.

Table 33. Correlation coefficient (r) of soil nutrient and total uptake of nutrients with FFB yield

DMP	Correlation betwen soil nutrient at 0-25 cm and FFB yield	Total uptake of nutrient and FFB yield
Nitrogen	0.280	0.861**
Phosphorus	0.667**	0.873**
Potassium	0.641**	0.847**
Calcium	0.337	0.645**
Magnesium	0.026	0.165

** Significant at P = 0.01 level

Among the available nutrients in the top soil at 0-25 cm depth, available phosphorus and available potassium were significantly and positively correlated with FFB yield. Increase in availability of these nutrients due to fertilizer application has already been discussed.

4.8.7 Correlation between total nutrient uptake with FFB yield

The correlation coefficient values between total nutrient uptake and FFB yield are also given in Table 33. The study revealed highly significant positive correlation of uptake of N, P, K and Ca with FFB yield. Importance of these primary nutrients in the production of oil palm FFB yield is conclusively illustrated by this finding which needs no further discussion.

4.8.8 Correlation between leaf nutrient and nutrient uptake

The relationship between leaf nutrient status of N, P, K, Ca and Mg and uptake of these elements through harvested bunches as well as the total uptake by the whole palm are given in Table 34.

Table 34. Correaltion coefficient (r) between leaf nutrient content and nutrient removal by bunches as well as by the palm

Nutrient uptake	Leaf nutrient content				
	N	P	K	Ca	Mg
a. By bunches					
N uptake	0.6235**	0.2903	0.6757**	-0.2789	-0.4512**
P uptake	0.6012**	0.2842	0.6293**	-0.2474	-0.4960**
K uptake	0.4869**	0.2982	0.5861**	-0.1799	-0.4490**
Ca uptake	0.4104*	0.1762	0.4952**	-0.1419	-0.3905*
Mg uptake	0.4361**	0.2865	0.5354**	-0.0449	-0.4946**
b. Total uptake by palm					
N uptake	0.6735**	0.4299**	0.7120**	-0.3723*	0.5903**
P uptake	0.5540**	0.4211*	0.6518**	-0.3524*	0.5471**
K uptake	0.6623**	0.3940*	0.7411**	-0.3957*	0.1819
Ca uptake	0.4056*	0.4359**	0.4704**	-0.1405	0.0866
Mg uptake	-0.1830	0.3821*	0.0056	-0.1032	0.4445**

* Significant at P = 0.05 level

** Significant at P = 0.01 level

The uptake of N, P, K and Ca by bunches and the palm as a whole were found positively correlated with leaf N content. Mg uptake through bunches was positively correlated with N content of leaf. Increased bunch production due to better nitrogen nutrition has resulted in more uptake of Mg in bunches.

The total uptake of N, P, K, Ca and Mg by palm was found positively correlated with leaf P. Importance of P nutrition and its influence in increasing the uptake of other nutrient elements has become evident from this study.

The Uptake of N, P, K and Ca both through bunches and by the palm as a whole was positively correlated with leaf K content.

The uptake of N, P and K by the palm was negatively correlated with leaf Ca.

Uptake of N, P , K, Ca and Mg through bunches were found negatively correlated with leaf Mg content. Heavy removal of nutrient through bunches reduced the leaf Mg status which resulted in negative correlation. The total uptake of N P and Mg was positively correlated with Mg content of leaf. The importance of Mg in photosynthesis and oil synthesis has resulted in such increased uptake.

4.8.9 Interrelationship of nutrient contents and nutrient uptake

Correlations matrix to show the inter relationship among leaf nutrient contents and among total nutrient uptake are furnished in Table 35.

The leaf nitrogen content was found positively and significantly correlated with leaf phosphorus and potassium contents. This might be due to the synergistic relationship between N, P and K in plant. Ollagnier and Ochs (1981) reported that the level of P varied positively with level of N in leaf. Simultaneous increases in leaf N and leaf P has also been reported by Hartley (1988). However leaf Ca and Mg were found negatively correlated with N, P and K content. This might be due to the antagonistic influence of potassium on these cations. Again calcium and magnesium are seen positively correlated between themselves.

Table 35. Correlation matrix of leaf nutrient content and total uptake of nutrients showing interrelationship between nutrients

Nutrient	Correlation coefficient (r) between leaf nutrient contents				Correlation coefficient (r) between uptake of differnt nutrients			
	P	K	Ca	Mg	P	K	Ca	Mg
N	0.5116**	0.7193**	-0.3922**	-0.4995**	0.9368**	0.9519**	0.7646**	0.1203
P		0.5768**	-0.5600**	-0.4226*		0.8796**	0.7274**	0.1938
K			-0.6640**	-0.6189**			0.6592**	0.0043
Ca				0.3924				0.4588**

S* – Significant at P = 0.05 level

S** – Significant at P = 0.01 level

Uptake of N, P and K were significantly and positively correlated. Unlike in the case of calcium content of leaf, its uptake was positively correlated with total N, P and K uptake. Mg uptake failed to show any significant correlation in uptake with any nutrient elements other than calcium. Calcium uptake showed significant positive correlation with magnesium uptake.

The positive interrelations between N, P and K in both content and uptake are evident from this study. Eventhough there was an antagonistic influence especially of potassium on calcium and magnesium content of leaf, it has not been significantly manifested on total Mg uptake by the crop due to larger removal of magnesium through bunches. Calcium and magnesium uptake found to be significantly and positively correlated, might be due to the antagonistic influence of potassium on both these nutrients alike. The very high positive and significant correlation coefficient values for uptake between N and P (0.9368), N and K (0.9519), and P and K (0.8796) indicate the existence of an intense interrelationship in total uptake and removal of N P and K by oil palm.

4.9 Net profits and benefit cost ratio

Details on gross expenditure, gross returns, net return and the benefit cost ratio of different fertilizer and irrigation treatments are given in Table 36. The expenditure and returns were worked out using the prevailing price of inputs and the produces. The details of these calculations are mainly based on the earlier work published by the author (Varghese and Nampoothiri,.1988).

Statistical analysis of the net profit showed that the maximum profit of Rs. 61,089/- ha^{-1} $year^{-1}$ was obtained in F_2 treatment with F_1 and F_3 recording Rs. 53526/- and Rs. 50787/- respectively. However the F_0 treatment recorded a lowest net income of Rs.35131/- ha^{-1} $year^{-1}$.

Among the irrigation treatments, I_2 level has recorded a maximum net return of Rs.62691 ha^{-1} $year^{-1}$ followed by I_1 and I_0 which gave a net income of Rs. 48457/- and Rs. 39252/- respectively.

The mean benefit cost ratio obtained in different fertilizer treatments were F_0 - 2.66, F_1 - 2.82, F_2 - 2.83

and F_3 - 2.54. For irrigation treatments the ratios were I_0 - 2.45, I_1 - 2.63 and I_2 - 3.05. Thus maximum benefit cost ratios were also obtained with fertilizer application at F_2 level and irrigation at I_2 level.

Table 36. Effect of fertilizer and irrigation on net returns (Rs. ha^{-1} $year^{-1}$) and benefit cost ratio - (returns per rupee invested)

Treatment	Gross expenditure (Rs. ha^{-1} $year^{-1}$)	Gross returns (Rs. ha^{-1} $year^{-1}$)	Net returns (Rs. ha^{-1} $year^{-1}$)	B.C ratio
Fertilizer				
F_0	21079	56209	35131	2.66
F_1	29382	82908	53526	2.82
F_2	33327	94416	61089	2.83
F_3	32344	83131	50787	2.54
Irrigation				
I_0	27008	66260	39252	2.45
I_1	29933	78390	48457	2.63
I_2	30158	92849	62691	3.05

Part II. LEAF NUTRIENT RATIOS AND THE DRIS

1 Nutrient content of yield group of palms

Nutrient content of N, P, K, Ca and Mg in leaf 17 of three different yield groups of palms viz. those yielding (a) below 50 kg FFB palm^{-1} year $^{-1}$ (b) between 50 and 100 kg FFB palm^{-1} year^{-1} and (c) above 100 kg FFB palm^{-1} were determined separately for 40 palms each for two years. Data on concentration of nutrients of this low, medium and high yield group of palms averaged over two years (each figures is a mean of 80 observations) are presented in Table 37.

It was observed that the concentration of all nutrients were lowest in the low yielding palms and highest in the high yielding palms. The critical level of nutrients in frond 17 of oil palm are N(2.5%), P(0.15%), K(1.0%), Ca(0.60%) and Mg(0.24%) (Prevot and Ollagnier, 1954). Thus according to the critical nutrient level approach for the high yield group of palms N was same as critical level, P and Mg were slightly above the critical levels and K and Ca were slightly below the critical levels prescribed.

Table 37. Mean leaf nutrient content (per cent) of yield groups of palm

Nutrient content (per cent)	Yield groups (kg palm^{-1} year^{-1})		
	<50 kg	50-100 kg	>100 kg
N	2.399	2.446	2.494
P	0.163	0.165	0.167
K	0.870	0.901	0.901
Ca	0.493	0.529	0.545
Mg	0.300	0.305	0.312

2. Nutrient ratios and DRIS norms

To get a more comprehensive information based on these nutrient ratios, the methodology of the Diagnosis and Recommendation Integrated System (DRIS) was attempted for the first time on oil palm.

For the purposes of conducting DRIS analysis, palms which yielded more than 100 kg FFB $palm^{-1}$ $year^{-1}$ were taken as high yielding population and those which yielded less than 100 kg FFB $palm^{-1}$ $year^{-1}$ were considered as low yielding population. Variance ratios between these low and high yield group of palms were determined for all forms of expression. In DRIS calculations only one expression is used to relate each nutrient pair and is accomplished by comparing the variance of the form of expression of low yielding group to that of high yielding group.

The product forms of nutrient expression NP, PN etc. were also worked out and since none of the variance ratio were found significant, it is not presented. The ratio form of expression of nutrients namely N/P, P/N etc. were

Table 38. Variance ratio of nutrient ratios of palms

Ratio	High yielders >100 kg Mean	SD	Low yielders <100 kg Mean	SD	Variance ratio
N/P	15.075	2.096707	14.864	1.521262	0.526490
P/N	0.067	0.007878	0.068	0.006571	0.693548
N/K	2.830	0.477922	2.818	0.569387	1.419386
K/N	0.363	0.058943	0.369	0.074494	1.597294
N/Ca	4.833	1.233301	5.038	1.404147	1.296244
Ca/N	0.221	0.058408	0.213	0.055398	0.899473
N/Mg	8.627	2.556826	8.519	2.374115	0.862186
Mg/N	0.127	0.038956	0.126	0.033792	0.752306
P/K	0.190	0.033532	0.190	0.036730	1.200178
K/P	5.455	1.151393	5.450	1.028177	0.797423
P/Ca	0.321	0.072870	0.341	0.096343	1.748023
Ca/P	3.285	0.805125	3.150	0.850011	1.114610
P/Mg	0.571	0.149806	0.573	0.1466224	0.957981
Mg/P	1.871	0.489635	1.858	0.4460614	0.884972
K/Ca	1.755	0.523860	1.874	0.683659	1.703126
Ca/K	0.626	0.199351	0.604	0.217731	1.192899
K/Mg	3.115	0.989051	3.129	1.012683	1.048357
Mg/K	0.357	0.123947	0.355	0.118861	0.0919612
Ca/Mg	1.821	0.446512	1.748	0.468875	1.102677
Mg/ca	0.586	0.163350	0.614	0.167177	1.047408

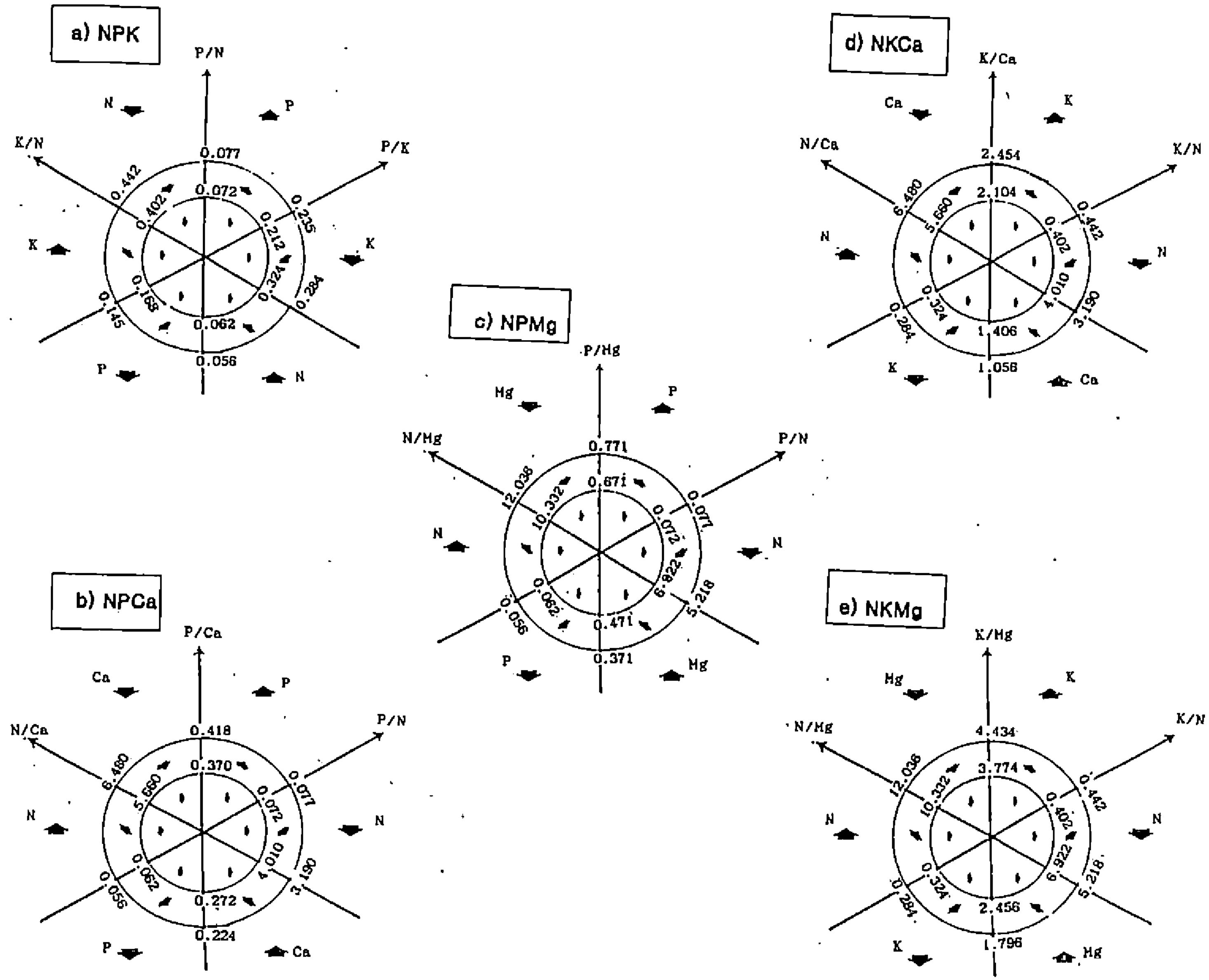
used in DRIS calculations and are given in Table 38. The form of expression of nutrient ratios (N/P or P/N) having largest variance ratio between high and low were thus selected as the DRIS reference parameter. In this instance P/N, K/N, N/Ca, N/Mg, P/K, P/Ca, P/Mg, K/Ca, K/Mg and Ca/Mg were having higher variance ratio and hence accepted as DRIS parameters.

The means and coefficients of variations of DRIS reference parameters in high yielding subpopulations were used as DRIS norms in calibration formulae as suggested by Beaufils (1973) for diagnostic purposes. These mean values and coefficients of variation of the high yielding palm constituting the DRIS norms are presented in Table 39.

3. DRIS charts and diagnosis using balance zones of nutrient ratios

DRIS norms of any three nutrient combination such as N K Mg, N P K, P K Mg and K Ca Mg etc. were related to one another in the form of a DRIS chart for oil palm (Fig. 18). The point of intersection of the lines indicating DRIS parameters of a nutrient combination correspond to the mean value of high yielding population for each form of expression. For example in the NKMg combination, K/N = 0.369, N/Mg = 8.627, K/Mg = 3.115, forms this mid point. This is the composition of oil palm leaf ratio desired in order to increase the chances of obtaining high yield. This desired composition however is not a single value but a range, demarkation of which is set at 4 SD/3 (Beaufils, 1971) where SB is standard deviation of high yielding subpopulation. All plant composition falling within the inner circle (Fig. 18) is considered balanced and is denoted by a horizontal arrow (→). The ratio gets imbalanced as it move away from this circle. The zone of imbalance is again divided into two viz: zone of moderate imbalance which is encomposed by the outer of the concentric circles with a diameter of 8 SD/3 which is indicated by slanting arrows (↖). Beyond this circle is the zone of imbalance denoted by vertical arrows (↓). The ranges of balanced nutrition of all the ten three nutrient combinations involving N, P, K, Ca and Mg thus arrived are expressed in the form of DRIS charts. DRIS charts for NPK, NPCa, NPMg, NKCa, NKMg, NCaMg, PKCa, PKMg, PCaMg and KCaMg are illustrated in FIg. 18a to 18j and details on ranges of values of these ratios are given in Table 40.

Fig. 18. DRIS charts of three nutrient combinations involving N, P, K, Ca and Mg



....Continued

Fig. 18. DRIS charts of three nutrient combinations involving N, P, K, Ca and Mg

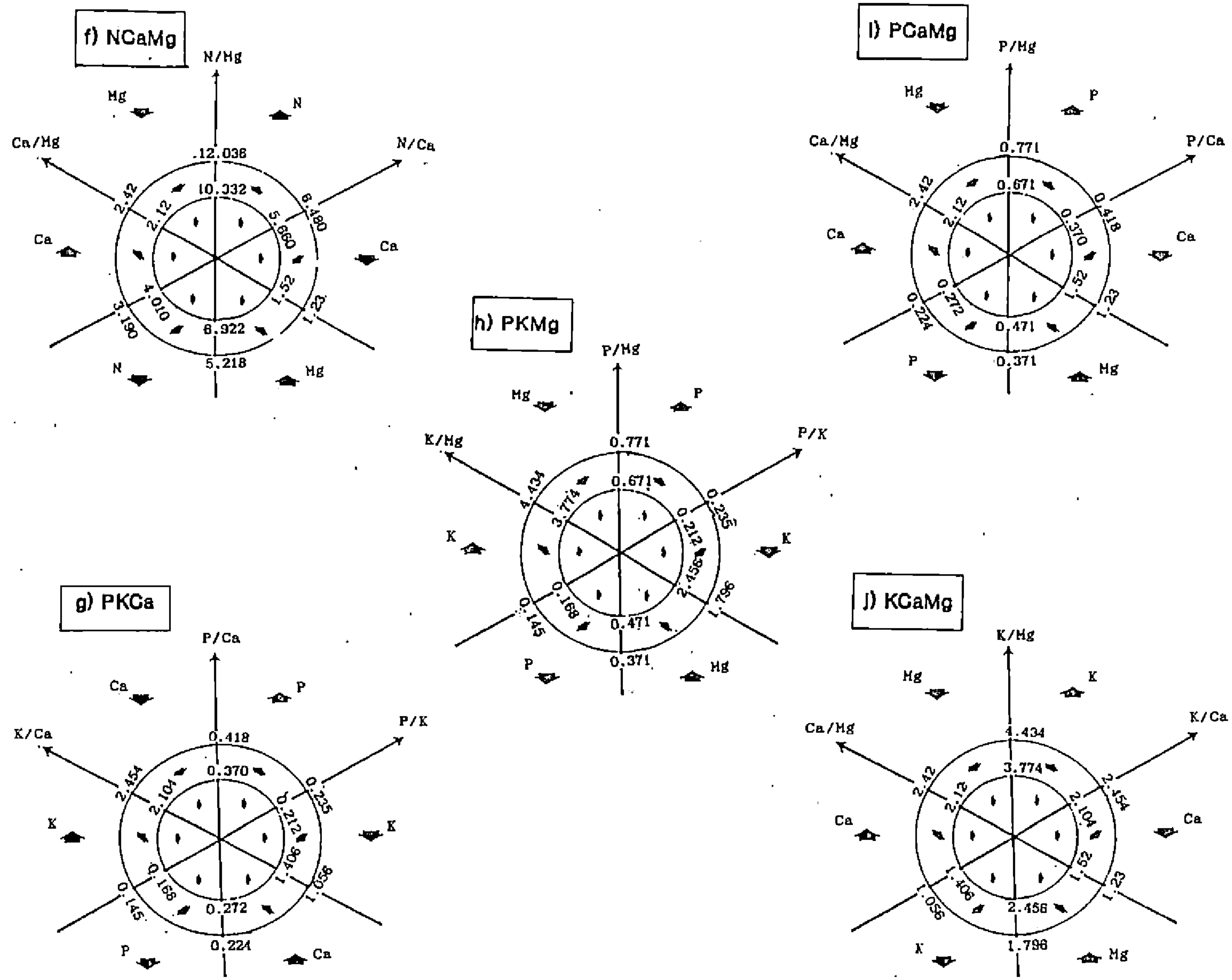


Table 40. Nutrient ratios considered important in oil palm with their norms, its ranges of values with in the zones of balance, moderate imbalance and imbalance

Nutrient ratios of importance	DRIS Norm ($\bar{X}$)	SD	Zone of balance	Zone of moderate imbalance	Zone of imbalance
P/N	0.067	0.007878	0.062 - 0.072	0.056 - 0.061 and 0.073 - 0.077	< 0.056 and > 0.077
K/N	0.363	0.058943	0.324 - 0.402	0.284 - 0.323 and 0.403 - 0.442	< 0.284 and > 0.442
N/Ca	4.833	1.233301	4.010 - 5.660	3.190 - 4.000 and 5.670 - 6.480	< 3.190 and > 6.480
N/Mg	8.627	2.556826	6.922 - 10.332	5.218 - 6.921 and 10.330 - 12.036	< 5.218 and > 12.036
P/K	0.190	0.33532	0.168 - 0.212	0.145 - 0.167 and 0.213 - 0.235	< 0.145 and > 0.235
P/Ca	0.321	0.072878	0.272 - 0.370	0.224 - 0.271 and 0.371 - 0.418	< 0.224 and > 0.418
P/Mg	0.571	0.149806	0.471 - 0.671	0.371 - 0.470 and 0.672 - 0.771	< 0.371 and > 0.771
K/Ca	1.755	0.523860	1.406 - 2.104	1.056 - 1.406 and 2.105 - 2.454	< 1.056 and > 2.454
K/Mg	3.115	0.989051	2.456 - 3.774	1.796 - 2.455 and 3.775 - 4.434	< 1.796 and > 4.434
Ca/Mg	1.821	0.446512	1.52 - 2.12	1.23 - 1.51 and 2.13 - 2.42	< 1.23 and > 2.42

This will facilitate to estimate the relationship between the nutrient ratios observed in a palm with that of the actual field experience. Thus the values of any unknown sample can be diagnosed for its nutrient balance which can form a guide for fertilizer application. Suitable corrective measures to overcome the imbalance can be recommended to attain the targeted yield. Such nutrient ratios for all the two nutrient combinations are presented in the table and figures and hence not attempted to discuss in detail as it is self explanatory.

4. Evaluation and application of DRIS in fertilizer experiment

For the evaluation of the DRIS norms constituted, the field experiment on irrigation and fertilizer experiment was used. Based on the mean nutrient content for two years, their nutrient ratios in the selected forms of expression for the DRIS analysis are summarised for all the 12 treatments of the experiment in Table 41. These nutrient ratios were compared with those DRIS norms evolved and the balancing behaviour of these chosen ratios in various treatments were determined and are given in Table 42.

The table and figures thus show that (K/N ratio is taken here as an example) the zone of balance of K/N ratio is 0.324 to 0.402. Any value of the ratio below the zone of balance of 0.324 and above 0.402 leads to slight or moderate imbalance and further lowering of values below 0.284 and above 0.442 leads to highly imbalanced situation.

Using the DRIS norms and the DRIS charts, the range of values of all important nutrient ratios which are considered optimum (zone of balance), ratios which are slightly lower or higher than the optimum (zone of moderate imbalance), and ratios that vary considerably from the optimum (zone of imbalance) were determined and are furnished in Table 40.

The zone of balance gives the optimum ratios for obtaining maximum yield of oil palm. Nutrient supply are to be made in such a way as to have the nutrient ratios of palms fall within this zone of balancing. The performance and yield of palms will be determined by the degree of imbalancing. Under moderately imbalanced conditions there will be reduction in yields depending on the degree of imbalance due to the nutrient supply which was insufficient. Under imbalanced conditions yield will be severely reduced.

Table 41. Mean of selected nutrient ratios in different treatments of irrigation and fertilises experiment

Nutrient ratios	Treatments											
	I_0F_0	I_0F_1	I_0F_2	I_0F_3	I_1F_0	I_1F_1	I_1F_2	I_1F_3	I_2F_0	I_2F_1	I_2F_2	I_2F_3
P/N	0.0616	0.0595	0.0592	0.0557	0.0657	0.0621	0.0587	0.0590	0.0648	0.0618	0.0565	0.0577
K/N	0.2502	0.3025	0.3133	0.2894	0.2429	0.3185	0.3423	0.3415	0.2709	0.2756	0.3403	0.3462
N/Ca	3.1758	3.2863	3.6740	3.9832	2.8831	2.9935	4.8362	3.8860	2.9403	3.0822	3.7581	3.8855
N/Mg	6.5449	6.5000	6.9116	9.5073	5.2445	7.4984	7.8607	7.6226	5.3000	6.5407	10.032	7.7098
P/K	0.2460	0.1966	0.1888	0.1923	0.2706	0.1951	0.1715	0.1727	0.2393	0.2242	0.1661	0.1667
P/Ca	0.1954	0.1955	0.2173	0.2217	0.1895	0.1860	0.2838	0.2281	0.1906	0.1904	0.2124	0.2242
P/Mg	0.4029	0.3867	0.4088	0.5292	0.3447	0.4660	0.4613	0.4407	0.3436	0.4241	0.5669	0.4448
K/Ca	0.7947	0.9944	1.1512	1.1529	0.7003	0.9535	1.6552	1.3206	0.7966	0.8493	1.2788	1.3450
K/Mg	1.6377	1.9695	2.1657	2.7218	1.2738	2.3883	2.6904	2.6037	1.4359	1.8023	3.4134	2.6688
Ca/Mg	2.0609	1.9779	1.8812	1.3869	1.8190	2.5049	1.6254	1.9717	1.8026	2.1220	2.6893	1.9842

Table 42. Balancing behaviour of important nutrient ratios involving N, P, K, Ca and Mg in oil palm in various treatments of field experiment

Ratios considered important	Fertilizer and irrigation treatments											
	F_0			F_1			F_2			F_3		
	I_0	I_1	I_2	I_0	I_1	I_2	I_0	I_1	I_2	I_0	I_1	I_2
P/N	MI	B	B	MI	B	B	MI	MI	MI	MI	MI	MI
K/N	I	I	I	MI	MI	I	MI	B	B	MI	B	B
N/Ca	I	I	I	MI	I	I	MI	B	MI	MI	MI	MI
N/Mg	MI	MI	MI	MI	B	MI	MI	B	B	B	B	B
P/K	I	I	I	B	B	MI	B	B	B	B	B	MI
P/Ca	I	I	I	I	I	I	I	B	I	I	MI	MI
P/Mg	MI	I	I	MI	MI	MI	MI	MI	B	B	MI	MI
K/Ca	I	I	I	I	I	I	MI	B	MI	MI	MI	MI
K/Mg	I	I	I	MI	MI	MI	MI	B	B	B	B	B
Ca/Mg	B	B	B	B	I	B	B	B	I	MI	B	B

B = Balanced

MI = Moderately imbalanced

I = Imbalanced

Balancing behaviour of all three nutrient combinations were also arrived at and are furnished in Table 43. From these tables it was observed that majority of these nutrient combinations were more balanced in F_2 (90%) and F_3 (93%) treatments compared to F_0 (33%) and F_1 (60%) treatments. Such a balanced situation helped in producing more FFB yield at F_2 level of fertilizer application.

When I_1F_2, I_2F_2 and I_2F_3 treatments were compared, bunch yields were more in I_2F_2 than I_1F_2 and I_2F_3. When the balancing situation of nutrient ratios were studied in these treatments, it was observed that P/Mg ratio was well balanced in I_2F_2 and not in other two treatments. Being an oil yielding crop, magnesium nutrition and its relationship with phosphorus become important factors in deciding improved bunch yield in I_2F_2 treatment. When majority of ratios other than P/Mg is well balanced in both I_1F_2 and I_2F_3, it resulted in more vegetative dry matter production and not bunch yields. This important finding brings out that for increased bunch production of oil palm, not only balancing of nutrients are important, but also balancing of the specific nutrient ratio P/Mg is important, the range being 0.471 to 0.671.

Table 43. Balancing behaviour of three nutrient combinations of experimental treatments

Three nutrient combinations	Two nutrient combinations	Treatments											
		I_0F_0	I_0F_1	I_0F_2	I_0F_3	I_1F_0	I_1F_1	I_1F_2	I_1F_3	I_2F_0	I_2F_1	I_2F_2	I_2F_3
NPK	P/N	M1	M1	M1	M1	B	B	M1	M1	B	B	M1	M1
	P/K	1	B	B	B	1	B	B	B	1	M1	M1	M1
	K/N	1	M1	M1	M1	1	M1	B	B	1	1	B	B
NPCa	P/N	M1	M1	M1	M1	B	B	M1	M1	B	B	M1	M1
	P/Ca	1	1	1	1	1	1	B	M1	1	1	1	1
	N/Ca	1	M1	M1	M1	1	1	B	M1	1	1	M1	M1
NPMg	P/N	M1	M1	M1	M1	B	B	M1	M1	B	B	M1	M1
	P/Mg	M1	M1	M1	B	1	M1	M1	M1	1	M1	B	M1
	N/Mg	M1	M1	M1	B	M1	B	B	B	M1	M1	B	B
NPK	K/N	1	M1	M1	M1	1	M1	B	B	1	1	B	B
	K/Ca	1	1	M1	M1	1	1	B	M1	1	1	M1	M1
	N/Ca	1	M1	M1	M1	1	1	B	M1	1	1	M1	M1
NKMg	K/N	1	M1	M1	M1	1	M1	B	B	1	1	B	B
	N/Mg	M1	M1	M1	B	M1	B	B	B	M1	M1	B	B
	K/Mg	1	M1	M1	B	1	M1	B	B	1	M1	B	B
NCaMg	N/Ca	1	M1	M1	M1	1	1	B	M1	1	1	M1	M1
	N/Mg	M1	M1	M1	B	M1	B	B	B	M1	M1	B	B
	Ca/Mg	B	B	B	M1	B	1	B	B	B	B	1	B
PKCa	P/K	1	B	B	B	1	B	B	B	1	M1	M1	M1
	K/Ca	1	1	M1	M1	1	1	B	M1	1	1	M1	M1
	P/Ca	1	1	1	1	1	1	B	M1	1	1	1	1
PKMg	P/Ca	1	B	B	B	1	B	B	B	1	M1	M1	M1
	P/Mg	M1	M1	M1	B	1	M1	M1	M1	1	M1	B	M1
	K/Mg	1	M1	M1	B	1	M1	B	B	1	M1	B	B
PCaMg	P/Ca	1	1	1	1	1	1	B	M1	1	1	1	1
	P/Mg	M1	M1	M1	B	1	M1	M1	M1	1	M1	B	M1
	Ca/Mg	B	B	B	M1	B	1	B	B	B	B	1	B
KCaMg	K/Ca	1	1	M1	M1	1	1	B	M1	1	1	M1	M1
	K/Mg	1	M1	M1	B	1	M1	B	B	1	M1	B	B
	Ca/Mg	B	B	B	M1	B	1	B	B	B	B	1	B

5. Quantification of imbalances using DRIS indices

The imbalances were quantified by determining nutrient index values (Walworth and Summer, 1987). From the norms already selected, indices were calculated for each nutrient using following formulae as found applicable in the present investigation.

$$\text{N index} = \frac{-f\,(P/N) - f(K/N) + f\,(N/Ca) + f\,(N/Mg)}{X}$$

$$\text{P index} = \frac{f\,(P/N) + f\,(P/K) + f\,(P/Ca) + f(P/Mg)}{X}$$

$$\text{K index} = \frac{f\,(K/N) - f\,(P/K) + f\,(K/Ca) + f\,(Ca/Mg)}{X}$$

$$\text{Ca index} = \frac{-f\,(N/Ca) - f\,(P/Ca) - f\,(K/Ca) + f\,(Ca/Mg)}{X}$$

$$\text{Mg index} = \frac{-f\,(N/Mg) - f\,(P/Mg) - f\,(K/Mg) - f\,(Ca/Mg)}{X}$$

Where, when $P/N \geq p/n$

$$f\,(P/N) = \left(\frac{P/N}{p/n} - 1\right) \frac{1000}{CV}$$

or when $P/N < p/n$

$$f\,(P/N) = \left(1 - \frac{p/n}{P/N}\right) \frac{1000}{CV}$$

Where P/N is the value of the ratio of the two elements in the tissue of the plant being diagnosed, p/n is the optimum value or norm for that ratio, CV is the coefficient of variation associated with the norm and X is the number of functions comprising the nutrient index.

Based on the calculation nutrient indices determined for each nutrient in the three nutrient combinations involving N, P, K, Ca and Mg for the treatment which gave maximum bunch yield i.e. I_2 F_2 are furnished in Table 44. The DRIS indices indicated varying intensity of nutritional imbalances among treatments. It may be recalled that the index for any nutrient is the mean of the weighted deviations for all ratios involving that nutrient and the calculated DRIS indices provide a measure of nutrient balance within the sample of interest. It may be seen from Table 44 that the sum of the indices irrespective of sign were lower for NKMg, P K Mg and N P Mg and were higher for PKCa, NPCa and PCaMg and their ranking are given in the Table.

This clearly shows the importance of magnesium nutrition along with N, P and K for better yield of palms.

Table 44. Order of balancing of three nutrient combinations in the best yielding treatment (I_2 F_2) of the fertilizer experiment evaluated using nutrient indices

Sl. No.	Nutrient Combination	Indices of the 1st 2nd and 3rd ntrient in the respective nutrient combination			Sum of indices of the 3 nutrients irrespective of sign (NII)	Ranks assigned in the order of blancing based of NII	Remarks
1.	N P K	10.01	-12.03	2.02	23.06	5	
2.	N P Ca	2.35	-19.22	16.88	38.45	9	
3.	N P Mg	10.70	-8.09	-2.61	21.40	3	
4.	N K Ca	-3.55	-8.09	11.85	23.70	4	
5.	N K Mg	4.80	-.553	-4.26	9.61	1	Most balanced
6.	N Ca Mg	-2.86	15.1	-12.24	30.2	6	
7.	P K Mg	-15.35	-2.17	17.52	35.04	8	
8.	P K Mg	-4.22	5.59	-1.37	11.54	2	Second best
9.	P Ca Mg	-11.42	20.77	-9.36	41.54	10	
10.	K Ca Mg	-4.73	15.74	-11.01	31.48	7	

Relative insufficiency of some nutrient would always correspond to sufficiency or excess of some other nutrient because of the inherent symmetry in the DRIS formulae for calculation of DRIS indices. To improve balancing of nutrients in any situation, additional application of nutrient that are short in supply is done in amounts relative to the proportion of imbalance. This is made possible through quantification of the nutrient which is less in supply by calculating the index for each nutrient in the combination of the sample in comparison with the standard DRIS norm values.

In this instance nutrient index value of different treatments of the irrigation and fertilizer experiment were worked out (Table 45). Since deviations were measured, the DRIS indices sum to zero. The nutrient with the most negative index is considered the most relatively insufficient or most limiting. The increasing indices represent the order of sufficiency up to the most relatively excessive or least limiting nutrient. From the nutrient analysis data (Table 19) nitrogen was found optimum at F_2 and F_3 levels, K and P were below its critical levels and calcium and magnesium were above the critical nutrient level in most of the treatments.

Table 45. Progressive diagnosis of N, P, K, Ca and Mg requirements of oil palm using DRIS indices on data from irrigation and fertilizer experiment

Treatment	Leaf composition					DRIS Indices					Sum of indices irrespective of sign	Total dry matter yield (kg palm^{-1} year^{-1})
	N	P	K	Ca	Mg	N	P	K	Ca	Mg		
I_0F_0	2.258	.139	.565	.711	.345	1	-9	-29	24	13	76	101.67
I_0F_1	2.353	.140	.712	.716	.362	-1	-14	-15	19	11	60	143.22
I_0F_2	2.502	.148	.784	.681	.362	0	-12	-10	13	9	44	157.76
I_0F_3	2.605	.145	.754	.654	.274	7	-10	-9	14	-2	42	166.34
I_1F_0	2.145	.141	.521	.774	.409	-4	-8	-38	27	23	100	97.00
I_1F_1	2.317	.144	.738	.774	.309	-4	-11	-12	25	2	54	158.19
I_1F_2	2.539	.149	.839	.525	.323	3	-8	-2	1	6	20	175.38
I_1F_3	2.424	.143	.828	.627	.318	1	-12	-4	10	5	32	173.78
I_2F_0	2.067	.134	.560	.703	.390	-6	-11	-28	24	21	90	151.03
I_2F_1	2.250	.139	.620	.730	.344	-2	-11	-23	23	13	72	166.58
I_2F_2	2.548	.144	.867	.678	.254	4	-12	-1	15	-6	38	183.74
I_2F_3	2.444	.141	.846	.629	.317	1	-13	-3	11	4	32	183.38

However subjecting the data to DRIS analysis has brought out not only the order of requirement of the nutrients, but also the importance of magnesium nutrition at higher levels of fertilizer application. The manifestation of this phenomenon is better evidenced in the performance of irrigated treatment I_2 which is presented in Table 46. The order of requirement in a particular treatment combination is to be assessed for the most critical one limiting crop production. Now let us examine the relative importance of a particular nutrient among the five nutrients analysed. This is necessary to know their relative level of sufficiency in a particular treatment combination. The relative order of importance in the irrigated (I_2) treatment under different fertilizer levels are given below as an example.

I_2F_0 = K > P > N > Mg > Ca

I_2F_1 = K > P > N > Mg > Ca

I_2F_2 = P > Mg > K > N > Ca

I_2F_3 = P > K > N > Mg > Ca

It could be seen that magnesium has become a crucial element at I_2F_2 indicating that sufficient quantity of magnesium is to be ensured at this level. However at F_3

level the order of importance of Mg is found shifted. The data on dry matter production showed that at I_2F_3 the vegetative dry matter production was maximum where as bunch dry matter was lesser.

The more negative index value of any nutrient indicated the greater need for supply of that particular nutrient. The results also diagnosed potassium as limiting at the lower levels of F_0 and F_1 treatment and its subsequent correction at F_2 which resulted in F_2 becoming the highest yielding treatment combination. Importance of major nutrients based on the study which are presented in Table 46 are discussed.

a) Nitrogen

Perusal of Table 45 indicates, that nitrogen is not a major limiting factor even in the control plot as revealed by its very low deviations. This also might be due to the fact that the plots did not receive any phosphorus and potassium. However nitrogen index which were negative at F_0 and F_1 levels became positive at the F_2 level which showed slight insufficiency at F_0 and F_1 levels and excess at F_2 and

Table 46. Order of requirement of nutrients determined using DRIS from treatments of irrigation and fertilizer experiment

Fertilizer / Irrigation	F_0	F_1	F_2	F_3
I_0	K>P>N>Mg>Ca	K>P>N>Mg>Ca	P>K>N>Mg>Ca	P>K>Mg>N>Ca
I_1	K>P>N>Mg>Ca	K>P>N>Mg>Ca	P>K>Ca>N>Mg	P>K>N>Mg>Ca
I_2	K>P>N>Mg>Ca	K>P>N>Mg>Ca	P>Mg>K>N>Ca	P>K>N>Mg>Ca

F_3 levels irrespective of irrigation. This gives an opportunity to adjust the nitrogen application somewhere between F_1 and F_2 doses which might be the optimum dose. The leaf nutrient analysis presented (Table 19) also showed that F_2 has the maximum leaf N nutrient concentration and beyond F_2 there was a decrease in N concentration. So it is surmised that the optimum level is somewhere between F_1 and F_2. Dry matter production also showed a similar trend wherein the F_2 level of fertilizer with irrigation had given maximum dry matter yield.

b) Phosphorus

It is seen that utilization of applied P could not be improved even at the highest level of application of 900 g palm^{-1} year^{-1}. The inefficiency factor seems to be increasing with higher levels of application. This is a different trend than noticed in N and K. Reference to the uptake table of P show that beyond 600 g palm^{-1} year^{-1}, there was no further appreciable increase. This shows that the efficiency of utilization of applied P is considerably reduced at the highest level of phosphorus application. Probably the insufficiency factor usually applied in DRIS calculation is not operated at higher levels of nutrition under the conditions of the present experiment whereas it may be inefficiency ,factors under the particular agro ecological situation that was probably operating. That is why the negative value tends to increase even beyond 600 g level of phosphorus. Further experiment is definitely warranted to validate the interpretation of the DRIS formulae by comparing the results obtained in different locations.

c) Potassium

The table shows that the insufficiency level of K decreased as the dose of K was increased and it was almost well balanced at F_2 level. Leaf nutrient content showed significant improvement upto F_2 level (Table 19). The table depicting yield (Table 12) as well as TDM (Table 7) showed that beyond F_2 level there was no appreciable increase. The uptake figure (Table 28) also showed that the uptake was significantly increased upto F_2 level beyond which the increase was due to vegetative dry matter. The order of insufficiency of potassium also was found shifted at F_2 level from its first position of most insufficient element to this third position of a near balanced situatiion. However there was a small increase in the negative value at the highest level of fertilization which shows its relative imbalance with other elements beyond F_2 level.

d) Calcium

As noticed in Table 46 calcium was taken in excess than its requirement which caused imbalances in nutrition. Lack of potassium availability has comparatively increased the calcium content in its leaves causing imbalance. However when potassium was supplied in sufficient quantity as at F_2 and F_3 levels, the excess Ca content was reduced (Table 19) as was indicated by lower positive nutrient indices for calcium at this level compared to F_0 and F_1 levels.

e) Magnesium

When K was adequately applied at F_2 level, Mg became the second limiting nutrient in the treatment I_2F_2. Thus, although Mg was not applied, its importance in limiting yield was revealed by DRIS analysis of the experimental treatments. The identification of Mg as a potentially limiting nutrient is explained by background information on the experiment described. The soil of the experiment was gravelly laterite and had a low CEC and had been fertilized for many years. Although Mg deficiency is uncommon in oil palm, it can be associated with applications of K fertilizers. Thus, the induction of low Mg indices by K application under these experimental conditions is understandable. This induced Mg insufficiency might have arisen because of competition by K for uptake sites on roots. It is worth mentioning here that the sufficiency range method would not have indicated such a potential problem. Thus DRIS has the additional advantage of evaluating nutrient interactions. In F_2 more magnesium had been taken up (Table 27) and utilised for heavy bunch production and oil synthesis due to higher FFB yields obtained in this treatment. This might have produced nutrient imbalances in its leaves and emphasises the need for additional supply of magnesium. Hence the continuous supply of K over the years is to be supplemented with occasional supply of magnesium for optimum oil palm yields. When optimum NPK fertilizers were applied, application of 1.5 - 2 kg Kieserite palm^{-1} year^{-1} was recommended in Malaysia by Dolmat et al. (1989) not only to increase leaf Mg levels but also to improve nutrient balance especially with potassium. This is in conformity with the results of the present work.

6. Nutrient Imbalance Index (NII) and yield relationship

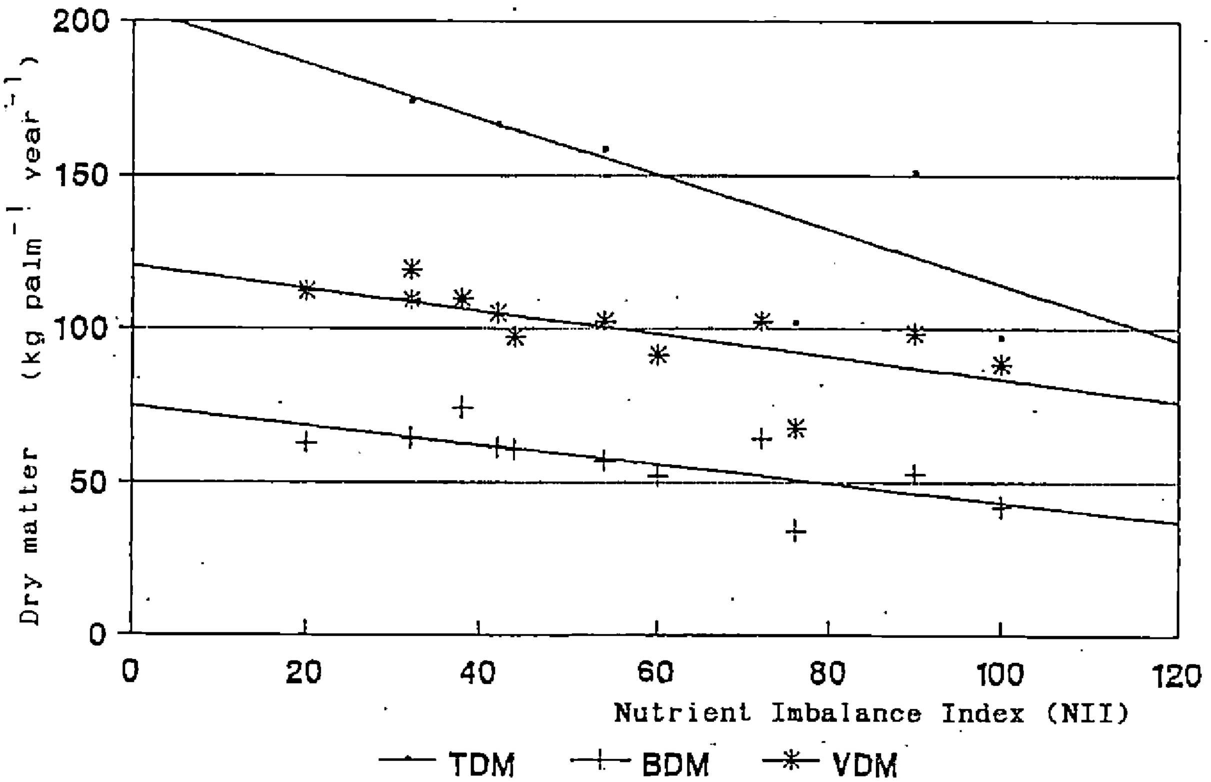
Nutrient imbalance indices involving all five nutrients were determined for every treatment of the field experiment and are presented in Table 45. The absolute sum of indices in the table is a measure of its relative balancing among the other nutrients at the various nutrient combination. The smaller the value of this sum, the better is the nutrient balance.

High nutrient imbalance indices were noted for F_0 and F_1 plots and were least for F_2 and F_3 treatments especially under irrigated conditions. The absolute sum of NII plotted against VDM, BDM and TDM and are presented in Fig. 19.

Most of the measured factors N, P, K, Ca and Mg limited oil palm yield and consequently got lowest production when sum of indices were large. Large yields were obtained only when the sum of indices were small, i.e., when N, P, K, Ca and Mg were more well balanced.

The NII presented in Table 45. is a measure of balance among nutrients in each treatment of the irrigation and fertilizer experiment. The larger the value of NII, the greater the intensity of imbalances among nutrients. NII measured the extent to which a particular nutrient deviated from the established norm. It is noticed that important ratios came under the zone of balanced nutrition for the F_2 treatments especially when irrigated. These are the treatments in which higher total dry matter, VDM and yields were also recorded. The treatment I_2F_2 in which maximum FFB yield was produced, major nutrient N, P and K were found to be balanced with magnesium ie., N/Mg, P/Mg and K/Mg were well balanced.

Fig. 19. Production of dry matter (VDM, BDM and TDM) as influenced by NII



It was observed (Fig. 19) that irrespective of irrigation, yields were poor in F_0 plots which recorded the maximum NII. NII values were lesser in F_1 than in F_0 plot which produced still higher dry matter yield. NII values were least in F_2 and F_3 plots which recorded maximum dry matter yield.

It may also be noted that whenever the NII was more the contribution to bunch yield was less. Thus under imbalanced nutrition, BDM production was reduced as noticed in F_0 and F_1 treatments. But when NII was less both TDM and BDM were more. This indicated that balanced nutrition is important to meet the vegetative requirement initially and once it is met, most of the remaining photosythates were used for bunch and oil production.

Thus the study of nutrient imbalance index has established the comparative superiority of F_2 level of fertilizer application over the remaining levels. Of all nutrients, K recorded most negative index and was the nutrient that has limited the growth and yield of oil palm at lower fertilizer levels. The order of requirement in general was K > P > N > Mg > Ca. K is seen balanced at F_2 level of fertilizer application. N at F_2 level appears to be a dose slightly higher than its requirement. Soil data also support the view as there was no difference between fertilizer treatments for organic carbon and available nitrogen contents. Insufficiency of P at higher levels indicates that there must be some inefficiency factor that is preventing proper P nutrition. Supply of potassium at F_2 level is 1200 g K_2O per palm also warrants application of magnesium to avoid imbalancing. To improve balancing of nutrients and to obtain maximum bunch yield at F_2 level, it is necessary to increase efficiency of applied phosphorus. Mg is required for oil and fatty acid synthesis and was more utilised at F_2 level due to heavy bunch production. Again at F_3 level Mg imblancing was not observed mainly because at this level, vegetative dry matter production was larger than at F_2 level for which magnesium would have been sufficient. Proper balanced nutrition is also found necessary to increase the bunch dry matter production in oil palm.

Part III. CLIMATE AND YIELD RELATIONSHIP OF OIL PALM

The yield distribution of oil palm for the period 1990-92 under rainfed and irrigated conditions of Palode are given in Table 47 and the average monthly distribution is depicted in Fig. 20. Peak production was observed during March, April, May and June with least production in the months of August, September October and November. The variations in weather parameters namely rainfall (RF), rainy days (RD), dry spell (DS), maximum temperature (MAT), minimum temperature (MIT), diurnal variation (DV), rainy days (RD) and daily Pan Evaporation (PE) during different months based on ten years data from 1983 to 1993 are presented in Table 48. It is envisaged to establish the interrelationship between climate and yield of oil palm in this study.

III.1 Influence of climate on yield

In oil palm, primordia initiation takes place 33-40 months ahead of harvest (Hartley, 1988).

There are reports indicating that the climate during the preceeding months, sometimes extending up to 42

Table 47. Monthly yield of FFB kg ha^{-1} during 1990-1992 in unirrigated (I_0F_2) and irrigated (I_2F_2) treatments

Months	Unirrigated (I_0F_2)				Irrigated (I_2F_2)			
	1990	1991	1992	Mean	1990	1991	1992	Mean
Jan	1059.0	281.0	403.0	581.0	1954.0	1298.0	678.0	1310.0
Feb	1271.0	1827.0	1059.0	1385.7	2987.0	2516.0	577.0	2026.7
Mar	4814.0	1086.0	291.0	2063.7	4359.0	3607.0	2277.0	3414.0
Apr	2659.0	3268.0	3850.0	3259.0	2442.0	1938.0	5323.0	3234.3
May	2638.0	4926.0	3204.0	3589.3	1833.0	6006.0	2583.0	3407.3
Jun	1345.0	4062.0	3210.0	2872.3	821.0	1742.0	3363.0	1975.3
Jul	0.0	371.0	673.0	348.0	572.0	1430.0	805.0	935.7
Aug	646.0	0.0	381.0	321.3	1234.0	334.0	821.0	796.3
Sep	810.0	450.0	169.0	476.3	1192.0	132.0	376.0	566.7
Oct	927.0	318.0	201.0	482.0	1388.0	371.0	387.0	715.3
Nov	768.0	185.0	0.0	317.7	1769.0	212.0	387.0	789.3
Dec	768.0	450.0	106.0	441.3	1202.0	689.0	408.0	766.3

Fig. 20. Monthly distribution of FFB yield (kg ha^{-1}) in irrigatied (I_2F_2) and unirrigated (I_0F_2) treatments

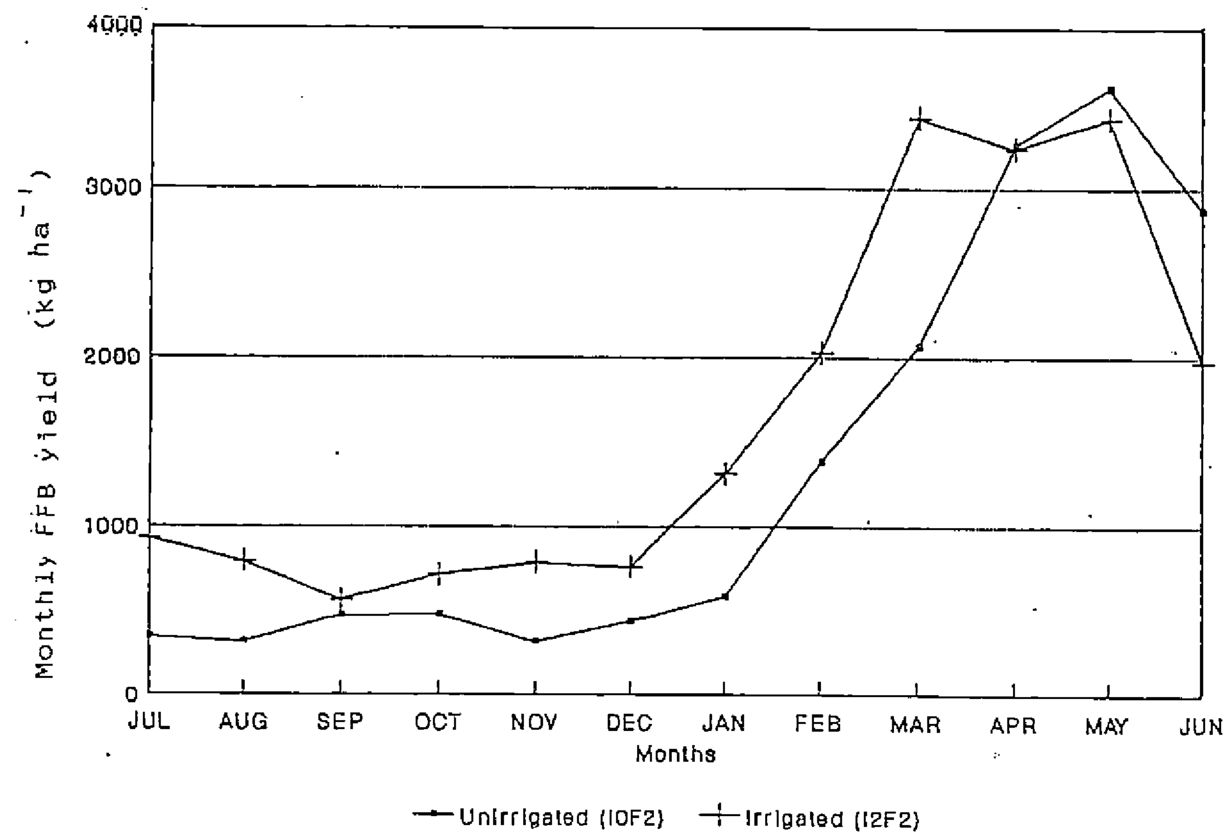


Table 48. Variations in monthly weather parameters at Palode (July 1983 to June 1993)

Months	RF	RD	DS	MAT	MIT	DV	RH	PE
	Weather Parameters							
JUL	348.4	16.4	14.9	29.9	22.8	7.4	81.7	3.2
AUG	236.4	14.5	17.3	30.0	22.7	7.4	80.8	3.2
SEP	232.1	11.8	20.6	31.1	22.5	8.8	78.5	3.7
OCT	372.9	16.1	13.9	31.2	22.2	9.0	81.7	3.2
NOV	281.8	12.3	17.8	31.3	21.6	9.9	79.2	3.3
DEC	62.0	3.8	27.3	32.4	20.4	12.1	71.3	3.9
JAN	32.1	1.7	29.2	33.1	19.4	13.8	68.1	4.7
FEB	50.3	2.8	28.0	34.4	20.4	14.3	66.3	5.8
MAR	77.6	4.7	27.2	35.0	21.7	13.6	69.3	5.5
APR	232.1	13.3	17.4	34.2	23.6	10.8	73.9	4.9
MAY	261.1	14.2	16.3	32.8	24.0	9.0	78.1	4.3
JUN	480.7	22.2	8.0	29.9	23.0	7.0	85.2	3.1
TOTAL	2667.6	134.4	237.6					
MEAN				32.1	22.0	10.3	76.2	4.1

RF : Rain fall (mm/month)

RD : Rainy days (days/month)

DS : Dry spell (days/month)

MAT : Maximum temperature (degree C)

MIT : Minimum temperature (degree C)

DV : Diurnal variation (degree C)

RH : Relative humidity (per cent)

PE : Daily pan evaporation (mm)

months before harvest had a pronounced influence on the production of oil palm Sparnaaij et al. (1963), Corley (1973), Ferwerda (1977) and Ong (1982a, 1982b and 1983). Such attempts under Indian conditions have not so far been made. In this study efforts were made to relate the influence of climatic parameters experienced by the crop prior to the harvest on number of bunches produced, average bunch weight and fresh fruit bunch yield from the data obtained in four representative treatments I_0F_0, I_2F_0, I_0F_2 and I_2F_2 of the field experiment. The correlation coefficients were worked out to establish the relationship of the climatic factors such as rainfall (Table 49), rainy days (Table 50), dry spell (Table 51), maximum temperature (Table 52), minimum temperature (Table 53), diurnal variation (Table 54), relative humidity (Table 55) and Pan evaporation (Table 56) with the above yield attributes.

From these correlation data it was observed that in all representative treatments of I_0F_0, I_2F_0, I_0F_2, and I_2F_2 certain lag periods had strong influence with the climatic parameters studied. Uniformity in lag periods for significant correlations were found more conspicuous for the characters such as the number of bunches and FFB yield. The average

Table 49. Correlation coefficients (r) between rainfall and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0			I2F0			I0F2			I2F2		
	NB	FFB	ABW	NB	FFB	ABW	NB	FFB	ABW	NB	FFB	ABW
0	0.377 *	0.346 *	-.041	0.005	0.052	0.076	0.257	0.214	-.143	-.051	-.063	-.135
1	-.180	-.144	-.001	-.255	-.261	-.275	-.292	-.290	-.231	-.284	-.306	-.237
2	-.371 *	-.342 *	-.130	-.459**	-.503**	-.464**	-.448**	-.463**	-.396 *	-.480**	-.512**	-.221
3	-.502**	-.505**	-.442**	-.455**	-.471**	-.320	-.452**	-.477**	0.017	-.470**	-.497**	-.213
4	-.498**	-.481**	-.418**	-.394 *	-.412 *	-.176	-.382 *	-.406 *	0.057	-.319	-.326 *	-.265
5	-.334 *	-.313	-.120	-.189	-.212	-.143	-.193	-.218	0.100	-.106	-.116	-.346 *
6	-.066	-.047	0.227	0.166	0.126	-.043	0.051	0.056	0.052	0.029	0.011	-.044
7	0.206	0.214	0.151	0.136	0.082	0.163	0.126	0.138	0.227	0.086	0.075	0.045
8	0.214	0.173	0.103	0.135	0.129	0.219	0.137	0.132	0.215	0.122	0.145	0.289
9	0.125	0.034	-.112	0.232	0.296	0.361 *	0.133	0.164	0.075	0.355 *	0.370 *	0.205
10	0.350 *	0.245	-.079	0.435**	0.509**	0.195	0.375 *	0.455**	0.002	0.449**	0.501**	0.310
11	0.388 *	0.360 *	-.003	0.359 *	0.384 *	0.158	0.406 *	0.458**	0.225	0.166	0.202	0.268
12	0.115	0.148	-.037	0.036	0.078	0.118	0.097	0.153	0.130	0.062	0.075	0.061
13	-.118	-.158	-.278	-.357 *	-.333 *	-.228	-.266	-.250	-.033	-.342 *	-.343 *	-.102
14	-.325 *	-.306	0.029	-.359 *	-.381 *	-.182	-.434**	-.436**	-.079	-.377 *	-.400 *	-.199
15	-.454**	-.426**	0.037	-.460**	-.447**	-.012	-.438**	-.468**	-.245	-.419**	-.459**	-.446**
16	-.485**	-.474**	-.026	-.396 *	-.409 *	-.315	-.386 *	-.417**	-.236	-.284	-.316	-.385 *
17	-.358 *	-.356 *	0.034	-.223	-.275	-.503**	-.279	-.298	-.260	-.104	-.100	-.230
18	-.091	-.102	0.071	0.208	0.097	-.263	0.054	0.058	0.065	0.112	0.104	-.203
19	0.362 *	0.418**	0.426**	0.489**	0.383 *	-.017	0.420**	0.404 *	0.018	0.379 *	0.354 *	0.062
20	0.429**	0.470**	0.213	0.391 *	0.365 *	0.210	0.468**	0.445**	0.111	0.474**	0.471**	0.133
21	0.369 *	0.301	0.030	0.377 *	0.359 *	0.148	0.341 *	0.315	0.039	0.338 *	0.337 *	0.195
22	0.367 *	0.351 *	0.049	0.220	0.277	0.218	0.270	0.261	-.240	0.282	0.316	0.241
23	0.458**	0.472**	0.001	0.424**	0.443**	0.121	0.539**	0.551**	-.064	0.372 *	0.367 *	0.165
24	0.344 *	0.325 *	-.147	-.156	-.118	0.015	0.156	0.128	-.036	-.109	-.115	0.037
25	-.046	-.007	-.136	-.170	-.143	-.192	-.185	-.160	-.142	-.266	-.275	-.060
26	-.228	-.262	-.142	-.388 *	-.427**	-.179	-.467**	-.492**	0.011	-.541**	-.545**	-.076
27	-.397 *	-.342 *	-.006	-.444**	-.438**	0.034	-.477**	-.503**	-.211	-.433**	-.445**	-.009
28	-.398 *	-.384 *	-.104	-.318	-.339 *	-.062	-.402 *	-.443**	-.007	-.316	-.329 *	-.100
29	-.323 *	-.298	0.018	-.124	-.171	-.100	-.176	-.190	0.166	-.039	-.038	-.020
30	0.060	-.010	0.049	0.280	0.311	0.193	0.170	0.189	0.206	0.290	0.307	0.116
31	0.338 *	0.288	0.232	0.426**	0.395 *	0.297	0.340 *	0.363 *	0.216	0.267	0.288	0.242
32	0.438**	0.485**	0.343 *	0.356 *	0.389 *	0.376 *	0.291	0.333 *	0.183	0.319	0.360 *	0.432**
33	0.345 *	0.344 *	0.267	0.292	0.331 *	0.363 *	0.281	0.293	0.073	0.330 *	0.362 *	0.387 *
34	0.302	0.234	-.148	0.315	0.397 *	0.255	0.322 *	0.348 *	0.021	0.312	0.320	0.272
35	0.245	0.257	0.061	0.138	0.198	0.236	0.219	0.243	-.075	0.246	0.294	0.265
36	0.044	0.050	-.044	-.043	0.042	0.063	0.109	0.112	0.092	-.164	-.147	-.006
37	-.213	-.132	-.023	-.355 *	-.335 *	-.258	-.274	-.236	-.174	-.183	-.202	-.145
38	-.245	-.234	-.162	-.423**	-.469**	-.408 *	-.334 *	-.387 *	-.187	-.508**	-.552**	-.396 *
39	-.637**	-.557**	-.030	-.459**	-.500**	-.230	-.590**	-.618**	0.020	-.410 *	-.441**	-.311
40	-.548**	-.526**	-.016	-.405 *	-.403 *	-.101	-.406 *	-.472**	-.337 *	-.331 *	-.355 *	-.404 *
41	-.424**	-.385 *	-.090	-.075	-.132	-.419**	-.132	-.148	0.001	-.015	-.041	-.239
42	0.010	0.042	0.035	0.085	0.040	-.035	0.121	0.103	0.085	0.149	0.164	0.040

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 50. Correlation coefficients (r) between rainy days and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	0.322 *	0.325 *	-.127	-.058	0.004	0.080	0.140	0.138	-.155	-.143	-.144	-.039
1	-.119	-.068	-.074	-.368 *	-.350 *	-.176	-.321	-.320	-.091	-.381 *	-.397 *	-.202
2	-.341 *	-.285	0.084	-.501**	-.518**	-.228	-.499**	-.535**	-.395 *	-.556**	-.590**	-.180
3	-.556**	-.536**	-.161	-.572**	-.569**	-.176	-.595**	-.636**	-.151	-.546**	-.567**	-.258
4	-.537**	-.524**	-.181	-.381 *	-.417**	-.275	-.409 *	-.436**	-.059	-.329 *	-.329 *	-.111
5	-.334 *	-.339 *	-.099	-.181	-.227	-.202	-.203	-.225	0.101	-.009	-.021	-.264
6	-.039	-.062	0.113	0.307	0.257	-.080	0.124	0.145	0.140	0.162	0.161	-.002
7	0.265	0.273	0.189	0.388 *	0.313	0.160	0.268	0.281	0.289	0.296	0.287	0.072
8	0.332 *	0.328 *	0.249	0.377 *	0.351 *	0.269	0.329 *	0.315	0.138	0.330 *	0.355 *	0.306
9	0.277	0.230	-.044	0.321	0.370 *	0.396 *	0.288	0.289	0.077	0.373 *	0.390 *	0.305
10	0.492**	0.457**	0.064	0.417**	0.478**	0.248	0.497**	0.535**	-.021	0.509**	0.542**	0.328 *
11	0.519**	0.487**	-.018	0.264	0.331 *	0.255	0.465**	0.483**	0.102	0.186	0.200	0.181
12	0.273	0.276	0.030	0.022	0.110	0.204	0.131	0.171	-.049	0.027	0.039	0.091
13	-.039	-.055	-.156	-.379 *	-.349 *	-.278	-.289	-.275	-.221	-.426**	-.423**	-.071
14	-.414 *	-.371 *	0.000	-.444**	-.485**	-.260	-.569**	-.574**	-.125	-.529**	-.537**	-.072
15	-.649**	-.616**	-.181	-.580**	-.550**	-.110	-.598**	-.619**	-.166	-.543**	-.566**	-.263
16	-.640**	-.623**	-.243	-.424**	-.467**	-.323 *	-.464**	-.484**	0.055	-.327 *	-.355 *	-.329 *
17	-.453**	-.431**	0.033	-.262	-.291	-.227	-.325 *	-.362 *	-.025	-.174	-.165	-.214
18	-.158	-.137	0.144	0.208	0.154	-.030	0.063	0.070	0.162	0.180	0.170	-.199
19	0.313	0.343 *	0.391 *	0.372 *	0.265	-.023	0.348 *	0.322 *	0.020	0.335 *	0.305	0.010
20	0.364 *	0.391 *	0.271	0.387 *	0.374 *	0.267	0.393 *	0.372 *	0.102	0.424**	0.430**	0.186
21	0.398 *	0.325 *	0.024	0.517**	0.536**	0.276	0.447**	0.460**	0.112	0.501**	0.516**	0.285
22	0.520**	0.465**	-.019	0.321	0.369 *	0.200	0.432**	0.436**	-.130	0.397 *	0.438**	0.306
23	0.488**	0.504**	-.018	0.475**	0.523**	0.184	0.547**	0.581**	-.028	0.402 *	0.421**	0.278
24	0.333 *	0.320	-.183	-.058	-.023	0.037	0.202	0.205	0.072	-.042	-.049	0.012
25	-.053	-.022	-.164	-.278	-.257	-.252	-.197	-.182	-.127	-.341 *	-.362 *	-.114
26	-.398 *	-.424**	-.223	-.519**	-.526**	-.145	-.588**	-.613**	-.053	-.638**	-.652**	-.197
27	-.566**	-.532**	-.133	-.609**	-.606**	-.129	-.627**	-.647**	-.197	-.561**	-.580**	-.219
28	-.536**	-.509**	-.070	-.511**	-.529**	-.234	-.539**	-.583**	-.141	-.448**	-.461**	-.231
29	-.430**	-.400 *	0.018	-.098	-.161	-.172	-.205	-.215	0.091	-.072	-.101	-.235
30	-.019	-.079	0.012	0.144	0.145	0.026	0.048	0.071	0.208	0.183	0.204	0.035
31	0.257	0.229	0.313	0.419**	0.365 *	0.208	0.281	0.291	0.199	0.249	0.280	0.245
32	0.382 *	0.406 *	0.291	0.458**	0.465**	0.373 *	0.338 *	0.373 *	0.196	0.432**	0.458**	0.354 *
33	0.464**	0.462**	0.213	0.391 *	0.407 *	0.326 *	0.444**	0.459**	0.031	0.510**	0.533**	0.385 *
34	0.440**	0.355 *	-.107	0.449**	0.518**	0.229	0.492**	0.506**	0.151	0.404 *	0.412 *	0.258
35	0.274	0.255	-.028	0.209	0.273	0.275	0.278	0.323 *	-.044	0.300	0.335 *	0.185
36	0.183	0.150	-.117	-.042	0.047	0.005	0.132	0.143	-.053	-.155	-.138	-.014
37	-.186	-.096	0.000	-.400 *	-.389 *	-.300	-.317	-.283	-.177	-.322 *	-.333 *	-.085
38	-.314	-.279	-.182	-.534**	-.557**	-.298	-.452**	-.491**	-.204	-.588**	-.638**	-.440**
39	-.664**	-.606**	-.075	-.570**	-.600**	-.338 *	-.658**	-.696**	-.102	-.522**	-.554**	-.339 *
40	-.609**	-.590**	-.041	-.424**	-.439**	-.144	-.490**	-.552**	-.292	-.371 *	-.386 *	-.340 *
41	-.442**	-.418**	-.012	-.169	-.214	-.314	-.195	-.213	-.009	-.064	-.071	-.228
42	-.037	-.004	0.088	0.138	0.053	-.179	0.121	0.108	0.105	0.094	0.076	-.044

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 51. Correlation coefficients (r) between dry spell and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	-.359 *	-.357 *	0.135	0.045	-.020	-.069	-.170	-.171	0.117	0.127	0.120	-.040
1	0.090	0.041	0.099	0.326 *	0.310	0.173	0.303	0.296	0.047	0.352 *	0.363 *	0.122
2	0.309	0.259	-.067	0.441**	0.457**	0.108	0.459**	0.492**	0.297	0.515**	0.545**	0.141
3	0.531**	0.510**	0.149	0.564**	0.537**	0.105	0.570**	0.608**	0.135	0.525**	0.542**	0.205
4	0.547**	0.530**	0.171	0.375 *	0.413 *	0.266	0.412 *	0.440**	0.061	0.321	0.321	0.108
5	0.350 *	0.358 *	0.128	0.187	0.232	0.209	0.204	0.225	-.125	0.011	0.023	0.265
6	0.035	0.060	-.113	-.310	-.259	0.075	-.131	-.152	-.147	-.174	-.172	0.003
7	-.270	-.277	-.196	-.392 *	-.318	-.161	-.275	-.287	-.286	-.295	-.284	-.046
8	-.331 *	-.329 *	-.258	-.376 *	-.348 *	-.271	-.324 *	-.312	-.134	-.327 *	-.352 *	-.303
9	-.283	-.236	0.026	-.316	-.364 *	-.381 *	-.287	-.284	-.051	-.373 *	-.389 *	-.296
10	-.480**	-.443**	-.048	-.416**	-.473**	-.232	-.489**	-.528**	0.022	-.501**	-.534**	-.328 *
11	-.519**	-.486**	0.021	-.265	-.333 *	-.262	-.466**	-.485**	-.098	-.196	-.210	-.185
12	-.278	-.278	-.024	-.022	-.112	-.191	-.140	-.180	0.042	-.026	-.038	-.084
13	0.038	0.052	0.155	0.377 *	0.347 *	0.270	0.292	0.275	0.217	0.427**	0.424**	0.069
14	0.408 *	0.365 *	-.008	0.448**	0.488**	0.263	0.570**	0.576**	0.133	0.535**	0.544**	0.082
15	0.658**	0.624**	0.183	0.585**	0.559**	0.121	0.609**	0.630**	0.163	0.552**	0.575**	0.255
16	0.641**	0.624**	0.235	0.424**	0.467**	0.305	0.466**	0.489**	-.044	0.322 *	0.351 *	0.328 *
17	0.456**	0.436**	-.018	0.260	0.286	0.237	0.319	0.354 *	0.019	0.172	0.162	0.212
18	0.151	0.128	-.146	-.213	-.157	0.024	-.070	-.078	-.167	-.189	-.179	0.192
19	-.321	-.349 *	-.391 *	-.375 *	-.272	0.020	-.354 *	-.328 *	-.023	-.335 *	-.304	0.001
20	-.363 *	-.390 *	-.269	-.387 *	-.373 *	-.262	-.385 *	-.368 *	-.104	-.418**	-.425**	-.195
21	-.401 *	-.331 *	-.039	-.511**	-.528**	-.279	-.444**	-.454**	-.102	-.497**	-.511**	-.280
22	-.503**	-.447**	0.031	-.315	-.365 *	-.198	-.423**	-.427**	0.125	-.388 *	-.430**	-.308
23	-.487**	-.504**	0.017	-.477**	-.522**	-.187	-.545**	-.577**	0.033	-.411 *	-.429**	-.277
24	-.339 *	-.325 *	0.184	0.055	0.018	-.026	-.211	-.214	-.073	0.038	0.041	-.012
25	0.043	0.012	0.161	0.257	0.241	0.244	0.180	0.165	0.124	0.324 *	0.348 *	0.115
26	0.377 *	0.404 *	0.211	0.517**	0.524**	0.150	0.578**	0.605**	0.063	0.634**	0.650**	0.208
27	0.568**	0.533**	0.134	0.607**	0.603**	0.132	0.633**	0.650**	0.187	0.571**	0.587**	0.201
28	0.528**	0.505**	0.068	0.511**	0.528**	0.213	0.542**	0.587**	0.145	0.446**	0.460**	0.228
29	0.429**	0.399 *	-.009	0.107	0.165	0.175	0.208	0.218	-.074	0.078	0.105	0.226
30	0.013	0.068	-.024	-.152	-.153	-.040	-.052	-.075	-.214	-.189	-.210	-.049
31	-.261	-.233	-.321	-.414 *	-.363 *	-.206	-.285	-.295	-.201	-.246	-.276	-.238
32	-.377 *	-.400 *	-.283	-.455**	-.461**	-.371 *	-.328 *	-.364 *	-.195	-.422**	-.448**	-.365 *
33	-.460**	-.459**	-.227	-.383 *	-.397 *	-.329 *	-.436**	-.447**	-.029	-.504**	-.527**	-.385 *
34	-.421**	-.338 *	0.112	-.434**	-.503**	-.222	-.475**	-.490**	-.155	-.391 *	-.400 *	-.255
35	-.266	-.248	0.020	-.210	-.273	-.279	-.274	-.317	0.051	-.305	-.338 *	-.181
36	-.180	-.146	0.128	0.031	-.059	0.004	-.144	-.155	0.044	0.147	0.130	0.022
37	0.182	0.090	-.006	0.395 *	0.385 *	0.284	0.315	0.281	0.171	0.312	0.320	0.071
38	0.301	0.263	0.162	0.521**	0.542**	0.293	0.437**	0.478**	0.210	0.585**	0.635**	0.439**
39	0.653**	0.588**	0.071	0.557**	0.591**	0.342 *	0.644**	0.680**	0.096	0.501**	0.534**	0.327 *
40	0.582**	0.566**	0.036	0.419**	0.435**	0.126	0.470**	0.539**	0.298	0.362 *	0.379 *	0.340 *
41	0.448**	0.426**	0.025	0.166	0.206	0.315	0.196	0.212	0.001	0.065	0.070	0.225
42	0.037	0.004	-.089	-.137	-.051	0.176	-.119	-.107	-.089	-.098	-.080	0.043

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 52. Correlation coefficients (r) between maximum temperature and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	0.119	0.098	0.093	0.424**	0.408 *	0.105	0.358 *	0.368 *	0.173	0.555**	0.565**	0.160
1	0.552**	0.479**	0.076	0.711**	0.701**	0.286	0.710**	0.730**	0.224	0.693**	0.721**	0.289
2	0.693**	0.653**	0.094	0.643**	0.662**	0.297	0.684**	0.726**	0.295	0.594**	0.629**	0.303
3	0.606**	0.605**	0.207	0.451**	0.466**	0.224	0.492**	0.525**	0.008	0.382 *	0.399 *	0.306
4	0.343 *	0.314	-.094	0.108	0.153	0.154	0.206	0.218	-.046	0.052	0.035	0.103
5	0.018	0.005	-.214	-.237	-.167	0.033	-.132	-.118	-.138	-.212	-.204	0.096
6	-.284	-.294	-.272	-.515**	-.434**	-.053	-.373 *	-.387 *	-.148	-.479**	-.474**	-.189
7	-.467**	-.439**	-.166	-.509**	-.450**	-.245	-.459**	-.440**	-.203	-.459**	-.467**	-.254
8	-.415**	-.367 *	-.054	-.514**	-.542**	-.361 *	-.491**	-.496**	-.166	-.528**	-.556**	-.348 *
9	-.508**	-.441**	0.097	-.433**	-.493**	-.321	-.536**	-.552**	0.064	-.494**	-.503**	-.237
10	-.545**	-.515**	0.071	-.256	-.332 *	-.116	-.447**	-.482**	0.009	-.244	-.270	-.217
11	-.309	-.327 *	0.048	0.044	-.014	-.084	-.114	-.141	0.011	0.166	0.161	-.076
12	0.036	0.017	0.077	0.407 *	0.365 *	0.065	0.311	0.310	0.190	0.432**	0.450**	0.156
13	0.410 *	0.388 *	0.118	0.610**	0.595**	0.256	0.630**	0.650**	0.317	0.663**	0.669**	0.081
14	0.623**	0.589**	0.058	0.608**	0.616**	0.147	0.686**	0.714**	0.112	0.584**	0.590**	0.163
15	0.645**	0.622**	0.090	0.463**	0.476**	0.238	0.503**	0.519**	0.052	0.419**	0.433**	0.226
16	0.431**	0.426**	0.070	0.151	0.201	0.185	0.270	0.276	-.134	0.081	0.094	0.175
17	0.114	0.129	-.118	-.147	-.105	0.056	-.015	-.021	-.206	-.159	-.180	0.004
18	-.158	-.162	-.270	-.432**	-.355 *	-.155	-.255	-.256	-.233	-.321	-.319	-.067
19	-.368 *	-.409 *	-.401 *	-.536**	-.500**	-.291	-.446**	-.439**	-.038	-.541**	-.540**	-.226
20	-.483**	-.454**	-.057	-.507**	-.538**	-.315	-.566**	-.565**	-.147	-.564**	-.585**	-.338 *
21	-.580**	-.522**	-.030	-.450**	-.503**	-.313	-.566**	-.572**	-.043	-.523**	-.555**	-.332 *
22	-.548**	-.534**	-.002	-.339 *	-.409 *	-.206	-.496**	-.512**	0.136	-.316	-.328 *	-.127
23	-.392 *	-.416**	-.003	-.087	-.136	-.028	-.256	-.281	0.112	-.087	-.088	-.095
24	-.065	-.068	0.121	0.350 *	0.326 *	0.213	0.163	0.181	0.211	0.415**	0.434**	0.104
25	0.462**	0.432**	0.246	0.549**	0.567**	0.317	0.607**	0.617**	0.169	0.628**	0.655**	0.234
26	0.674**	0.656**	0.242	0.684**	0.687**	0.249	0.720**	0.756**	0.187	0.664**	0.677**	0.241
27	0.673**	0.649**	0.206	0.541**	0.543**	0.258	0.572**	0.595**	0.016	0.472**	0.486**	0.264
28	0.455**	0.422**	0.017	0.273	0.318	0.146	0.341 *	0.362 *	-.044	0.262	0.277	0.232
29	0.182	0.145	-.143	-.070	-.020	0.027	0.029	0.032	-.222	-.074	-.059	0.155
30	-.125	-.103	-.255	-.297	-.274	-.172	-.169	-.178	-.208	-.282	-.304	-.200
31	-.352 *	-.319	-.249	-.477**	-.470**	-.382 *	-.375 *	-.386 *	-.165	-.419**	-.444**	-.303
32	-.450**	-.439**	-.166	-.521**	-.560**	-.372 *	-.503**	-.543**	-.167	-.550**	-.588**	-.442**
33	-.471**	-.433**	0.021	-.398 *	-.478**	-.371 *	-.527**	-.564**	-.149	-.495**	-.523**	-.329 *
34	-.364 *	-.301	0.185	-.270	-.381 *	-.164	-.372 *	-.434**	-.114	-.270	-.301	-.201
35	-.146	-.153	0.126	0.029	-.014	-.018	-.064	-.105	0.028	0.085	0.071	-.007
36	0.179	0.124	0.083	0.357 *	0.318	0.146	0.258	0.252	0.106	0.371 *	0.381 *	0.196
37	0.555**	0.497**	0.206	0.653**	0.655**	0.371 *	0.584**	0.602**	0.213	0.593**	0.629**	0.357 *
38	0.687**	0.654**	0.243	0.626**	0.676**	0.459**	0.622**	0.665**	0.159	0.553**	0.606**	0.552**
39	0.712**	0.693**	0.158	0.498**	0.543**	0.385 *	0.534**	0.575**	0.102	0.411 *	0.442**	0.490**
40	0.461**	0.462**	0.062	0.198	0.248	0.248	0.257	0.282	0.042	0.142	0.171	0.425**
41	0.127	0.110	-.103	-.073	0.020	0.330 *	-.008	-.002	-.002	-.089	-.071	0.229
42	-.167	-.173	-.127	-.354 *	-.259	0.026	-.253	-.248	-.177	-.287	-.275	0.012

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 53. Correlation coefficients (r) between minimum temperature and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	0.256	0.188	-.179	0.111	0.169	-.067	0.255	0.318	0.048	0.211	0.232	-.035
1	0.149	0.124	-.041	-.020	-.024	-.179	0.066	0.097	-.085	-.117	-.139	-.258
2	-.085	-.086	0.003	-.236	-.245	-.260	-.246	-.216	-.223	-.239	-.270	-.355 *
3	-.357 *	-.376 *	-.078	-.542**	-.609**	-.451**	-.536**	-.577**	-.396 *	-.634**	-.664**	-.341 *
4	-.642**	-.605**	-.057	-.512**	-.575**	-.450**	-.633**	-.660**	-.274	-.442**	-.475**	-.376 *
5	-.520**	-.545**	-.153	-.382 *	-.440**	-.405 *	-.398 *	-.428**	-.254	-.287	-.313	-.382 *
6	-.177	-.211	-.055	-.069	-.122	-.292	-.082	-.101	-.001	-.037	-.058	-.296
7	0.106	0.124	0.319	0.185	0.104	-.143	0.107	0.098	-.093	0.135	0.129	-.129
8	0.277	0.279	0.340 *	0.295	0.204	0.028	0.180	0.159	0.013	0.165	0.148	-.041
9	0.381 *	0.390 *	0.436**	0.372 *	0.332 *	0.082	0.235	0.224	-.195	0.327 *	0.346 *	0.420**
10	0.451**	0.400 *	0.057	0.401 *	0.383 *	0.306	0.395 *	0.369 *	0.007	0.373 *	0.387 *	0.342 *
11	0.462**	0.421**	0.046	0.364 *	0.429**	0.339 *	0.445**	0.451**	0.007	0.434**	0.472**	0.443**
12	0.477**	0.449**	-.004	0.248	0.347 *	0.259	0.400 *	0.418**	-.067	0.243	0.271	0.260
13	0.356 *	0.360 *	0.063	0.106	0.160	0.029	0.192	0.238	0.026	0.022	0.041	0.196
14	0.084	0.121	0.078	-.304	-.286	0.029	-.225	-.241	-.148	-.473**	-.480**	0.070
15	-.405 *	-.315	0.053	-.511**	-.474**	-.016	-.589**	-.601**	-.133	-.518**	-.521**	-.011
16	-.597**	-.561**	-.075	-.587**	-.566**	-.106	-.632**	-.679**	-.174	-.552**	-.550**	-.026
17	-.540**	-.485**	-.009	-.323 *	-.310	-.046	-.384 *	-.419**	-.043	-.191	-.191	-.106
18	-.263	-.215	0.075	0.007	-.006	-.038	-.022	-.046	0.063	0.042	0.050	-.050
19	0.031	0.087	0.207	0.218	0.162	0.003	0.204	0.188	0.264	0.277	0.271	-.044
20	0.236	0.265	0.297	0.415**	0.357 *	0.029	0.314	0.299	0.105	0.358 *	0.355 *	0.127
21	0.319	0.321	0.121	0.447**	0.400 *	0.262	0.368 *	0.346 *	0.172	0.413 *	0.410 *	0.187
22	0.405 *	0.407 *	0.091	0.468**	0.474**	0.277	0.497**	0.475**	0.030	0.514**	0.521**	0.295
23	0.404 *	0.375 *	-.169	0.319	0.386 *	0.299	0.487**	0.471**	0.052	0.408 *	0.425**	0.210
24	0.403 *	0.379 *	-.195	0.291	0.385 *	0.159	0.480**	0.517**	0.049	0.316	0.330 *	0.170
25	0.365 *	0.363 *	-.160	0.008	0.025	-.024	0.182	0.196	0.028	-.099	-.113	-.044
26	0.017	0.072	-.034	-.321	-.279	0.020	-.284	-.280	-.080	-.415**	-.395 *	0.051
27	-.296	-.271	-.142	-.421**	-.440**	-.132	-.435**	-.470**	-.155	-.470**	-.500**	-.127
28	-.477**	-.474**	-.182	-.466**	-.531**	-.254	-.493**	-.542**	-.152	-.382 *	-.420**	-.206
29	-.495**	-.525**	-.225	-.244	-.246	-.075	-.343 *	-.354 *	0.073	-.243	-.243	-.087
30	-.233	-.311	-.168	0.001	-.023	-.063	-.087	-.062	0.355 *	-.008	0.003	-.077
31	0.095	0.060	0.062	0.150	0.099	-.002	0.077	0.098	0.100	0.128	0.132	0.016
32	0.277	0.271	0.247	0.397 *	0.355 *	0.238	0.207	0.224	0.179	0.273	0.278	0.148
33	0.369 *	0.365 *	0.313	0.405 *	0.379 *	0.266	0.293	0.310	0.123	0.345 *	0.358 *	0.297
34	0.422**	0.368 *	0.190	0.384 *	0.412 *	0.402 *	0.363 *	0.357 *	-.007	0.378 *	0.407 *	0.362 *
35	0.375 *	0.303	0.008	0.330 *	0.425**	0.367 *	0.410 *	0.438**	-.019	0.370 *	0.411 *	0.397 *
36	0.421**	0.383 *	-.013	0.116	0.190	0.143	0.289	0.344 *	0.025	0.187	0.215	0.220
37	0.239	0.251	0.154	-.086	-.025	-.020	-.001	0.037	-.084	-.171	-.152	0.075
38	-.120	-.096	-.016	-.220	-.189	-.066	-.266	-.244	-.140	-.320	-.340 *	-.109
39	-.391 *	-.359 *	-.018	-.512**	-.531**	-.248	-.530**	-.560**	-.309	-.453**	-.464**	-.160
40	-.710**	-.647**	-.014	-.535**	-.542**	-.270	-.635**	-.685**	-.187	-.587**	-.581**	-.153
41	-.654**	-.565**	-.015	-.307	-.331 *	-.217	-.392 *	-.400 *	-.002	-.170	-.187	-.242
42	-.167	-.145	-.030	-.125	-.182	-.267	0.003	-.051	0.007	0.011	-.018	-.291

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 54. Correlation coefficients (r) between diurnal variation and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	-.055	-.032	0.169	0.253	0.208	0.115	0.123	0.096	0.101	0.294	0.290	0.138
1	0.328 *	0.288	0.079	0.539**	0.534**	0.311	0.491**	0.489**	0.213	0.579**	0.612**	0.357 *
2	0.562**	0.533**	0.068	0.608**	0.627**	0.364 *	0.644**	0.659**	0.342 *	0.573**	0.616**	0.420**
3	0.647**	0.655**	0.197	0.631**	0.678**	0.412 *	0.659**	0.705**	0.221	0.630**	0.658**	0.414 *
4	0.605**	0.563**	-.040	0.357 *	0.424**	0.358 *	0.496**	0.520**	0.113	0.277	0.282	0.280
5	0.291	0.295	-.084	0.021	0.106	0.242	0.111	0.138	0.029	-.011	0.009	0.278
6	-.129	-.119	-.185	-.368 *	-.276	0.114	-.249	-.250	-.116	-.357 *	-.341 *	0.009
7	-.430**	-.417**	-.295	-.504**	-.416**	-.125	-.424**	-.405 *	-.117	-.439**	-.442**	-.139
8	-.475**	-.438**	-.215	-.564**	-.541**	-.306	-.487**	-.481**	-.141	-.510**	-.524**	-.260
9	-.579**	-.531**	-.131	-.516**	-.544**	-.291	-.532**	-.539**	0.143	-.543**	-.559**	-.385 *
10	-.643**	-.594**	0.027	-.395 *	-.445**	-.239	-.539**	-.553**	0.003	-.371 *	-.399 *	-.336 *
11	-.460**	-.453**	0.014	-.143	-.219	-.228	-.302	-.326 *	0.005	-.084	-.106	-.272
12	-.197	-.198	0.062	0.197	0.118	-.072	0.051	0.042	0.178	0.218	0.219	-.003
13	0.147	0.128	0.061	0.420**	0.382 *	0.183	0.395 *	0.388 *	0.232	0.501**	0.496**	-.031
14	0.439**	0.395 *	0.007	0.613**	0.611**	0.099	0.635**	0.665**	0.157	0.677**	0.684**	0.092
15	0.690**	0.629**	0.043	0.603**	0.594**	0.190	0.671**	0.689**	0.104	0.571**	0.584**	0.179
16	0.618**	0.597**	0.090	0.398 *	0.426**	0.194	0.511**	0.538**	-.020	0.327 *	0.336 *	0.147
17	0.345 *	0.330 *	-.085	0.042	0.068	0.065	0.172	0.184	-.137	-.030	-.046	0.054
18	0.006	-.020	-.241	-.330 *	-.266	-.099	-.182	-.172	-.207	-.263	-.265	-.027
19	-.291	-.349 *	-.400 *	-.507**	-.453**	-.220	-.433**	-.420**	-.155	-.539**	-.535**	-.148
20	-.471**	-.463**	-.186	-.576**	-.570**	-.247	-.570**	-.562**	-.159	-.590**	-.605**	-.311
21	-.582**	-.540**	-.082	-.550**	-.565**	-.358 *	-.596**	-.589**	-.116	-.586**	-.608**	-.335 *
22	-.602**	-.592**	-.047	-.482**	-.535**	-.289	-.610**	-.611**	0.084	-.487**	-.500**	-.240
23	-.492**	-.496**	0.079	-.221	-.290	-.166	-.429**	-.441**	0.059	-.264	-.273	-.174
24	-.250	-.240	0.187	0.113	0.048	0.078	-.120	-.125	0.131	0.149	0.155	-.008
25	0.165	0.143	0.263	0.406 *	0.411 *	0.248	0.364 *	0.364 *	0.112	0.518**	0.545**	0.196
26	0.487**	0.446**	0.195	0.662**	0.643**	0.173	0.669**	0.694**	0.177	0.694**	0.694**	0.152
27	0.639**	0.609**	0.221	0.605**	0.617**	0.254	0.636**	0.669**	0.089	0.580**	0.605**	0.256
28	0.571**	0.545**	0.104	0.432**	0.498**	0.234	0.496**	0.536**	0.044	0.382 *	0.412 *	0.272
29	0.382 *	0.371 *	0.012	0.074	0.111	0.058	0.195	0.203	-.196	0.070	0.081	0.156
30	0.033	0.088	-.092	-.208	-.180	-.088	-.074	-.093	-.327 *	-.194	-.214	-.100
31	-.292	-.252	-.204	-.408 *	-.377 *	-.263	-.300	-.319	-.167	-.357 *	-.376 *	-.217
32	-.466**	-.455**	-.249	-.580**	-.585**	-.390 *	-.466**	-.503**	-.214	-.535**	-.564**	-.391 *
33	-.538**	-.508**	-.154	-.505**	-.548**	-.410 *	-.536**	-.572**	-.174	-.542**	-.569**	-.396 *
34	-.492**	-.418**	0.031	-.403 *	-.499**	-.336 *	-.466**	-.507**	-.078	-.400 *	-.438**	-.341 *
35	-.310	-.275	0.084	-.162	-.245	-.215	-.272	-.316	0.030	-.145	-.178	-.224
36	-.106	-.123	0.066	0.185	0.117	0.023	0.022	-.013	0.061	0.156	0.147	0.016
37	0.253	0.207	0.059	0.501**	0.469**	0.269	0.406 *	0.397 *	0.194	0.506**	0.520**	0.206
38	0.543**	0.508**	0.177	0.558**	0.575**	0.356 *	0.581**	0.598**	0.189	0.563**	0.611**	0.444**
39	0.717**	0.686**	0.121	0.637**	0.679**	0.408 *	0.672**	0.717**	0.246	0.543**	0.571**	0.432**
40	0.726**	0.691**	0.052	0.444**	0.483**	0.327 *	0.542**	0.588**	0.135	0.434**	0.451**	0.384 *
41	0.466**	0.403 *	-.063	0.127	0.206	0.355 *	0.222	0.231	0.000	0.038	0.060	0.299
42	-.014	-.031	-.069	-.168	-.069	0.175	-.174	-.139	-.125	-.202	-.177	0.179

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 55. Correlation coefficients (r) between relative humidity and yield from lag 0 to lag 42 months in different treatments

Lag	I0F0 NB	I0F0 FFB	I0F0 ABW	I2F0 NB	I2F0 FFB	I2F0 ABW	I0F2 NB	I0F2 FFB	I0F2 ABW	I2F2 NB	I2F2 FFB	I2F2 ABW
0	0.178	0.173	-.112	-.193	-.123	-.027	-.006	-.001	-.128	-.229	-.225	-.082
1	-.273	-.211	-.075	-.441**	-.431**	-.260	-.428**	-.428**	-.214	-.506**	-.540**	-.308
2	-.508**	-.435**	-.004	-.603**	-.631**	-.326 *	-.646**	-.681**	-.367 *	-.620**	-.651**	-.287
3	-.667**	-.621**	-.148	-.594**	-.626**	-.302	-.618**	-.683**	-.139	-.601**	-.620**	-.277
4	-.585**	-.544**	-.119	-.352 *	-.398 *	-.234	-.401 *	-.439**	-.038	-.203	-.216	-.214
5	-.212	-.220	-.014	-.049	-.105	-.167	-.034	-.072	0.054	0.054	0.038	-.245
6	0.122	0.119	0.185	0.393 *	0.335 *	-.027	0.270	0.285	0.239	0.315	0.305	0.012
7	0.398 *	0.379 *	0.240	0.449**	0.386 *	0.224	0.375 *	0.377 *	0.186	0.374 *	0.370 *	0.109
8	0.394 *	0.355 *	0.104	0.453**	0.450**	0.263	0.371 *	0.375 *	0.136	0.369 *	0.393 *	0.337 *
9	0.376 *	0.344 *	-.007	0.399 *	0.438**	0.357 *	0.353 *	0.373 *	0.031	0.435**	0.471**	0.445**
10	0.464**	0.420**	-.117	0.331 *	0.416**	0.312	0.478**	0.510**	0.101	0.366 *	0.401 *	0.304
11	0.375 *	0.360 *	-.108	0.153	0.243	0.233	0.342 *	0.381 *	0.107	0.120	0.135	0.201
12	0.158	0.158	-.083	-.189	-.104	0.108	-.022	0.011	-.020	-.182	-.181	-.059
13	-.228	-.227	-.095	-.503**	-.461**	-.223	-.479**	-.455**	-.127	-.581**	-.574**	-.086
14	-.556**	-.513**	-.002	-.601**	-.627**	-.220	-.711**	-.726**	-.220	-.651**	-.673**	-.210
15	-.749**	-.711**	-.163	-.572**	-.585**	-.283	-.648**	-.666**	-.149	-.481**	-.506**	-.310
16	-.663**	-.668**	-.207	-.351 *	-.394 *	-.283	-.433**	-.458**	0.068	-.258	-.269	-.256
17	-.384 *	-.383 *	0.002	-.012	-.046	-.194	-.119	-.120	0.130	0.067	0.072	-.240
18	0.026	0.032	0.151	0.326 *	0.252	-.048	0.224	0.237	0.196	0.273	0.269	-.114
19	0.396 *	0.434**	0.389 *	0.438**	0.367 *	0.127	0.428**	0.414 *	0.112	0.437**	0.417**	0.033
20	0.429**	0.434**	0.230	0.427**	0.409 *	0.192	0.425**	0.415**	0.038	0.436**	0.431**	0.135
21	0.432**	0.377 *	0.051	0.424**	0.435**	0.256	0.424**	0.416**	-.041	0.452**	0.459**	0.207
22	0.455**	0.403 *	-.052	0.344 *	0.410 *	0.157	0.460**	0.467**	-.190	0.393 *	0.421**	0.237
23	0.395 *	0.376 *	-.179	0.183	0.234	0.050	0.366 *	0.395 *	-.058	0.185	0.207	0.157
24	0.213	0.222	-.159	-.137	-.109	-.163	0.082	0.097	-.049	-.174	-.186	-.070
25	-.177	-.153	-.215	-.400 *	-.411 *	-.303	-.366 *	-.354 *	-.075	-.490**	-.527**	-.246
26	-.489**	-.495**	-.186	-.626**	-.632**	-.174	-.695**	-.720**	-.133	-.705**	-.721**	-.226
27	-.692**	-.669**	-.125	-.624**	-.639**	-.197	-.718**	-.755**	-.171	-.636**	-.653**	-.247
28	-.628**	-.589**	-.047	-.436**	-.473**	-.181	-.520**	-.550**	-.095	-.333 *	-.346 *	-.214
29	-.304	-.307	-.016	-.041	-.065	-.117	-.089	-.091	0.152	0.028	0.022	-.127
30	0.116	0.071	0.115	0.317	0.283	0.060	0.211	0.239	0.311	0.297	0.311	0.066
31	0.409 *	0.385 *	0.355 *	0.500**	0.470**	0.334 *	0.383 *	0.402 *	0.185	0.393 *	0.420**	0.225
32	0.460**	0.457**	0.329 *	0.520**	0.542**	0.381 *	0.427**	0.462**	0.134	0.468**	0.498**	0.412 *
33	0.446**	0.429**	0.147	0.382 *	0.410 *	0.295	0.408 *	0.436**	0.024	0.441**	0.461**	0.395 *
34	0.329 *	0.272	-.152	0.255	0.349 *	0.240	0.345 *	0.374 *	0.083	0.284	0.317	0.272
35	0.173	0.150	-.168	0.104	0.191	0.156	0.217	0.257	-.002	0.153	0.177	0.101
36	0.041	0.051	-.107	-.218	-.148	-.098	-.031	-.014	-.132	-.191	-.185	-.154
37	-.284	-.201	-.003	-.428**	-.433**	-.351 *	-.368 *	-.361 *	-.185	-.488**	-.514**	-.265
38	-.530**	-.463**	-.091	-.627**	-.671**	-.380 *	-.611**	-.648**	-.166	-.626**	-.678**	-.459**
39	-.733**	-.694**	-.151	-.625**	-.672**	-.397 *	-.677**	-.731**	-.199	-.536**	-.573**	-.420**
40	-.641**	-.637**	-.121	-.366 *	-.404 *	-.242	-.466**	-.524**	-.145	-.290	-.307	-.342 *
41	-.325 *	-.286	0.042	0.018	-.048	-.246	-.031	-.045	-.010	0.122	0.106	-.260
42	0.136	0.144	0.084	0.326 *	0.244	-.123	0.319	0.306	0.184	0.294	0.277	-.086

"*" Significant at P= 0.05 "**" Significant at P=0.01

Table 56. Correlation coefficients (r) between pan evaporation and yield from lag 0 to lag 42 months in different treatments

	I0F0			I2F0			I0F2			I2F2		
Lag	NB	FFB	ABW	NB	FFB	ABW	NB	FFB	ABW	NB	FFB	ABW
0	0.183	0.144	0.124	0.458**	0.428**	0.195	0.368 *	0.359 *	0.150	0.483**	0.508**	0.301
1	0.449**	0.449**	0.129	0.729**	0.737**	0.339 *	0.703**	0.738**	0.253	0.745**	0.779**	0.385 *
2	0.626**	0.568**	-.092	0.518**	0.563**	0.264	0.664**	0.698**	0.379 *	0.533**	0.570**	0.317
3	0.611**	0.610**	0.077	0.432**	0.454**	0.207	0.518**	0.552**	0.099	0.399 *	0.402 *	0.210
4	0.384 *	0.378 *	0.029	0.081	0.131	0.229	0.170	0.164	-.128	0.012	-.003	0.005
5	-.023	0.007	-.029	-.257	-.205	0.060	-.152	-.164	-.240	-.287	-.301	-.015
6	-.340 *	-.329 *	-.215	-.575**	-.511**	-.229	-.445**	-.469**	-.321	-.483**	-.488**	-.152
7	-.525**	-.526**	-.329 *	-.554**	-.534**	-.327 *	-.487**	-.489**	-.149	-.510**	-.511**	-.235
8	-.421**	-.401 *	-.196	-.442**	-.441**	-.306	-.435**	-.423**	-.010	-.429**	-.446**	-.281
9	-.379 *	-.316	0.122	-.340 *	-.407 *	-.243	-.416**	-.427**	0.045	-.392 *	-.406 *	-.280
10	-.397 *	-.359 *	0.112	-.106	-.177	-.100	-.328 *	-.351 *	0.094	-.208	-.234	-.159
11	-.250	-.247	0.120	0.046	-.037	-.023	-.131	-.161	0.027	0.139	0.137	0.025
12	0.028	-.016	-.016	0.349 *	0.320	0.119	0.264	0.249	0.198	0.366 *	0.385 *	0.176
13	0.359 *	0.327 *	0.077	0.570**	0.575**	0.326 *	0.576**	0.602**	0.291	0.668**	0.685**	0.212
14	0.694**	0.637**	0.028	0.594**	0.641**	0.261	0.751**	0.786**	0.159	0.599**	0.607**	0.136
15	0.679**	0.653**	0.133	0.465**	0.490**	0.210	0.507**	0.549**	0.088	0.386 *	0.402 *	0.238
16	0.433**	0.422**	0.117	0.111	0.162	0.210	0.177	0.187	-.175	-.016	0.000	0.177
17	0.016	0.036	-.085	-.196	-.156	-.008	-.138	-.125	-.200	-.205	-.209	0.085
18	-.241	-.246	-.239	-.469**	-.417**	-.111	-.341 *	-.359 *	-.232	-.416**	-.415**	-.016
19	-.476**	-.478**	-.365 *	-.532**	-.473**	-.236	-.452**	-.436**	-.013	-.430**	-.429**	-.236
20	-.450**	-.450**	-.120	-.442**	-.471**	-.327 *	-.457**	-.463**	-.069	-.482**	-.499**	-.340 *
21	-.495**	-.432**	0.081	-.374 *	-.431**	-.304	-.471**	-.483**	-.061	-.391 *	-.424**	-.389 *
22	-.443**	-.415**	0.114	-.198	-.284	-.235	-.382 *	-.398 *	0.040	-.263	-.283	-.169
23	-.316	-.311	0.095	-.073	-.155	-.069	-.215	-.252	0.096	-.039	-.056	-.112
24	-.041	-.053	0.085	0.332 *	0.322 *	0.163	0.171	0.170	0.096	0.396 *	0.417**	0.141
25	0.421**	0.378 *	0.098	0.534**	0.555**	0.337 *	0.595**	0.600**	0.168	0.648**	0.676**	0.210
26	0.731**	0.722**	0.246	0.694**	0.713**	0.222	0.798**	0.828**	0.106	0.675**	0.689**	0.237
27	0.659**	0.662**	0.180	0.444**	0.468**	0.245	0.541**	0.570**	0.046	0.384 *	0.398 *	0.229
28	0.435**	0.411 *	0.013	0.222	0.250	0.091	0.276	0.296	-.023	0.123	0.125	0.191
29	0.055	0.032	-.188	-.281	-.232	-.015	-.183	-.190	-.223	-.236	-.216	0.138
30	-.270	-.253	-.250	-.301	-.282	-.097	-.260	-.277	-.206	-.324 *	-.346 *	-.161
31	-.451**	-.428**	-.303	-.530**	-.508**	-.347 *	-.425**	-.434**	-.108	-.414 *	-.436**	-.306
32	-.459**	-.441**	-.180	-.412 *	-.453**	-.363 *	-.405 *	-.426**	-.068	-.448**	-.475**	-.380 *
33	-.416**	-.409 *	-.042	-.322 *	-.390 *	-.303	-.440**	-.468**	0.038	-.409 *	-.431**	-.324 *
34	-.261	-.200	0.214	-.136	-.253	-.119	-.284	-.321	-.082	-.164	-.189	-.150
35	-.037	-.034	0.204	0.102	0.051	0.038	-.012	-.057	0.037	0.130	0.120	0.029
36	0.197	0.156	0.124	0.427**	0.375 *	0.180	0.335 *	0.321	0.089	0.443**	0.441**	0.198
37	0.552**	0.465**	0.063	0.586**	0.606**	0.342 *	0.589**	0.599**	0.148	0.622**	0.652**	0.304
38	0.678**	0.619**	0.177	0.633**	0.673**	0.347 *	0.655**	0.698**	0.146	0.534**	0.587**	0.489**
39	0.692**	0.664**	0.103	0.425**	0.482**	0.334 *	0.483**	0.539**	0.105	0.338 *	0.364 *	0.386 *
40	0.459**	0.464**	0.097	0.105	0.143	0.174	0.181	0.209	-.061	0.018	0.036	0.322 *
41	0.038	0.032	-.114	-.196	-.122	0.192	-.176	-.178	-.051	-.271	-.265	0.163
42	-.316	-.303	-.073	-.454**	-.378 *	0.035	-.420**	-.421**	-.237	-.347 *	-.329 *	0.019

"*" Significant at P= 0.05 "**" Significant at P=0.01

bunch weight was not found much influenced and the few significant correlations observed also remained erratic and hence not further studied. In otherwords a uniform trend in significant correlation of climatic parameters with number of bunches produced and the FFB yield at certain specific lag periods have been brought out from this study. As these observed significant correlations followed uniformity in lag periods between treatments, only the production obtained in I_0F_2 and I_2F_2 were taken into consideration and studied further.

These relatively important lag periods are presented in Table 57 (I_0F_2) and Table 58 (I_2F_2). Moreover the combined influence of all the climatic parameters has been presented in the same tables. The lag periods having significance remained almost similar in these two treatments with higher correlation coefficient values in I_0F_2 both for number of bunches produced and FFB yield. It is worth mentioning here that the FFB yield distribution pattern also followed a similar trend in both irrigated and unirrigated plots though slightly better yields were obtained during most of the months in the irrigated plot (Fig. 20).

Table 57. Correlation coefficients (r) between weather variables and number of bunches as well as FFB yield significant at 0.05 level in IOF2 treatment

Lag	NB								FFB							
	RF	RD	DS	MAT	MIT	DV	RH	DE	RF	RD	DS	MAT	MIT	DV	RH	DE
0				0.358				0.368				0.368				0.359
1				0.710		0.491	-.428	0.703				0.730		0.489	-.428	0.738
2	-.448	-.499	0.459	0.684		0.644	-.646	0.664	-.463	-.535	0.492	0.726		0.659	-.681	0.698
3	-.452	-.595	0.570	0.492	-.536	0.659	-.618	0.518	-.477	-.636	0.608	0.525	-.577	0.705	-.683	0.552
4	-.382	-.409	0.412		-.633	0.496	-.401		-.406	-.436	0.440		-.660	0.520	-.439	
5					-.398								-.428			
6				-.373				-.445				-.387				-.469
7				-.459		-.424	0.375	-.487				-.440		-.405	0.377	-.489
8		0.329	-.324	-.491		-.487	0.371	-.435				-.496		-.481	0.375	-.423
9				-.536		-.532	0.353	-.416				-.552		-.539	0.373	-.427
10	0.375	0.497	-.489	-.447	0.395	-.539	0.478	-.328	0.455	0.535	-.528	-.482	0.369	-.553	0.510	-.351
11	0.406	0.465	-.466		0.445		0.342		0.458	0.483	-.485		0.451	-.326	0.381	
12					0.400								0.418			
13				0.630		0.395	-.479	0.576				0.650		0.388	-.455	0.602
14	-.434	-.569	0.570	0.686		0.635	-.711	0.751	-.436	-.574	0.576	0.714		0.665	-.726	0.786
15	-.438	-.598	0.609	0.503	-.589	0.671	-.648	0.507	-.468	-.619	0.630	0.519	-.601	0.689	-.666	0.549
16	-.386	-.464	0.466		-.632	0.511	-.433		-.417	-.484	0.489		-.679	0.538	-.458	
17		-.325			-.384					-.362	0.354		-.419			
18								-.341								-.359
19	0.420	0.348	-.354	-.446		-.433	0.428	-.452	0.404	0.322	-.328	-.439		-.420	0.414	-.436
20	0.468	0.393	-.385	-.566		-.570	0.425	-.457	0.445	0.372	-.368	-.565		-.562	0.415	-.463
21	0.341	0.447	-.444	-.566	0.368	-.596	0.424	-.471		0.460	-.454	-.572	0.346	-.589	0.416	-.483
22		0.432	-.423	-.496	0.497	-.610	0.460	-.382		0.436	-.427	-.512	0.475	-.611	0.467	-.398
23	0.539	0.547	-.545		0.487	-.429	0.366		0.551	0.581	-.577		0.471	-.441	0.395	
24					0.480								0.517			
25				0.607		0.364	-.366	0.595				0.617		0.364	-.354	0.600
26	-.467	-.588	0.578	0.720		0.669	-.695	0.798	-.492	-.613	0.605	0.756		0.694	-.720	0.828
27	-.477	-.627	0.633	0.572	-.435	0.636	-.718	0.541	-.503	-.647	0.650	0.595	-.470	0.669	-.755	0.570
28	-.402	-.539	0.542	0.341	-.493	0.496	-.520		-.443	-.583	0.587	0.362	-.542	0.536	-.550	
29					-.343								-.354			
30																
31	0.340			-.375			0.383	-.425	0.363			-.386			0.402	-.434
32		0.338	-.328	-.503		-.466	0.427	-.405	0.333	0.373	-.364	-.543		-.503	0.462	-.426
33		0.444	-.436	-.527		-.536	0.408	-.440		0.459	-.447	-.564		-.572	0.436	-.468
34	0.322	0.492	-.475	-.372	0.363	-.466	0.345		0.348	0.506	-.490	-.434	0.357	-.507	0.374	
35					0.410					0.323			0.438			
36								0.335					0.344			
37				0.584		0.406	-.368	0.589				0.602		0.397	-.361	0.599
38	-.334	-.452	0.437	0.622		0.581	-.611	0.655	-.387	-.491	0.478	0.665		0.598	-.648	0.698
39	-.590	-.658	0.644	0.534	-.530	0.672	-.677	0.483	-.618	-.696	0.680	0.575	-.560	0.717	-.731	0.539
40	-.406	-.490	0.470		-.635	0.542	-.466		-.472	-.552	0.539		-.685	0.588	-.524	
41					-.392								-.400			
42								-.420								-.421

It was also observed that both the number of bunches and FFB yield showed stronger relationship with climate exactly at same lag periods. Here again the correlation coeffficient values were more for FFB yield than for number of bunches. All these inferences drawn have provided sufficient ground for restricting detailed investigations only on FFB yield in I_0F_2 treatment.

III.2 Identification of important lag periods

When the correlation coefficients of the different climatic parameters determined were observed together for combined influence, certain lag periods were found important. The significant correlations of all parameters were clustered around certain specific lag periods. From Table 58 it could be seen that out of the 42 months lag period, seven lag periods were conspicuous in exerting the influence of climate on FFB yield. Proceeding further the attention has been focussed on the values attaining P = 0.001 level of significance only, eventhough in other tables mentioned previously only values attaining significance at 0.05 level was taken.

Table 58. Correlation coefficients (r) between weather variables and number of bunches as well as FFB yield significant at 0.05 level in I2F2 treatment

Lag	NB								FFB							
	RF	RD	DS	MAT	MIT	DV	RH	DE	RF	RD	DS	MAT	MIT	DV	RH	DE
0				0.555				0.483				0.565				0.508
1		-.381	0.352	0.693		0.579	-.506	0.745		-.397	0.363	0.721		0.612	-.540	0.779
2	-.480	-.556	0.515	0.594		0.573	-.620	0.533	-.512	-.590	0.545	0.629		0.616	-.651	0.570
3	-.470	-.546	0.525	0.382	-.634	0.630	-.601	0.399	-.497	-.567	0.542	0.399	-.664	0.658	-.620	0.402
4		-.329			-.442				-.326	-.329			-.475			
5																
6				-.479		-.357		-.483				-.474		-.341		-.488
7				-.459		-.439	0.374	-.510				-.467		-.442	0.370	-.511
8		0.330	-.327	-.528		-.510	0.369	-.429		0.355	-.352	-.556		-.524	0.393	-.446
9	0.355	0.373	-.373	-.494	0.327	-.543	0.435	-.392	0.370	0.390	-.389	-.503	0.346	-.559	0.471	-.406
10	0.449	0.509	-.501		0.373	-.371	0.366		0.501	0.542	-.534		0.387	-.399	0.401	
11					0.434								0.472			
12				0.432				0.366				0.450				0.385
13	-.342	-.426	0.427	0.663		0.501	-.581	0.668	-.343	-.423	0.424	0.669		0.496	-.574	0.685
14	-.377	-.529	0.535	0.584	-.473	0.677	-.651	0.599	-.400	-.537	0.544	0.590	-.480	0.684	-.673	0.607
15	-.419	-.543	0.552	0.419	-.518	0.571	-.481	0.386	-.459	-.566	0.575	0.433	-.521	0.584	-.506	0.402
16		-.327	0.322		-.552	0.327				-.355	0.351		-.550	0.336		
17																
18								-.416								-.415
19	0.379	0.335	-.335	-.541		-.539	0.437	-.430	0.354			-.540		-.535	0.417	-.429
20	0.474	0.424	-.418	-.564	0.358	-.590	0.436	-.482	0.471	0.430	-.425	-.585	0.355	-.605	0.431	-.499
21	0.338	0.501	-.497	-.523	0.413	-.586	0.452	-.391	0.337	0.516	-.511	-.555	0.410	-.608	0.459	-.424
22		0.397	-.388		0.514	-.487	0.393			0.438	-.430	-.328	0.521	-.500	0.421	
23	0.372	0.402	-.411		0.408				0.367	0.421	-.429		0.425			
24				0.415				0.396				0.434	0.330			0.417
25		-.341	0.324	0.628		0.518	-.490	0.648		-.362	0.348	0.655		0.545	-.527	0.676
26	-.541	-.638	0.634	0.664	-.415	0.694	-.705	0.675	-.545	-.652	0.650	0.677	-.395	0.694	-.721	0.689
27	-.433	-.561	0.571	0.472	-.470	0.580	-.636	0.384	-.445	-.580	0.587	0.486	-.500	0.605	-.653	0.398
28		-.448	0.446		-.382	0.382	-.333		-.329	-.461	0.460		-.420	0.412	-.346	
29																
30								-.324								-.346
31				-.419		-.357	0.393	-.414				-.444		-.376	0.420	-.436
32		0.432	-.422	-.550		-.535	0.468	-.448	0.360	0.458	-.448	-.588		-.564	0.498	-.475
33	0.330	0.510	-.504	-.495	0.345	-.542	0.441	-.409	0.362	0.533	-.527	-.523	0.358	-.569	0.461	-.431
34		0.404	-.391		0.378	-.400				0.412	-.400		0.407	-.438		
35					0.370					0.335	-.338		0.411			
36				0.371				0.443				0.381				0.441
37		-.322		0.593		0.506	-.488	0.622		-.333		0.629		0.520	-.514	0.652
38	-.508	-.588	0.585	0.553		0.563	-.626	0.534	-.552	-.638	0.635	0.606	-.340	0.611	-.678	0.587
39	-.410	-.522	0.501	0.411	-.453	0.543	-.536	0.338	-.441	-.554	0.534	0.442	-.464	0.571	-.573	0.364
40	-.331	-.371	0.362		-.587	0.434			-.355	-.386	0.379		-.581	0.451		
41																
42								-.347								-.329

Table 59. Correlation coefficients (r) between weather variables and number of bunches as well as FFB yield significant at 0.001 level in I0F2 treatment

Lag	NB								FFB							
	RF	RD	DS	MAT	MIT	DV	RH	DE	RF	RD	DS	MAT	MIT	DV	RH	DE
0																
1				0.710				0.703				0.730				0.738
2				0.684		0.644	-.646	0.664		-.535		0.726		0.659	-.681	0.698
3		-.595	0.570		-.536	0.659	-.618			-.636	0.608		-.577	0.705	-.683	0.552
4					-.633								-.660			
5																
6																
7																
8																
9				-.536		-.532						-.552		-.539		
10						-.539				0.535	-.528			-.553		
11																
12																
13				0.630				0.576				0.650				0.602
14		-.569	0.570	0.686		0.635	-.711	0.751		-.574	0.576	0.714		0.665	-.726	0.786
15		-.598	0.609		-.589	0.671	-.648			-.619	0.630		-.601	0.689	-.666	0.549
16					-.632								-.679	0.538		
17																
18																
19																
20				-.566		-.570						-.565		-.562		
21				-.566		-.596						-.572		-.589		
22						-.610								-.611		
23	0.539	0.547	-.545						0.551	0.581	-.577					
24																
25				0.607				0.595				0.617				0.600
26		-.588	0.578	0.720		0.669	-.695	0.798		-.613	0.605	0.756		0.694	-.720	0.828
27		-.627	0.633	0.572		0.636	-.718	0.541		-.647	0.650	0.595		0.669	-.755	0.570
28		-.539	0.542							-.583	0.587		-.542	0.536	-.550	
29																
30																
31																
32												-.543				
33						-.536						-.564		-.572		
34																
35																
36																
37				0.584				0.589				0.602				0.599
38				0.622		0.581	-.611	0.655				0.665		0.598	-.648	0.698
39	-.590	-.658	0.644	0.534	-.530	0.672	-.677		-.618	-.696	0.680	0.575	-.560	0.717	-.731	0.539
40					-.635	0.542				-.552	0.539		-.685	0.588		
41																
42																

From Table 59 the seven such distinct lag periods thus identified were lag 1-4, 9-10, 13-16, 20-23, 25-28, 32-33 and 37-40. Another aspect comes out of the table is that the lag periods having a very definite and strong influence on FFB yield could be identified. These lag periods were observed to have greater association with all or most of the eight climatic parameters tested.

After identifying such important lag periods, the combined effect of the identified lag periods were determined and are presented (Table 60) so as to have a meaningful interpretation. These results revealed that the combination of consecutive months of each climatic parameters associated with yield had higher correlation values thus indicating better relationship of combined influence.

From the table on relationships of combined lag period (Table 60) it became clear that out of the eight climatic factors studied, four played a positive role while the other four a negative influence at any given lag period. These two groups of parameters having opposite influence thus identified are Group 1 - RH, RF, RD, and MIT and Group 2-DV, MAT, DS and PE. For the purpose of convenience for discussions these two groups are designated as wet factors and dry factors respectively.

Table 60. Correlation coefficients (r) between weather variables and FFB yield for combined lag periods in IOF2

Lag	RF	RD	DS	MAT	MIT	DV	RH	PE
1 - 4	-.645	-.729	0.719	0.736	-.431	0.748	-.757	0.735
9 - 10	0.364	0.478	-.469	-.568	0.333	-.589	0.485	-.427
13 - 16	-.616	-.706	0.711	0.720	-.432	0.713	-.782	0.725
20 - 23	0.614	0.649	-.642	-.629	0.516	-.681	0.571	-.534
25 - 28	-.647	-.742	0.740	0.753	-.416	0.727	-.806	0.782
32 - 33	0.382	0.484	-.477	-.595	0.296	-.573	0.483	-.494
37 - 40	-.637	-.712	0.706	0.665	-.493	0.709	-.731	0.664

RF : Rain fall (mm/month)

RD : Rainy days (days/month)

DS : Dry spell (days/month)

MAT : Maximum temperature (degree C)

MIT : Minimum temperature (degree C)

DV : Diurnal variation (degree C)

RH : Relative humidity (per cent)

PE : Daily pan evaporation (mm)

Based on the magnitude of correlations obtained the order of influence of these parameters on FFB yield are presented in table 61.

Table 61. Order of influence of climatic parameters (positive and negative) at combined lag periods

Combined lag periods	Positively correlated	Negatively correlated
1-4	DV>MAT>PE>DS	RH>RD>RF>MIT
9-10	RH>RD>RF>MIT	DV>MAT>DS>PE
13-16	PE>MAT>DV>MIT	RH>RD>RF>MIT
20-23	RD>RF>RH>MIT	DV>DS>MAT>PE
25-28	PE>MAT>DS>DV	RH>RD>RF>MIT
32-33	RD>RH>RF>MIT	MAT>DV>DS>PE
37-40	DV>DS>MAT>PE	RH>RD>RF>MIT

It was observed that the climatic parameters of both groups followed an alternating trend of positive and negative influence at half yearly intervals. Observation of data presented by Ong (1982a) also showed such a relationship.

Palm yields were thus influenced by a definite period of wet and dry factors alternating with each other in a specific cycle. Because of the changing positive and negative influence of the very same climatic parameter, it may not be advisable to drastically alter this definite requirement of the crop for better yields. This might be the reason why oil palm is mostly distributed and successfully cultivated in the humid tropical regions where such alternate wet or rainy and dry seasons exist. The significant negative relationship for climatic parameters especially the wet factors indicate that a complete change or shift to a fully wet situation also may not be advisable. The positive influence of dry factors emphasise the importance of the requirement of dry weather conditions.

III.3 Importance of different lag periods

The lag periods identified having significant impact of climatic variables on yield and the importance of such lag period to the crop are explained.

Lag 1-4

This is the bunch development stage of the crop. During lag 1-4 period the crop required a rainless period of warm days and cooler nights. High rainfall with more rainy days and humidity conditions are not ideal during this period as indicated by highly significant negative correlation coefficient values. Thus the proportionately higher yield obtained during April to June is due to the influence of scanty rains during December to March, low minimum temperature during winter and high maximum temperature.

Lag 9-10

This period is important as inflorescence abortion occurred during this lag period. Good rainfall with more rainy days and high relative humidity were found beneficial as it can prevent the inflorescence abortion. Dry periods with high temperature and wider variations between day and night temperatures were found disadvantageous during this period. The above illustrations will hold good here also. Dry conditions and lack of moisture cause abortion of female inflorescences during 9-10 months prior to harvest and reduced yield. (Corley, 1976c).

Lag 13-16

During Lag 13-16 lag period warm rainless days were found favourable for good yields. Warm bright days have ensured adequate photosynthate supply to the developing inflorescence.

Lag 20-23

Continuous water supply and wet conditions during lag 20-23 months was found to positively influence yield. As this is the period just after differentiation, adequate moisture supply is important for developing inflorescence. Larger variations in day and night temperature were found unfavourable during this lag period.

Lag 25-28

Dry bright sunny days during lag 25-28 were found to improve yield. More rainy days with high rainfall and high relative humidity were undesirable. The heavy clouds and overcast skies during such rainy season might have prevented sufficient solar radiation to fall on the leaves. This reduced the assimilation rate and adversely affected the female flower differentiation at lag 25-28 months period as it coincides with sex differentiation stage of the crop (Corley, 1976c). Workers like Sparnaaij (1960) and Ong (1982b) also reported that female flower differentiation occured when there was bright sunlight during warm dry seasons.

Lag 32-33

During lag 32-33, high temperature was found harmful whereas adequate moisture supply was favourable for good yield. Development of inflorescence primordia might have occured during this period.

Lag 37-40

Warm sunny days during lag 37-40 were found to favourably influence yield of the crop. Bright sunlight might have ensured adequate photsynthesis and supply of assimilates for inflorescence primordia initiation during the period.

Thus the yield of oil palm was found significantly influenced by wet or dry factors at these specific lag periods before harvest as discussed. Providing conditions to meet such requirement of the crop may improve palm yields.

III.6 Selection of weather parameters for yield prediction

Correlation analysis helped us to identify seven lag periods, weather at which were important in determining the FFB yield of oil palm. In order to study the relative importance of each of these lag periods in explaining the variations in monthly yield, regression analysis was carried out using all the eight variables. The R^2 values obtained for different lag periods were 0.679 (1-4), 0.510 (9-10), 0.67 (13-16), 0.640 (20-23), 0.749 (25-28), 0.488 (32-33) and 0.615 (37-40). Thus the lag period 25-28 turned out to be the most significant one which explained 75% of the variation in yield. From the correlation studies (Table 60) it was observed that the 25-28 lag period was found important when all the eight parameters were considered. However for six variables the 26-28 lag period was seen more crucial. Hence for studying the relative importance of different weather parameters the period 26-28 only was considered. So further regression analysis was carried out using this lag period. The R^2 values determined for different combinations of parameters (step up regression) are presented in Table 62. As seen from table, relative humidity (RH) alone was found to explain 65 per cent of the total variation. When maximum temperature (MAT) and rainfall (RF) were also considered as explanatory variables, the R^2 went up to 70 per cent. Inclusion of other variables had only marginal influence in explaining the monthly variations in yield. When all the

Table 62. Changes in R^2 values with addition of weather parameters and yield prediction models using the parameters at lag 26-28 months

Sl. No.	Constant term	RH	MAT	RF	DS	RD	MIT	DV	PE	R^2
		Regression coefficient according to								
1.	15458.34	-61.90 (7.795)	..	..	..	..	..	..	..	0.650
2.	30211.02	-85.52 (17.92)	-97.55 (66.89)	..	..	..	..	..	..	0.671
3.	40603.84	-123.43 (26.75)	-128.60 (66.66)	1.82 (0.97)	..	..	..	..	..	0.703
4.	28233.26	-89.08 (36.16)	-117.08 (70.77)	2.57 (1.15)	50.17 (37.195)	..	..	..	..	0.719
5.	-9980.36	-87.78 (36.16)	-79.54 (70.77)	3.05 (1.15)	418.59 (267.84)	372.88 (268.53)	..	..	..	0.736
6.	-16967.66	-85.21 (37.01)	-49.55 (97.21)	3.33 (1.32)	484.68 (307.57)	445.66 (315.32)	-45.43 (99.41)	..	..	0.738
7.	-16156.10	-92.41 (34.85)	-284.22 (12560)	2.43 (1.30)	483.41 (287.88)	468.84 (295.31)	283.38 (12565)	28369 (12558)	..	0.779
8.	-47017.27	-12.05 (56.77)	-38908 (13507)	3.06 (1.30)	7[illegible].0 (317.56)	713.43 (317.08)	38576 (13449)	38754 (13480)	616.77 (315.03)	0.801

Note : Standard errors of regression coefficient are given in parenthesis.

eight parameters were considered R^2 value went upto 80 per cent. However in view of the three climatic parameters namely RH, MAT and RF which explained 70 per cent of the variation, it is suggested that this can be used for yield prediction purposes. The model thus obtained is of the form :

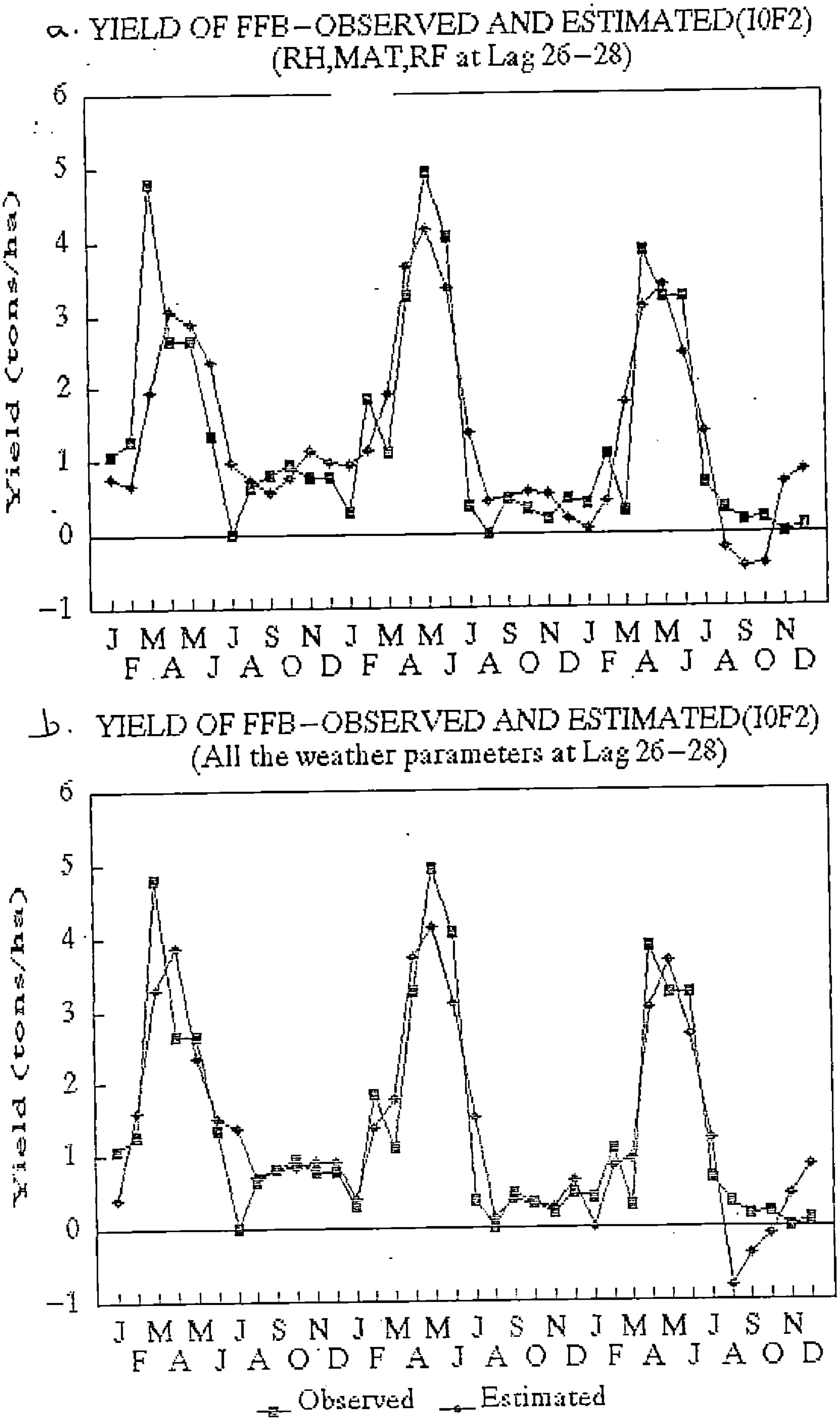
$$Y = 40603 - 123.4\ RH - 128.6\ MAT + 1.82\ RF\ (R^2 = 0.703)$$

Using this model expected yields from the period January 1990 to December 1992 were worked out. The observed and expected values were found to tally very much as can be seen from Fig. 21a.

The exercise was repeated using four, five, six, seven and all the eight variables in the order in which the R^2 value increased as noted in step up regression (Table 62) The details on yield prediction models obtained using different weather parameters at lag 26-28 months are also presented in the same table. The model thus obtained using all the eight variables is of the form :

$$Y = -47017.27 - 12.05RH - 38908\ MAT + 3.06\ RF + 754\ DS + 713.43\ RD + 38576\ MIT + 38754\ DV + 616.77\ PE\ (R^2=0.801)$$

Fig. 21. Observed and estimated FFB yield under unirrigated conditions using prediction models



The expected yields obtained using this model along with the observed yields for the 36 months period are presented in Fig. 21b.

All the information furnished was for the I_0F_2 plot which was under unirrigated conditions. However there will be situations where the oil palm plantations are irrigated and prediction of yield with climatic parameters will have to be made. To attain this objective the figures obtained in I_2F_2 were utilized for working out similar prediction model. The model obtained for irrigated situation with the three parameters of RH, MAT and RF is of the form :

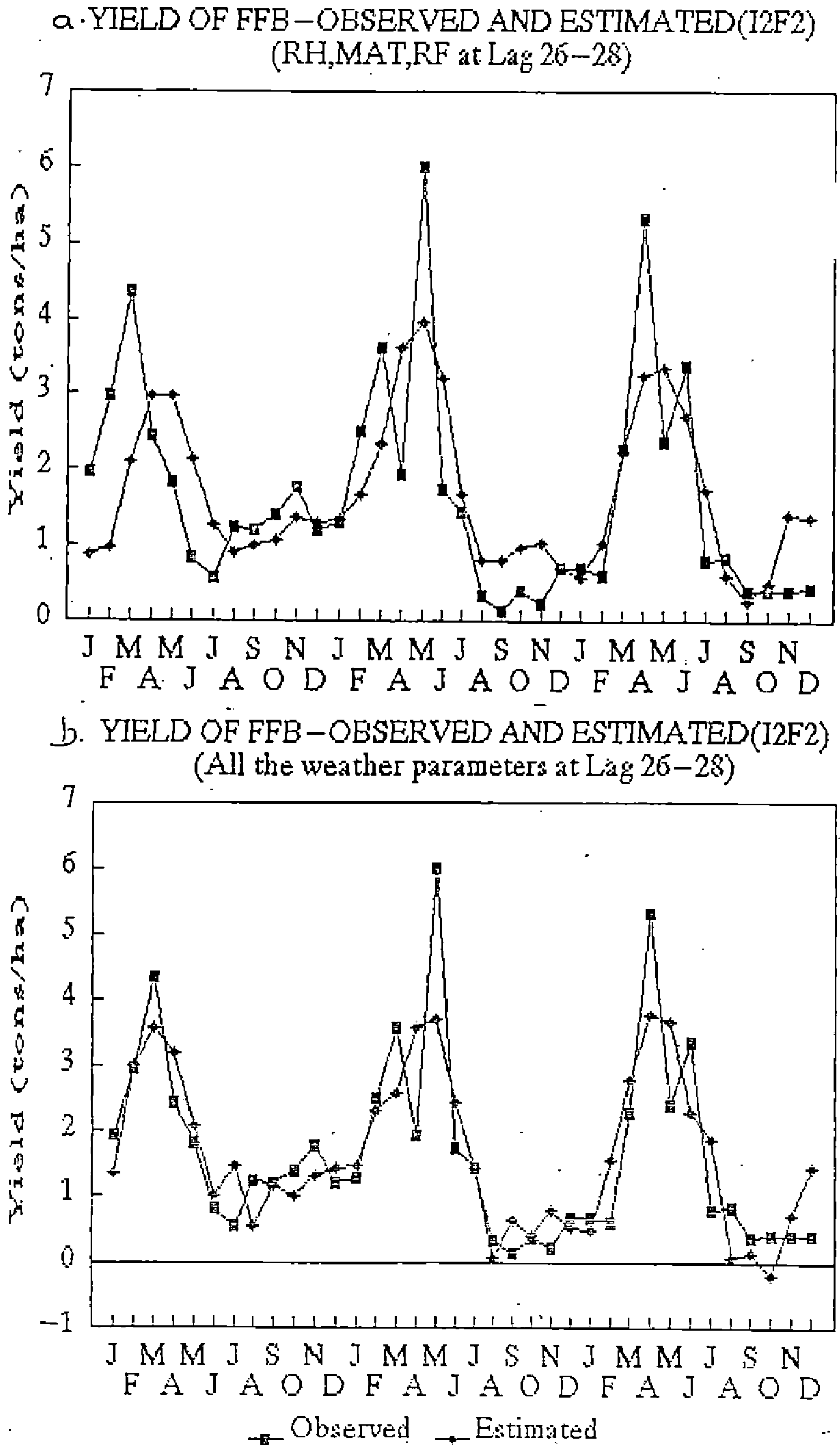
$$Y = 29660.92 - 82.81\ RH - 97.99\ MAT + 0.43\ RF\ (R^2 = 0.50)$$

and using all the eight parameters the model obtained is :

$$Y = -34017.06 - 71.19\ RH - 17483\ MAT + 2.11\ RF + 476.39\ DS + 426.88\ RD + 17646\ MIT + 17624\ DV - 550.96\ PE\ (R^2 = 0.68)$$

The expected yields obtained using the models and the observed yields were found to tally very much as depicted

Fig. 22. Observed and estimated FFB yield under irrigated conditions using prediction models



in Fig. 22a and 22b. Neverthless the study showed that the influence of weather parameters was slightly reduced as represented by relatively lower R^2 values. However the general prediction and parameters remained the same.

This is the first attempt on oil palm, to study the relationship between yield and climate under Indian conditions. The results will be applicable in situations where comparable climatic conditions prevail and similar agronomic practices are followed.

SUMMARY

SUMMARY

The study comprised of three parts. The first part of the study consisted of a field experiment conducted on mature *tenera* hybrid oil palms of the Central Plantation Crops Research Institute (CPCRI) at Palode, Kerala. The experiment was conducted to study the response of fertilizer and irrigation and to explore the interrelationship between soil and plant nutrients on growth and yield by superimposing the treatments. The treatments consisted of fertilizer levels of F_0 (no fertilizer), F_1 (600:300:600), F_2 (1200:600:1200) and F_3 (1800:900:1800) of $N:P_2O_5:K_2O$ palm^{-1} year^{-1}. The irrigation levels were I : I_0 (no irrigation), I_1 (45 l palm^{-1} day^{-1}) and I_2 (90 l palm^{-1} day^{-1}) supplied through drip irrigation system. The 4 x 3 factorial experiment was conducted in RBD with three replications.

The second part of the study was on the interrelationship of leaf nutrient ratios of yield group of palms and its interpretation using the Diagnosis and Recommendation Integrated System (DRIS).

The third part was a study conducted to assess the climate required by the crop upto 42 months prior to harvest.

The results of the investigation under each part are summarised below:

Part I: Effect of nutrition and irrigation on growth and yield of oil palm

1. Application of fertilizer at F_2 level was found essential for annual leaf production and number of functional leaves on the crown. For other leaf characters like width of leaflet and leaf area F_1 level was found sufficient.

   I_2 level of irrigation was necessary to produce maximum number of leaflets per leaf and leaf area.

2. F_2 level of fertilizer was found sufficient for leaf and trunk dry matter production. The male flower dry matter production was not increased beyond F_1 level. The mesocarp dry matter which is the dominant component of bunch dry matter was maximum at F_2 level of fertilizer application. The bunch dry matter production, total

dry matter production and therefore the crop growth rate were also maximum at this level of fertilizer application.

I_2 level of irrigation has given maximum leaf dry matter production whereas for trunk dry matter I_1 level was sufficient. Maximum male flower dry matter production was observed in I_0 plot as more male flowers were produced under unirrigated condition. The mesocarp dry matter production and bunch dry matter production were maximum at I_2 level. Thus the total dry matter production and crop growth rate were also maximum at I_2 level. Irrigation at I_2 level seems to be required by the palm as the dry matter production of economic parts were more at I_2 level.

3. Physiological parameters such as the relative leaf water content, leaf water potential, stomatal resistance, leaf temperature and net photosynthesis were not influenced by fertilizer application, whereas irrigation at I_2 level was found important for all these characters.

4. Irrigation at I_2 level has significantly increased soil moisture content as well as the root concentration in top 30 cm layer of soil.

5. The female flower production as well as the sex ratio were more at F_2 level of fertilizer application and I_2 level of irrigation.

6. Of the various bunch and fruit characters, only the single fruit weight was influenced by F_2 level of fertilizer and I_2 level of irrigation.

7. For most of the oil yield components such as fruit to bunch, mesocarp to fruit, oil to mesocarp, kernel to fruit, oil to kernel and oil to bunch ratios, the F_1 level seems to be sufficient. Oil to mesocarp and oil to kernel ratios were found reduced at F_3 and F_2 levels.

   Irrigation at I_1 level was found sufficient for fruit to bunch and oil to bunch ratio.

8. Number of bunches and average bunch weight were maximum at F_2 and F_3 levels respectively. Irrigation at I_2 level has produced more number of bunches.

9. F_2 level of fertilizer application has produced an FFB yield of 17.33t ha^{-1} $year^{-1}$ which is the maximum.

   Irrigation at I_2 level also resulted in highest FFB production of 16.78 t ha^{-1} $year^{-1}$.

10. Palm oil yield was maximum at F_2 level of fertilizer application producing 4.72 t ha^{-1} $year^{-1}$ and at I_2 level of irrigation recording 4.64 t ha^{-1} $year^{-1}$.

11. Maximum kernel oil yield of 373 kg ha^{-1} $year^{-1}$ was obtained with F_2 level of fertilizer application.

12. Maximum content of N and K in leaf was at F_2 level of fertilizer . Leaf P content was not found influenced by fertilizer treatments. Leaf Ca has increased upto F_1 level of application.

    Irrigation at I_2 level has increased P content whereas the N content was decreased.

13. N and P uptake by the palm was significantly increased at F_2 level whereas total K uptake was maximum at F_3

level. Uptake of Ca was sufficient at F_1 level. There was a reduction in Mg uptake with increased level of fertilizer application.

Irrigation at I_2 level has recorded maximum N,K and Ca uptake.

14. From correlation studies it was observed that FFB yield was significantly and positively correlated with various growth and yield attributes. It was also related to soil nutrient status, leaf nutrient content and uptake of nutrients.

15. The net income and the benefit cost ratio were also found maximum at F_2 level of fertilizer application and I_2 level of irrigation.

Part II : Leaf nutrient ratios and the DRIS

DRIS norms and DRIS parameters were determined for oil palm using various ratios of desirable and less desirable group of palms. This is the first ever attempt of DRIS analysis on oil palm in the world.

1. DRIS charts were constituted for three nutrient combinations involving N,P,K,Ca and Mg and zones of balance, moderate imbalance and high imbalance were identified and illustrated. Nutrient ratios which are optimum, below optimum and above optimum were determined to assess the balance situation in an unknown sample.

2. Evaluation of DRIS approach with the field experiment on fertilizer and irrigation revealed that majority of the nutrient combinations were more balanced in the F_2 and F_3 treatments.

3. The treatment combinations of the experiment found more well balanced were I_1F_2, I_2F_2 and I_2F_3. However the main difference of I_2F_2, which produced maximum FFB yield with the other two, was that the P/Mg ratio was balanced in I_2F_2 and not in others. For better FFB production, balancing of P/Mg ratio is thus found important as both elements are involved in oil synthesis.

4. Nutrient Imbalance Index (NII) was worked out for each nutrient using all the nutrient combinations involving a particular nutrient. The relative

degree of sufficiency or insufficiency of each nutrient and their order of importance were identified in the treatment combinations of the field experiment using Nutritional Imbalance Index (NII). The order of relative importance of nutrients obtained for oil palm was K > P > N > Mg > Ca.

Potassium was found to be the most required nutrient element for oil palm. At F_2 level the order of requirement of K was found shifted to the third position and P and Mg became more crucial as given below P > Mg > K > N > Ca.

The importance of Mg nutrition to oil palm especially with higher levels of fertilizer application has been brought out from this study.

5. Nitrogen which recorded negative index value at lower levels became positive at F_2 level which indicate that nitrogen at F_2 level is near optimum. The relative insufficiency of phosphorus which continued even at F_3 level indicated that some inefficiency factor might have been operating. K which emerged as the most

insufficient nutrient at lower levels showed sufficiency at F_2 level. This was also manifested in the leaf nutrient content as well as total uptake of potassium. However continued uptake of K beyond F_2 level has only resulted in more vegetative growth. Calcium was seen relatively sufficient in all treatments. The calcium index values were least in F_2 and F_3 treatments. Though Mg was found sufficient in most cases, at F_2 level which produced maximum bunch yield and which showed optimum K nutrition, Mg was found becoming relatively insufficient. So continued application of higher levels of fertilizer especially KCl must also ensure additional supply of Mg to oil palm.

6. The sum of the NII irrespective of being positive or negative was more in F_0 and F_1 treatments and was lesser in F_2 and F_3 treatments. So larger NII values indicated more imbalancing and correspondingly low yields. When NII values were least the nutrients were balanced and correspondingly both total dry matter and bunch yields were higher.

Fertilizer nutrient management programme to provide optimum balancing of nutrient is a must for increased FFB production of oil palm. Among the nutrient levels tested the F_2 level of fertilizer application was found to show a near balanced situation in oil palm.

Part III : **Climate and yield relationship of oil palm**

1. Correlation studies on influence of monthly climatic variables up to 42 lag months before harvest revealed that the number of bunches produced and FFB yield followed similar trend of significant relationship at certain specific lag period.

2. Climate at seven specific lag periods were found important during the 42 months lag period. These important lag periods were 1-4, 9-10, 13-16, 20-23, 25-28, 32-33 and 37-40 months before harvest.

3. The climatic parameters that influenced the yield were found to have positive and negative influence alternating with each other. Out of the eight variables tested four each were found to have either positive or

negative influence at any given time. The four wet factors were relative humidity, rainfall, rainy days and minimum temperature and the four dry factors were diurnal variation, maximum temperature, dry spell and daily pan evaporation.

4. Both wet and dry factors influenced the production of palm. It was observed that the crop required an essentially warm dry condition during 1-4, 13-16, 25-28 and 37-40 lag periods and wet humid conditon during 9-10, 20-23 and 32-33 lag periods.

5. Lag 25-28 is found to be more important based on the relationship of climatic variables.

6. Relative humidity is the most important climatic parameter followed by maximum temperature and rainfall. Together these three variables accounted for 65% variation in yield and all the eight variables together accounted for 80% of the variation in yield.

7. Yield prediction is possible in oil palm as early as 26-28 months before harvest using the three variables

of relative humidity, rainfall and maximum temperature and the prediction models are also presented.

CONCLUSIONS

1. The fertilizer requirement of mature *tenera* hybrid oil palm is 1200 g N+600g P_2O_5 + 1200 g K_2O $palm^{-1}$ $year^{-1}$. Application of water through drip irrigation at the rate of 90 litres $palm^{-1}$ day^{-1} is necessary for a mature palm.

2. The order of requirement of nutrients by oil palm under the tested conditions is determined as $K > P > N > Mg > Ca$

   It was also established that at the F_2 level of fertilizer application, the nutrition is more balanced. The importance of application of magnesium along with other nutrients is established.

3. The climate during 25-28 month lag period was found to be crucial for oil palm. Relative humidity, maximum temperature and rainfall are most important. Yield prediction is possible as early as 26-28 months in advance.

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* Originals not seen

APPENDIX

Appendix I

Weather parameters at Palode
(July 1983 to June 1993)

Months	Weather Parameters							
	RF	RD	DS	MAT	MIT	DV	RH	PE
JUL	348.4	16.4	14.9	29.9	22.8	7.4	81.7	3.2
AUG	236.4	14.5	17.3	30.0	22.7	7.4	80.8	3.2
SEP	232.1	11.8	20.6	31.1	22.5	8.8	78.5	3.7
OCT	372.9	16.1	13.9	31.2	22.2	9.0	81.7	3.2
NOV	281.8	12.3	17.8	31.3	21.6	9.9	79.2	3.3
DEC	62.0	3.8	27.3	32.4	20.4	12.1	71.3	3.9
JAN	32.1	1.7	29.2	33.1	19.4	13.8	68.1	4.7
FEB	50.3	2.8	28.0	34.4	20.4	14.3	66.3	5.8
MAR	77.6	4.7	27.2	35.0	21.7	13.6	69.3	5.5
APR	232.1	13.3	17.4	34.2	23.6	10.8	73.9	4.9
MAY	261.1	14.2	16.3	32.8	24.0	9.0	78.1	4.3
JUN	480.7	22.2	8.0	29.9	23.0	7.0	85.2	3.1
TOTAL	2667.6	134.4	237.6					
MEAN				32.1	22.0	10.3	76.2	4.1

RF : Rain fall (mm/month)

RD : Rainy days (days/month)

DS : Dry spell (days/month)

MAT : Maximum temperature (degree C)

MIT : Minimum temperature (degree C)

DV : Diurnal variation (degree C)

RH : Relative humidity (per cent)

PE : Daily pan evaporation (mm)

EFFECT OF NUTRITION AS INFLUENCED BY IRRIGATION ON GROWTH AND YIELD OF OIL PALM (*Elaeis guineensis* Jacq.)

By

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ABSTRACT OF THE THESIS
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ABSTRACT

A field experiment was conducted in the oil palm plantations of the Central Plantation Crops Research Institute (CPCRI) Research Centre, Palode, Kerala to study the response of mature oil palm to fertilizer and irrigation applications with respect to growth, yield and uptake of nutrients. There were four levels of fertilizers viz: F_0 - 0:0:0, F_1 - 600:300:600, F_2 - 1200:600:1200 and F_3 - 1800:900:1800 g N : P_2O : K_2O $palm^{-1}$ $year^{-1}$. The three levels of irrigation were: I_0 - no irrigation, I_1 - 45 l $palm^{-1}$ day^{-1} and I_2 - 90 l $palm^{-1}$ day^{-1}. The 4x3 factorial experiment was laid out in randomised block design with three replications.

The study was also envisaged to establish the importance of leaf nutrient ratios of yield group of palms and its application in identifying nutrient limitations through the Diagnosis and Recommendation Integrated System (DRIS) approach in oil palm.

The influence of various climatic parameters on yield of oil palm was studied by relating the monthly yield

of oil palm in the field experiment with the monthly weather variables as far behind as 42 months before harvest.

Fertilizer application of 1200 g N + 600 g P_2O_5 + 1200 g K_2O $palm^{-1}$ $year^{-1}$ was found to improve the growth characters such as annual leaf production, number of leaves on the crown, dry matter production of leaf, trunk and bunches, total dry matter production and the crop growth rate. Increase in yield attributes such as number of female inflorescences, sex ratio, average single fruit weight and the number of bunches at F_2 level contributed to the significantly high FFB yield at F_2 level of fertilizer application. Both palm oil and palm kernel oil production were also maximum at F_2 level.

For the uptake of nutrients N, P and K by palm parts as well as by the palm as a whole, the F_2 level of fertilizer application was found to be the optimum. It was observed that 79% of the total uptake of N, 77% of P and 82% of K are removed annually through leaves and bunches from the system. A K-Mg antagonism was also detected in nutrient uptake.

The yield of palm was found positively correlated with leaf production, leaf area, net assimilation rate, number of bunches produced, vegetative dry matter, P and K in soil and the total uptake of N, P and K by the palm.

Both net income and benefit cost ratio were also found favorable at F_2 level of fertilizer application.

Irrigation at I_2 level has resulted in increased leaf production, leaflets per leaf, leaf area, leaf dry matter, mesocarp dry matter and the bunch dry matter. Physiological parameters like relative water content, leaf water potential, stomatal resistance, leaf temperature and net photosynthesis were all favourable at I_2 level of irrigation.

Female flower production, sex ratio, single fruit weight and number of bunches produced were also more in I_2 treatment. This has resulted in increasing FFB production at I_2 level. Palm oil production was also more at I_2 level. Total uptake of N, P, K and Ca were also found to be maximum at I_2 level of irrigation.

The net profit and benefit cost ratio were also maximum at I_2 level.

Leaf nutrient ratios of palms in different yield groups were used to evolve parameters and norms for Diagnosis and Recommendation Integrated System (DRIS) in oil palm. The range of nutrient ratios within the zones of balance, moderate imbalance and imbalance were determined which were also illustrated through DRIS charts for three nutrient combinations. The DRIS approach was used to evaluate the nutrient balancing of the different treatments of the field.

The order of relative importance of the five nutrients was determined using nutrient imbalance index (NII) values as indicated below:

$$K > P > N > Mg > Ca$$

The F_2 level of fertilizer application in the experiment was found to be the most balanced among the tested fertilizer levels. The possibility of magnesium becoming a potential limiting nutrient at higher levels of fertilizer application has been brought out from the study. The superiority of balanced nutrition in increasing total dry matter production and bunch yield became evident from the study.

The studies on climatic relationship with yield revealed that the pattern of variation in monthly yield remained the same inspite of irrigation throughout the summer months. The relationship of monthly yield of oil palm with monthly climatic parameters was evaluated up to a period 42 months before harvest. When eight climatic parameters were considered together, the influence of these weather parameters at seven specific lag periods viz. 1-4, 9-10, 13-16, 20-23, 25-28, 32-33 and 37-40 were found important for oil palm. Of these the lag 25-28 was found to be the most important as the relationship of climatic parameters with yield at this period was more. Relative humidity, maximum temperature and rainfall were identified as the most important variables influencing palm yield. Using results obtained from regression studies yield prediction models were constituted. It is concluded that yield prediction using the three or more variables is possible for oil palm 26-28 months in advance of harvest.

The salient findings from the study is that a fertilizer dose of 1200g N + 600 g P_2O_5 + 1200 g K_2O $palm^{-1}$ $year^{-1}$ and irrigation level of 90 l $palm^{-1}$ day^{-1} applied through drip system during the summer months are required to obtain maximum FFB yield from mature oil palm.

The order of importance of nutrients for oil palm is determined as K > P > N > Mg > Ca. With the above level of fertilizer application the palms were found to have a more balanced nutrition. However continued application of fertilizers might possibly lead to magnesium deficiency unless corrective measures are adopted.

Relative humidity, maximum temperature and rainfall are found to be the most important climatic parameters influencing oil palm yields. The influence of climatic parameters at seven lag periods 1-4, 9-10, 13-16, 20-23, 25-28, 32-33 and 37-40 were found to be more pronounced on palm yield. From these studies it became possible to predict oil palm yields 26-28 months in advance using models based on these weather parameters.