AVAILABILITY INDICES FOR STRESSED NUTRIENTS FOR COCONUT (*Cocos nucifera* L.) IN AN ULTISOL

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

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DECLARATION

I, hereby declare that this thesis entitled **"Availability Indices for Stressed Nutrients for Coconut (*Cocos nucifera L.*) in an Ultisol"** 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 of any degree, diploma, fellowship or other similar title, of any other university or society.

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प्रियापी

P. Priya

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Introduction

1. INTRODUCTION

Coconut is the most important tropical palm usually mentioned as 'The Tree of Heaven'. Until recently, this crop was playing the leading role in the economy of Kerala. However, declining trends in production and productivity are observed due to several reasons – the diseases especially root (wilt), the less care and management by the farmers because of low prices, high labour cost and decline in soil fertility. This is evident from the data on production and productivity of coconut at present and that in the late fifties (Government of Kerala, 2001).

Coconut being a cross pollinated highly heterozygous crop shows wide variability between individual palms, in productivity. Further the palms from the same ecotype, growing under different soil environment also differ in their productivity. The influence of soil fertility as well as the nutrient composition in soil and plant contribute significantly to the productivity.

In root (wilt) affected areas, the diseased and apparently healthy palms show notable differences in their respective nutrient composition. This is true in the case of healthy palms also, grown in healthy tract.

A fertile soil must have capacity to supply essential nutrient elements to plants in correct balances and proportions. This in turn must be reflected directly on yield of the crop.

The most effective tool for assessment of soil fertility is diagnostic soil test which in turn should reflect the bioavailable nutrient status of the soil in terms of nutrient supplying power of the soil. The gap if any, between this bio-available fraction and the crop requirement must then be correctly interpreted from the soil test results and form the basis for fertilizer recommendations.

Two general concepts of making fertilizer recommendation are the 'sufficiency level approach' and the 'cation saturation ratio approach' (Rehm, 1994). The present study with coconut as the test crop approaches the soil test result interpretation based on the latter in comparison with the former. The nutrient supplying power of the soil is the resultant of the equilibrium arrived in soil-plant system which can be represented as:

$$\text{Exchangeable Ions} \rightleftharpoons \text{Ions in solution} \rightleftharpoons \text{Ions in plant}$$

Further, the status of each of the ions of these components of the equilibrium reactions is governed by the interaction of the particular ion in question with the other ions in the system. This is termed as relative intensity by Khasawneh (1971). This relative intensity at equilibrium and further changes in activities of these ions follow ratio law. Thus the relative intensity of K in calcareous soils was calculated as $K/(Ca+Mg)^{1/2}$ by Beckett (1964) which was modified to $K/[(Ca+Mg)^{1/2} + (Al)^{1/3)}]$ for tropical acidic environment by Tinker (1964). Thus the ionic equilibrium in soil-plant system gets modified to:

$$\begin{matrix}\text{Ionic interaction} \\ \text{(Exchangeable)}\end{matrix} \rightleftharpoons \begin{matrix}\text{Ionic interaction} \\ \text{(Solution)}\end{matrix} \rightleftharpoons \begin{matrix}\text{Ionic interaction} \\ \text{(Plants)}\end{matrix}$$

It is in this context the well established fact of reduced K uptake under excessive levels of Ca and /or Mg should be viewed. Similarly toxic effects of Fe, Mn and Al are found to get neutralised by high doses of K under lateritic environment.

The problems of declining trends of productivity in many crops under the humid tropical lateritic environment of Kerala and lack of response to certain nutrient ions may get some solutions, if approached, in terms of relative proportions of the element in question rather than considering its absolute content.

Planting of coconut in laterites is one of the management techniques for prevention of soil degradation. It is also observed that well managed palms under lateritic environment give good yields.

Under the above contexts, a limited sample of fifty phenotypically identical West Coast Tall coconut palms varying in yield from 14.4 to 84.4 nuts $palm^{-1}yr^{-1}$, grown under an Ultisol generally referred as laterite, were selected for the study with the following objectives:

1. To study the ionic interaction and its significance in nutrient availability to coconut palms in lateritic environment
2. To elucidate the effect of dominant cations (Ca, Mg, Fe, Mn and Al) having higher relative intensity with respect to other cations (K and Na) on the availability of nutrients
3. To unravel the role of Net Ionic Equilibrium (NIE) based on Ratio Law on soil-plant system.

Review of Literature

2. REVIEW OF LITERATURE

The coconut palm adapts itself remarkably well and thrives in almost all types of well drained tropical soils such as coastal sand, red loam, laterite, alluvial and the reclaimed soils of the marshy low land. Coconut removes large quantities of nutrients from the soil continuously. Proper availability of nutrients to the palms is therefore of great importance and is to be ensured for high productivity under different soil environment.

With respect to nutrition of coconut palm, mineral nutrients should be supplied in proper quantities and in balanced proportions. In this chapter, the works so far carried out in this line are reviewed under different titles.

2.1 AVAILABLE NUTRIENT STATUS IN SOIL AND ITS EFFECT ON PLANT NUTRIENT CONTENT AND YIELD

For mature coconut palms (over 8 years old) Ziller and Prevot (1962) suggested the 14^{th} leaf as the index leaf for foliar diagnosis. Devi and Pandalai (1968) and Thomas (1973) opined that foliar nutrients composition reflected the nutrient status of soil. Querijero (1972) discussed the application of soil and leaf analyses in assessing the nutritional requirements of coconut and other crops. Magat (1975) and Mahilum (1976) reported that soil analysis supplemented by leaf analysis provides a better way of evaluating the nutrient status of growing palms.

2.1.a. Major Nutrients

Pillai and Davis (1963) reported that the quantitative sequence of importance of major nutrients for adult bearing palms are K > Na > Ca > Mg > P. Jack (1965) observed that soil K decreased from the surface to subsoil in the high yielding sites of coconut plantations, soil K was highly correlated with leaf K and soil and leaf K were highly correlated with the number of nuts produced.

In coconut, N fertilization tended to increase leaf K and Ca levels but decreased the Na and Mg levels. The N and K fertilization increased foliar Ca and Mg levels but depressed K and Na (Felizardo, 1965). Ollagnier *et al.* (1970) have reported that leaf nitrogen content of oil palm increased from 2.3 to 2.7 per cent by nitrogenous fertilizer application.

Muliyar and Nelliyat (1971) found that for palms yielding less than 60 nuts annually, the optimum dose of N ranged from 400 to 600 g with a mean of 480 g and that of K ranged between 890 and 1210 g per palm per year. Ollagnier and Ochs (1971) suggested that there is no direct proof on the effect of sodium in increasing the yield of coconut.

Reviewing the NPK nutrition of coconut, Nelliat (1973) recommended application of 320 g P_2O_5 palm^{-1} year^{-1} for palms yielding an average of 50 nuts/annum. He recommended a higher dose of 500 g P_2O_5 for palms with high yield potential.

Warrier and Piggot (1972) claimed to have found a high concentration of tissue N in fertilized plots of oil palm. In the absence of K fertilizers, leaf K content was low and tissue concentration increased when KCl was applied. They also observed low tissue P content when P fertilizers were not applied.

Wahid *et al.* (1974) in one of their experiments got significant positive correlation between soil and leaf K in coconut. Na correlated negatively with its concentration in leaf, though not significant. Withholding fertilizer application to coconut for one year, lowered foliar N and K levels significantly, but not P levels (Wahid *et al.*, 1975). They also reported that a general improvement of leaf N, P and K occurred after the onset of rains.

Breure and Rosenquist (1976) reported that application of MoP to coconut has resulted in an increase in Ca level in the 14th frond. Breure and Rosenquist (1977) also found that the application of Mg, Mn and S have not increased the yield of coconut.

Kanapathy (1977) in a study on dwarf coconut palm showed that there was no yield response to P fertilization. Potty (1978) recommended that palms belonging to high yield groups require a fertilizer schedule that emphasises more on P and K and palms belonging to low yield groups require a schedule that gives more importance to N and K. Margete *et al.* (1979) observed that KCl application improved the N-status of leaves which correlated with yield increase. The N content raised from 1.78% to a maximum of 2.03 per cent.

Manciot *et al.* (1979) found that NaCl dressing in coconut have stimulated increase in nut production. Gopi (1981) reported that coconut palms receiving higher levels of N and K fertilizers had high foliar N and K contents, while P fertilizers gave only a marginal increase in foliar P levels.

Krishnakumar (1983) reported that application of N, P and K fertilizers resulted in an increase in the content of these nutrients in the 2^{nd}, 10^{th} and 14^{th} leaves of coconut palm. Potassium was found to increase the leaf area, leaf colour, frond length, number of leaves, height and girth of palm, number of female flowers, nut set, number and size of nuts, nut weight and yield of copra (Pushpangadan, 1985; Nair *et al.*, 1988; Singh and Mishra, 1991 and Prabhakumari, 1992).

Loganathan and Atputharajah (1986) observed that MoP increased leaf K and Cl but decreased leaf Ca and Mg. Ammonium sulphate generally increased leaf N and Ca but decreased leaf K and Cl in coconut. Clarson *et al.* (1986) reported that application of Mg at the rate of 100 g per palm had maximum response on coconut yield in Kanyakumari district of Tamil Nadu. Cecil (1988) through his crop removal studies suggested that the quantitative requirement of Ca for coconut palm is much higher than that of P and it is mainly concerned with the proper growth and functioning of stem and leaves rather than on productivity of nuts. He also stated that Mg is one of the limiting nutrient elements in the nutrition of coconut which could enhance the yield as high as 40 per cent.

Anilkumar and Wahid (1989) found that yield response was highest for KCl application, from 2.1 nuts to 33.6 nuts $palm^{-1}$ $year^{-1}$ at the highest dose of 747 g $palm^{-1}$ $year^{-1}$.

Bopaiah and Cecil (1991) reported an yield increase of 123 to 160 per cent in palms receiving 500 g N along with 320 g P_2O_5 and 1200 g K_2O $palm^{-1}$ $year^{-1}$ in the coral soil of Lakshadweep. Sreelatha (1993) reported that, levels of K significantly influenced the coconut yield. More than 200% increase in nut yield was observed with K addition, over the no K treatments. She observed that yield of coconut was significantly and positively correlated with available K, exchangeable K and water soluble K.

Joseph *et al.* (1993) found that in laterite soil, K application is necessary to coconut trees for maintaining stability in nut yield, and in the soils with low to medium availability of K its requirement for coconut can be met by applying 500 g K_2O every year and a boosting effect can be obtained by combining with 935 g NaCl. Balanced nutrition of coconut palm is essential for achieving high and sustained yields. Quantity of fertilizer applied is largely dependent on the inherent soil fertility status and the productivity of the plantation. In general, adult palms should be supplied with 500 g N, 320 g P_2O_5 and 420 g K_2O/palm/year in 2 splits during pre-monsoon and post-monsoon seasons (Reddy and Upadhyay, 1998).

2.1.b. Micronutrients

Devi *et al.* (1975) observed that continuous application of NPK fertilizers without supplementing with micro nutrients to coconut might have found to lower the available Zn and Cu in the soil, which when amended resulted in the increased nutrient content and also nut yield.

Eschbach and Manciot (1981) found that application of Cu to young palms in the form of nutramine or to adult coconuts as $CuSO_4$ at 50 g per tree per year, never affected either growth or yield but on adult coconut palms application of $FeSO_4$ at the rate of 400 g $palm^{-1}$ $year^{-1}$ increased the number of nuts per tree and application of Mn increased both growth and number of nuts per tree while $ZnSO_4$ application at the rate of 50 g $palm^{-1}$ $year^{-1}$ did not have any effect on yield of nuts.

Along with recommended dose of NPK, 200 g of $ZnSO_4$ $palm^{-1}$ $year^{-1}$ has significantly increased the coconut yield to 122-129 nuts $palm^{-1}$ $year^{-1}$ which was 69.5 per cent higher than the control. It was also found that the application of $CuSO_4$ increased the Cu content of leaves but the increase in yield was not much pronounced (Vijayaraghavan *et al.*, 1988).

2.1.c Influence of Soil Properties on Plant Nutrient Content and Yield

Soil test values for exchangeable K often do not correlate well with crop responses in field experiments, notably when soils differ in clay content and clay composition (Jankovic and Nemeth, 1974; Goswami *et al.*, 1975; Grimme, 1975). This is not surprising as plant roots take up nutrients from the soil solution. As the K concentration in the solution increases, more K^+ ions can reach the plant roots within a given time and the amount of K^+ ions that can be taken up by the plant increases (Jankovic and Nemeth, 1974).

Sparks (1980) reported that soil solution K is the form taken up directly by the plants. He found that in soils high in total K which occur in micas and feldspars, the K forms are slowly released to solution and exchangeable form is available to plant and lack of crop response to K fertilization in the soil was due to high indigenous levels of mineral and non-exchangeable potassium.

Manikandan *et al.* (1986) reported that there was a prevalence of Cu, Zn and Mn deficiencies in coconut growing soils in Kasargod district of Kerala, the coastal sandy soils being more deficient than laterite soils. Pratheep (1998) observed that Ca content of soil decreased with increase in depth, however the decrease of Mg content was seen only upto 50 cm.

2.2 PLANT NUTRIENT CONTENT AND ITS RELATION TO YIELD

Indirakutty and Pandalai (1968) observed a general increase in foliar nutrient content of N, P_2O_5 and K_2O with increase in yield of coconut palm. Devi and Pandalai (1968) found that foliar N, phosphoric acid, potash, Fe and Mn were positively correlated with the yield of coconut.

Ollagnier *et al.* (1970) reported an yield increase of 5 per cent when leaf N concentration was raised from 2.3 to 2.7 per cent in coconut. Thomas (1973) observed positive correlation with yield in the case of foliar levels of N and Ca.

Manciot *et al.* (1980) suggested the critical level of iron as 50 ppm in the 14^{th} frond. They recommended the critical level of Cu as 5 to 7 ppm. They also reported that Al content increased with the age of the frond. There was a variation from 6 to 127 ppm.

Eschbach and Manciot (1981) remarked that the Fe content of coconut leaf can vary from 40 to 100 ppm. They recorded a variation from 9 to 48 ppm in aluminium content and fixed the critical level of copper at 4 to 5 ppm, and Mn at 100 ppm and that of Zn at 15 ppm.

According to Krishnakumar (1983), yield of palms was significantly correlated with N percentage of leaf lamina. The partial correlation coefficients between yield and the P content of 2nd, 10th and 14th leaves were not significant. Cecil (1984) reported that the N, P and K contents of 14th frond of healthy palms of high productivity were 1.93, 0.198 and 1.23 per cent respectively. Jose *et al.* (1991) reported that yield of palm was significantly correlated with N content of leaf lamina of 2nd, 10th and 14th leaves.

2.3 INFLUENCE OF NET IONIC EQUILIBRIUM (NIE) AND RELATIVE NUTRIENT CONTENT IN SOIL AND PLANT ON YIELD

The Basic Cation Saturation Ratio (BCSR) approach promotes the concept that maximum yields can only be achieved by creating an ideal ratio of Ca, Mg and K in the soil system (Rehm, 1994). Seena *et al.* (2001) observed that a meaningful soil test result interpretation for K is possible only if its interaction with dominant multivalent ions in the system in terms of Net Ionic Equilibrium (NIE) is considered.

Cordova (1965) showed that leaf Ca was highly correlated with soil exchangeable Ca and percentage base saturation of the CEC. According to him, excessive amount of soil exchangeable Ca depressed K uptake and leaf K was more related to percentage potassium saturation of the CEC than to its total amount in exchangeable form. Regardless of the amount of soil exchangeable Na, leaf Na tended to be lower in high yielders with sufficient soil available P and N. Highly productive trees tend to prefer soils in which the ratios of Ca/Mg, Mg/K, Ca/K and (Ca+Mg)/K varied narrowly only.

Indirakutty and Pandalai (1968) in a study with tall coconut palms growing in four different soil types reported increase in foliar contents of N, P_2O_5 and K_2O with increasing yield as against Ca and Mg. The foliar nutrients were in the decreasing order of N, P_2O_5, CaO and MgO. The total plant uptake of K was significantly correlated with the corresponding ratios of Ca to K in the soil obtained by neutral normal ammonium acetate extraction. The correlations were negative which confirms the preposition that as the ratio of Ca to K in soil increases, the leaf K decreases correspondingly (Nartea, 1969).

Foliar analysis by Smith (1969) had revealed that coconut yield is not a function of individual effect of nutrients but their interactions. Thomas (1973) observed relation between yield and N/P, N/K and Ca/Mg ratios in leaves. According to him the level of K had to be interpreted in terms of a balance between K and Ca. Thomas and Nandra (1974) after foliar analysis of high yielding and low yielding palms showed that yield is correlated with the above ratios.

Wahid *et al.* (1974) in a study in West Coast Tall, found a negative but insignificant correlation between root CEC and yield. The leaf 'K+Na' content fell with a rise in root CEC whereas that of 'Ca+Mg' got increased. Highly significant correlations were obtained between $\frac{K}{Na}$, and $\frac{K}{(Ca+Mg)}$ and $\frac{K}{Mg}$ ratios in the soil and their corresponding ratios in the leaves. The K contents of the leaf and soil were positively correlated with yield with a critical level of 0.8 to 1 per cent on a dry weight basis. The leaf potassium level was affected by the leaf levels of Na, Ca and Mg.

Mathew (1977) reported the importance of Mg in coconut nutrition and pointed out that imbalance in K-Mg ratio resulted in yellowing of leaves and reduction in yield. Manciot *et al.* (1979) reported nutrient antagonism in coconut namely K-Ca, K-Mg and K-Na. The application of high dose of KCl induced severe Mg deficiency. Manciot *et al.* (1980) pointed out that $MnSO_4$ had no action in the absence of Fe fertilization and once the Fe and Mn deficiencies are corrected, N and K deficiencies appears. They also opined that it is difficult to define a critical level for Mn in coconut. MoP application had decreased the leaf Ca content in coconut (Anon, 1980).

Narayanankutty (1983) reported that among the mineral nutrients, N and K had significant positive correlation with yield. Phosphorus, Ca and Mg failed to show any linear relationship. The nutrient ratios viz., N/Ca, K/P, K/Ca, K/Mg and $\frac{K}{(Ca+Mg)}$ also exhibited significant positive correlation with yield.

An investigation on the effects of Ca and Mn interaction on the growth and nutrition of *Epilobium hirsutum* L. was carried out by Nazrul-Islam (1986) and found that the plant showed both Ca deficiency at a level of 0.08 mg l^{-1} (Ca as $CaCl_2$ $6H_2O$) and Mn toxicity symptoms at the level of 5 mg l^{-1} (Mn as $MnSO_4$ $4H_2O$). An increase in the Ca level in the nutrient solution was effective in reducing 'Mn' toxicity.

Magat *et al.* (1988) noticed that leaf content of Mg proved to be negatively correlated with nuts per tree. As coconuts are regularly manured with high level of K, an induced deficiency of Mg is to be expected while there was a definite negative interaction of K on Mg absorption (Prabhakumari, 1992).

Mohanachandran (1990) reported that the prominent nutrient elements in leaf which play decisive roles in coconut production were found to be N, P, K, Cl and to some extent S whereas the role of Na is considerable only in cases of K deficiency.

Mathewkutty (1994) reported that among the nutrient elements, the mean values of N and Ca were found higher for the low yield group of coconut than for the high yield group while the reverse was true for P, Mg and Cl. The nutrient ratios for low yield group were higher than for high yield group in 26 cases and the nutrient ratios which gave higher values for high yield group were P/K, P/Ca, P/Fe, K/Fe, Mg/K, Mg/Ca and S/K. Among the nutrient ratios involving K, K/S in coconut populations under the study at Pilicode and Mannuthy and K/Cl, K/Fe, K/Zn and K/Mn at Mannuthy were negatively correlated with yield. K/Zn was positively correlated with yield at Pilicode. Positive correlations with yield were also recorded for K/Ca, K/Mg, K/Cl and K/Mn ratios at Balaramapuram. Among the significant correlations between yield and nutrient ratios involving Ca, only one ratio namely Ca/Zn gave positive 'r' value in Pilicode population. In all the other cases it was negative.

Materials and Methods

3. MATERIALS AND METHODS

In order to achieve the objectives of the study, a series of laboratory investigations, using the samples from the selected coconut palms and their rhizosphere were carried out as detailed below. The experimental palms were selected from the coconut garden of the Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara. The samples were collected during May, 2002 (pre-monsoon season) and November, 2002 (post-monsoon season).

3.1 IDENTIFICATION OF SAMPLE COCONUT PALMS

The population of the coconut palms was divided into two viz., low yielding and high yielding subpopulations, as per the procedure outlined by Mathewkutty (1994). For this, the yield data of the 250 coconut palms of the garden from May 1997 to May 2001 were collected and the mean yield and standard deviation for the entire population was worked out.

The palms having mean yield greater than the value for 'palm mean yield plus standard deviation' were grouped under high yielding subpopulation. Similarly, the palms having mean yield lower than the value for 'palm mean yield minus standard deviation' were grouped under low yielding subpopulation. Thus based on yield data for the previous four years, 50 sample coconut palms were selected of which first 25 belong to the high yield group and the others to the low yield group, starting from the highest yield in a descending order.

3.1.1 Collection and Processing of Leaf Samples

Leaf samples were collected during two seasons, pre-monsoon (May) and post-monsoon (November) from the 14^{th} frond as suggested in the sampling procedure by Fremond *et al.* (1966). Five leaflets from either side of the middle portion of the leaves were separated. Only the middle portion of the leaflet after discarding about 30 cm of either end was considered. The midrib of each leaflet was removed and only the leaf lamina was taken. The samples were cleaned with moist cotton to remove dust, cut into small pieces and dried first under shade and then in a hot air oven at $70^{o}C$ - $75^{o}C$. The dried samples were powdered in a grinder with stainless steel blades and stored in plastic bottles for analysis.

3.1.2 Collection and Processing of Soil Samples

Soil samples were collected from the basins of the sample coconut palms from two depths viz., 30 cm and 60 cm at pre-monsoon (May) and post-monsoon (November) seasons along with the plant sample collection. Soil samples were drawn from 30 cm depth at a lateral distance of one metre from the palm using augers. In the same pit again the augers were introduced to collect the soil samples from 30-60 cm depth. Samples were collected in the same manner from four locations in the basins of each palm and mixed. The sample size was reduced to about 1 kg by the procedure of quartering. Samples were then air dried under shade, powdered gently, sieved through a 2 mm sieve and that fraction passed through the 2 mm sieve were kept in air tight plastic containers for analysis.

3.1.3 Extraction of Soil Solution

The soil solutions from the surface soil samples were extracted by centrifugation technique (Moris, 1991) in the present study. Two hundred gram of each soil sample was used to extract soil solution. The sample is made into saturation paste using distilled water. Care was taken to avoid excess moisture and at the saturation point the soils were non-sticky and there was a glowing appearance. This saturation paste was transferred to the specially fabricated stainless steel centrifugal filter with a disc of Whatman No.42 filter paper placed at the perforated bottom.

Centrifugal filter used in the study was a modified version of that used by Moris (1991) (Fig.1). The modified stainless steel filter could be fabricated with local facilities at reduced cost and could be used with commonly available centrifuging apparatus. The filters were placed in the centrifuge and extracted the soil solution at 4000 rpm for 20 minutes. Extracted soil solutions were collected in plastic bottles and kept for analysis.

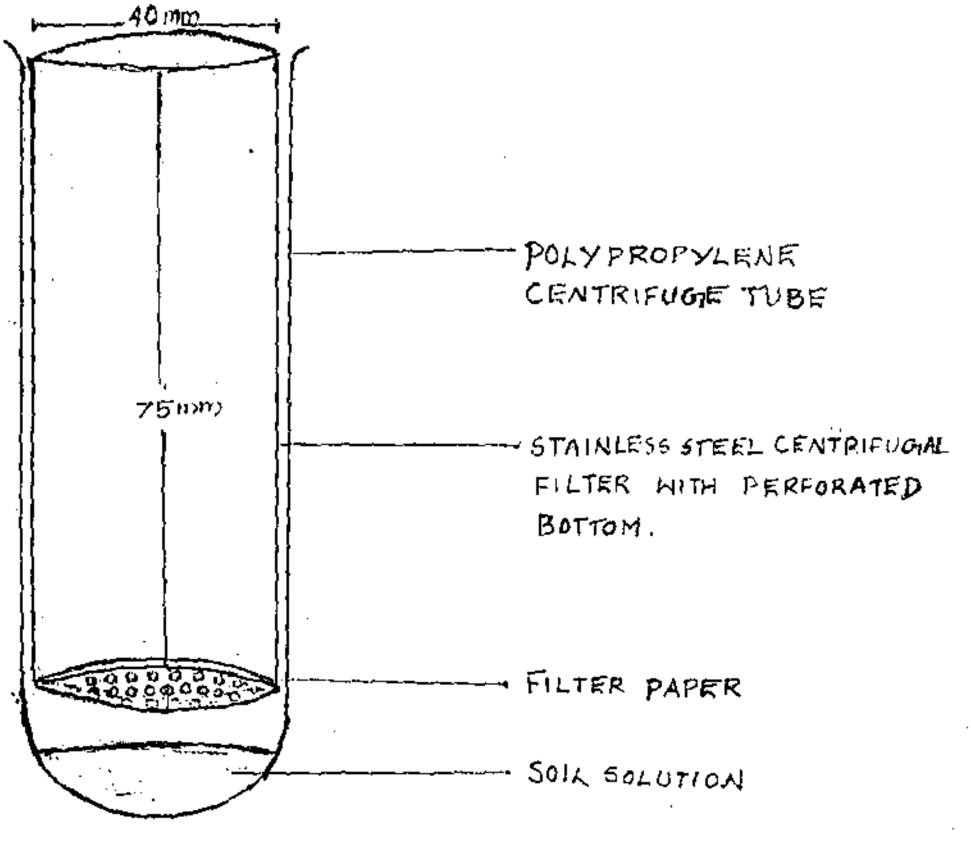


FIG. 1. CENTRIFUGAL FILTER ASSEMBLY

3.2 ESTIMATION OF NUTRIENT ELEMENTS IN THE LEAF SAMPLES

Leaf samples were analysed for N, P, K, Ca, Mg, Na, Al, Fe, Mn, Cu and Zn. Nitrogen was estimated by modified Kjeldahl's method as described by Jackson (1958). For this the monoacid digestion using sulfuric acid and digestion mixture was done and the digested samples were distilled using Microkjeldahl's distillation apparatus.

Determination of all other nutrients were carried out after digestion of the powdered plant sample with 2:1 nitric acid – perchloric acid mixture (Jackson, 1958).

Phosphorus in the digest was determined by the vanadomolybdate yellow colour method (Koenig and Johnson, 1942) and readings were taken in Spectronic-20, spectrophotometer. Potassium and sodium in the digest were estimated by flame photometry. Calcium and magnesium were determined using the versenate titration method (Hesse, 1971).

Fe, Mn, Cu and Zn were estimated using atomic absorption spectrophotometer Aluminium in the plant sample was estimated by colorimetric method using aluminon as described by Hsu (1963); Jayman and Sivasubramaniam (1974); Barnhisel and Bertch(1982).

Net Ionic Equilibrium ratios of cations in leaf samples were computed with respect to K and Na using the data on leaf content of cations expressed in cmol(+) kg^{-1} leaf sample.

3.3 DETERMINATION OF CHEMICAL PROPERTIES OF THE SOIL SAMPLES

Soil fertility parameters covering various electrochemical and chemical constituents of the soil, were analysed as per standard procedures.

3.3.1 Soil pH

The pH of the soil was determined by 1:2.5 soil water suspension potentiometrically using a pH meter (Jackson, 1958).

3.3.2 Electrical Conductivity

Electrical conductivity was determined in the supernatant liquid of the soil water suspension (1:2.5) with the help of conductivity meter (Jackson, 1958).

3.3.3 Organic Carbon

Organic carbon of the soil was determined by wet digestion method of Walkley and Black (Walkley and Black, 1934).

3.3.4 Available Phosphorus

Available phosphorus in the soil samples were determined by extracting with Bray No.1 reagent (Bray and Kurtz, 1945) and estimating colorimetrically by reduced molybdate ascorbic acid blue colour method using spectronic 20 spectrophotometer (Watanabe and Olsen 1965).

3.3.5 Neutral Normal Ammonium Acetate Extractable Cations

Available potassium and sodium were extracted with neutral normal ammonium acetate solution. Contents of respective elements in the extract were determined by flame photometry (Jackson, 1958). Available calcium and magnesium from the ammonium acetate extract were estimated by versenate titration method (Hesse, 1971).

3.3.6 Cation Exchange Capacity

The cation exchange capacity was determined by the method proposed by Hendershot and Duquette (1986). The exchangeable cations (Ca, Mg, Na, K, Al, Fe and Mn) present in the exchange sites in soil were replaced by 0.1 M $BaCl_2$ solution and the extracted cations were estimated, using standard procedures. The sum of these exchangeable cations expressed in cmol (+) kg^{-1} soil was recorded as CEC of soil.

3.3.7 Net Ionic Equilibrium Ratios in Soil

The ratios with respect to exchangeable monovalent K^+ and Na^+ ,to exchangeable divalent cations (Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{2+}) and trivalent cation (Al^{3+}), expressed as cmol(+) kg^{-1} soil, were computed following Ratio Law (Schofield, 1947).

3.3.8 Available Micronutrients (Fe, Mn, Cu and Zn) in Soil

Available micronutrients in both surface and subsurface samples were extracted using 0.1M HCl (Sims and Johnson, 1991), and Fe, Mn, Cu and Zn were estimated by atomic absorption spectrophotometer.

3.4 ASSAY OF SOIL SOLUTIONS

3.4.1 Estimation of Chemical Parameters of the Soil solutions

The pH and EC as well as the concentrations of P, K, Na, Ca, Mg, Fe, Mn, Cu and Zn in soil solutions were estimated following standard procedures.

3.4.2 Net Ionic Equilibrium Ratios

The concentrations of cations in soil solution expressed in cmol(+) kg^{-1} were used to compute NIE ratios in soil solution.

3.5 DATA PROCESSING AND STATISTICAL ANALYSIS

Data generated through chemical analyses of the samples (Plant, soil and soil solution) were tabulated and statistically analysed (Snedecor and Cochran, 1967).

Results

4. RESULTS

The data generated from the analyses of the soil, soil solution and leaf samples of the experiment are presented in this chapter.

4.1 YIELD OF PALMS

Table 1 represents the average yield of nuts palm^{-1} year^{-1} for the high yield group of coconut palms. In this group, of the 25 palms, the highest yield was for the first palm with an average of 84.4 nuts palm^{-1} year^{-1}. The lowest yield recorded in this group was 65 nuts palm^{-1} year^{-1} for the twenty fifth palm and the mean yield in this group was 71.42 nuts palm^{-1} year^{-1}.

The average nut yield palm^{-1} year^{-1} for the low yielding population of coconut palms are presented in table 2. Here the yield varied from 14.4 nuts palm^{-1} year^{-1} to 29 nuts palm^{-1} year^{-1}, and the mean yield in this group was 24.29 nuts palm^{-1} year^{-1}.

The soil samples taken from the basins of selected coconut palms at two seasons from 30 cm depth (surface) and at 60 cm depth (subsurface) were subjected to various analyses for estimation of different electrochemical properties like pH, electrical conductivity, organic carbon, pool of available nutrients viz., P, K, Ca, Mg, Fe, Mn, Cu and Zn as well as exchangeable cations viz., K, Na, Ca, Mg, Fe, Mn and Al. The data are presented hereunder:

4.2 ELECTROCHEMICAL PROPERTIES

pH, EC and organic C content of all the samples were determined and the results are presented below:

4.2.1 Pre-monsoon Surface Samples

For the pre-monsoon season, the soil samples collected from 30 cm depth were subjected to analyses of electrochemical parameters and these were grouped under two classes based on yield.

Table 1. Average yield of palms (High yielding population)

Sample No.	Yield (Nuts palm^{-1} yr^{-1})
1	84.4
2	83.8
3	81.8
4	79.2
5	76.4
6	75.4
7	73.2
8	72.2
9	71.8
10	70.0
11	69.6
12	69.6
13	69.4
14	68.8
15	68.8
16	68.2
17	68.2
18	68.2
19	68.0
20	67.2
21	66.8
22	66.6
23	66.4
24	66.4
25	65.0

Table 2. Average yield of palms (Low yielding population)

Sample No.	Yield (Nuts $palm^{-1}$ yr^{-1})
26	29.0
27	28.6
28	28.4
29	28.2
30	27.8
31	27.6
32	27.4
33	27.2
34	27.2
35	26.8
36	25.4
37	25.4
38	25.2
39	24.8
40	24.4
41	24.0
42	23.6
43	23.6
44	23.0
45	22.6
46	22.4
47	18.4
48	16.0
49	16.0
50	14.4

4.2.1.1 High Yielding Population

Table 3 shows the electrochemical properties of the pre-monsoon surface soil samples of high yielding population of coconut palms. pH of these samples ranged from 4.20 to 6.38. Electrical conductivity values ranged from 0.066 dSm^{-1} to 0.484 dSm^{-1}. The organic carbon values were between 0.56 and 1.58 per cent.

4.2.1.2 Low Yielding Population

The data on the electrochemical properties of the pre-monsoon surface soil samples of low yielding population of coconut palms are furnished in table 4. pH of the samples in this group ranged from 3.74 to 6.29. Electrical conductivity values ranged from 0.069 dSm^{-1} to 0.850 dSm^{-1}. The organic carbon values ranged from 0.33 to 1.67 per cent.

4.2.2 Pre-monsoon Subsurface Samples

The electrochemical properties for the soil samples taken from 60 cm depth are presented below:

4.2.2.1 High Yielding Population

The data on the electrochemical properties of soil under this class are depicted in table 5. pH of the samples ranged between 4.17 and 5.47. Electrical conductivity values ranged from 0.054 dSm^{-1} to 0.429 dSm^{-1}. Organic carbon content of the samples ranged from 0.44 to 1.46 per cent.

4.2.2.2 Low Yielding Population

The results presented in table 6 show that the pH values in this class ranged between 4.10 and 6.18. The electrical conductivity values ranged between 0.062 dSm^{-1} and 0.612 dSm^{-1}. The organic carbon ranged from 0.45 to 1.32 per cent .

4.2.3 Post-monsoon Surface Samples

For the post-monsoon season, the electrochemical properties are as follows:

Table 3. Electro-chemical properties of pre-monsoon surface samples (High yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
1	5.10	0.121	0.56
2	5.10	0.216	0.73
3	4.96	0.107	0.83
4	4.90	0.228	0.92
5	5.21	0.186	0.67
6	4.84	0.243	1.04
7	5.20	0.192	1.32
8	4.92	0.183	1.36
9	4.87	0.092	0.72
10	5.06	0.176	0.64
11	4.57	0.182	1.14
12	4.24	0.484	0.94
13	5.31	0.067	1.58
14	4.20	0.107	0.61
15	5.02	0.134	0.92
16	4.96	0.066	1.27
17	5.11	0.074	0.97
18	4.67	0.201	1.43
19	4.30	0.199	0.88
20	6.38	0.365	0.80
21	4.69	0.069	1.52
22	5.04	0.136	0.76
23	5.22	0.124	0.67
24	5.46	0.192	0.80
25	4.98	0.137	1.25

Table 4. Electro-chemical properties of pre-monsoon surface samples (Low yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
26	4.54	0.141	1.20
27	5.22	0.069	0.33
28	4.87	0.623	0.99
29	4.68	0.289	1.10
30	4.98	0.128	1.45
31	5.21	0.148	0.44
32	5.30	0.112	1.38
33	3.74	0.128	0.95
34	4.79	0.174	0.74
35	4.26	0.850	1.13
36	5.10	0.403	1.29
37	4.94	0.135	0.70
38	5.12	0.149	0.74
39	5.46	0.075	0.85
40	4.98	0.209	0.40
41	5.31	0.132	1.49
42	5.32	0.097	1.30
43	4.83	0.412	0.86
44	4.57	0.183	0.96
45	6.29	0.178	0.84
46	5.16	0.202	0.33
47	5.10	0.184	1.30
48	5.04	0.113	0.82
49	5.16	0.267	1.45
50	3.74	0.661	1.67

Table 5. Electro-chemical properties of pre-monsoon subsurface samples (High yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
1	5.10	0.112	0.76
2	5.20	0.204	0.78
3	5.17	0.092	0.96
4	5.00	0.101	0.98
5	5.28	0.069	0.70
6	4.83	0.201	1.12
7	5.08	0.184	1.02
8	5.43	0.241	1.46
9	4.31	0.269	0.86
10	5.02	0.194	0.86
11	4.84	0.174	0.46
12	4.28	0.324	0.86
13	5.47	0.054	0.72
14	4.90	0.086	0.69
15	5.26	0.204	0.97
16	5.11	0.104	0.72
17	4.98	0.245	0.99
18	4.17	0.164	0.94
19	5.16	0.162	0.93
20	5.08	0.267	1.25
21	4.30	0.086	0.44
22	4.82	0.055	0.94
23	5.40	0.083	0.76
24	4.60	0.429	0.85
25	4.84	0.126	1.04

Table 6. Electro-chemical properties of pre-monsoon subsurface samples (Low yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
26	4.65	0.092	0.64
27	5.09	0.098	0.52
28	4.10	0.281	1.10
29	4.76	0.239	0.85
30	5.48	0.069	1.04
31	4.76	0.340	1.32
32	5.16	0.261	0.99
33	5.05	0.278	1.29
34	5.02	0.412	0.82
35	4.80	0.612	0.94
36	4.90	0.062	0.82
37	5.08	0.186	0.82
38	5.19	0.161	0.87
39	5.71	0.102	1.01
40	4.81	0.386	0.90
41	5.52	0.121	1.25
42	5.24	0.089	0.79
43	4.76	0.318	1.20
44	4.92	0.179	0.45
45	6.18	0.166	0.98
46	5.08	0.108	1.25
47	4.86	0.492	0.96
48	5.26	0.091	0.99
49	5.30	0.147	1.10
50	5.10	0.412	1.12

4.2.3.1 High Yielding Population

The data in table 7 indicate that the pH values in this group ranged between 3.59 and 5.61. The electrical conductivity ranged between 0.064 dSm^{-1} and 0.407 dSm^{-1}. The organic carbon content ranged between 0.37 and 1.60 per cent.

4.2.3.2 Low Yielding Population

As presented in table 8 the pH values were in between 4.28 and 6.08. The electrical conductivity ranged between 0.076 dSm^{-1} and 1.290 dSm^{-1}. The organic carbon content ranged from 0.49 to 1.67 per cent.

4.2.4 Post-monsoon Subsurface Samples

The electrochemical properties of the soil samples from the subsurface horizons at post-monsoon season are as described below:

4.2.4.1 High Yielding Population

The pH values ranged between 3.85 and 5.59. The electrical conductivity values ranged between 0.057 and 0.298 dSm^{-1}. The organic carbon, varied between 0.41 and 1.24 per cent (Table 9).

4.2.4.2 Low Yielding Population

The data in table 10 show that the pH values varied between 4.25 and 6.14. The electrical conductivity values ranged between 0.061 dSm^{-1} and 0.861 dSm^{-1}. The organic carbon content varied from 0.56 to 1.21 per cent.

4.3 AVAILABLE NUTRIENTS

The data on available nutrient contents of the soil (P, K, Na, Ca, Mg, Fe, Mn, Cu and Zn) in mg kg^{-1} are presented below:

4.3.1 Pre-monsoon Surface Samples

For the pre-monsoon season the available nutrients estimated were grouped under high yield and low yield populations as given below:

Table 7. Electro-chemical properties of post-monsoon surface samples (High yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
1	5.09	0.118	0.37
2	5.60	0.249	0.93
3	5.20	0.098	1.23
4	4.80	0.407	0.74
5	5.16	0.109	0.56
6	5.60	0.097	0.99
7	5.57	0.168	0.94
8	5.61	0.243	0.91
9	4.59	0.064	0.50
10	5.12	0.165	0.41
11	4.62	0.164	0.82
12	4.60	0.367	0.85
13	5.34	0.092	1.29
14	4.80	0.097	1.13
15	5.28	0.122	0.89
16	5.20	0.086	1.40
17	5.28	0.146	1.32
18	4.48	0.184	0.89
19	5.39	0.102	0.84
20	5.04	0.218	1.41
21	3.59	0.066	1.60
22	4.92	0.142	0.87
23	5.14	0.166	0.72
24	4.60	0.154	0.74
25	5.04	0.149	0.72

Table 8. Electro-chemical properties of post monsoon surface samples (Low yielding population) -

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
26	5.04	0.112	0.84
27	5.15	0.077	0.54
28	5.28	0.076	0.94
29	4.61	0.246	0.96
30	4.67	0.186	0.69
31	5.10	0.120	0.63
32	5.40	0.319	0.85
33	4.97	0.081	0.49
34	4.96	0.198	0.67
35	4.28	1.290	0.89
36	4.63	0.326	0.76
37	5.02	0.142	0.64
38	4.91	0.179	0.62
39	5.68	0.201	0.79
40	5.18	0.214	0.76
41	5.08	0.118	0.83
42	4.96	0.112	0.86
43	5.61	0.401	0.84
44	4.64	0.168	0.57
45	6.08	0.184	0.76
46	5.24	0.118	0.87
47	5.09	0.321	0.82
48	4.96	0.107	1.67
49	4.94	0.269	1.24
50	4.90	1.120	0.95

Table 9. Electro-chemical properties of post-monsoon subsurface samples (High yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
1	4.84	0.113	0.82
2	5.40	0.198	1.01
3	5.18	0.070	0.92
4	4.80	0.081	0.87
5	5.05	0.086	0.41
6	5.10	0.144	0.93
7	4.97	0.201	1.06
8	5.34	0.234	1.24
9	4.68	0.189	0.78
10	4.84	0.261	0.78
11	5.06	0.194	0.98
12	5.59	0.298	0.92
13	4.82	0.104	1.02
14	4.60	0.098	0.91
15	5.08	0.191	1.01
16	5.08	0.132	0.98
17	3.85	0.145	1.01
18	4.28	0.178	0.89
19	5.49	0.076	0.66
20	5.26	0.204	0.92
21	4.28	0.057	0.75
22	4.84	0.139	1.17
23	5.06	0.138	0.89
24	4.80	0.167	0.88
25	4.76	0.139	0.63

Table 10. Electro-chemical properties of post -monsoon subsurface samples (Low yielding population)

Sample No.	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)
26	5.25	0.071	0.98
27	5.18	0.104	0.63
28	4.90	0.261	0.96
29	4.44	0.192	0.91
30	4.86	0.154	0.63
31	4.51	0.207	0.78
32	5.29	0.179	1.21
33	4.76	0.363	0.82
34	5.14	0.124	0.56
35	4.64	0.861	0.85
36	4.86	0.162	0.80
37	5.16	0.164	0.90
38	5.09	0.130	0.61
39	5.55	0.159	0.82
40	5.35	0.075	0.78
41	5.46	0.126	0.82
42	5.09	0.101	0.82
43	4.92	0.304	0.99
44	4.88	0.198	0.89
45	6.14	0.124	1.06
46	5.20	0.101	1.04
47	4.25	0.132	1.16
48	5.08	0.068	0.83
49	5.49	0.061	0.99
50	4.92	0.485	0.73

4.3.1.1 High Yielding Population

The values for available nutrients are presented in mg kg^{-1} in table 11. Available P values ranged between 2.84 and 25.4. Available K varied from 49.98 to 274.9. Available Na values were between 5.33 and 56.1. Available Ca values ranged between 220 and 760. The available Mg values ranged between 60 and 192. In the case of micronutrients, the available Fe values ranged between 36 and 60. Available Mn values were between 50 and 120. Available Cu values ranged from 1 to 20. Available zinc values were in between 2 and 23 .

4.3.1.2 Low Yielding Population

The data in table 12 indicate the available nutrient status of the soil in mg kg^{-1}. Available P values ranged from 5.95 to 30.1. Available K content ranged from 74.97 to 350.1. The available Na values were in between 5.33 and 77.40. Available Ca ranged between 260 and 720. Available Mg values were varying from 60 to 216. Available Fe ranged between 18 and 53. Available Mn values ranged from 40 to 120. Available Cu and available Zn values ranged between 1 and 13.

4.3.2 Pre-monsoon Subsurface Samples

The available nutrients were estimated for the soil samples taken from 60 cm depth for the pre-monsoon season and the results are grouped under the following classes.

4.3.2.1 High Yielding Population

Table 13 shows the estimated available nutrients expressed in mg kg^{-1} soil. Available P varied between 3.38 and 20.70. Available K values were in between 74.97 and 258.20. The values for available Na ranged between 2.67 and 58.60. The available Ca values varied from 180 to 820. Available Mg values ranged between 60 and 216. For micronutrients, the available Fe content ranged from 33 to 55. Available Mn ranged between 50 and 130. Available Cu values were in between 3 and 27 and available Zn ranged from 2 to 26.

4.3.2.2 Low Yielding Population

Table 11. Available nutrient status in mg kg^{-1} soil. (Pre-monsoon surface samples - High yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
1	22.60	150.03	21.32	280	192	52	90	13	9
2	20.50	166.70	39.98	240	156	60	110	8	16
3	17.50	208.40	56.10	460	84	55	100	8	9
4	12.00	183.40	15.30	760	132	42	80	11	19
5	22.80	166.70	23.90	400	144	41	100	12	23
6	7.40	116.60	12.67	540	168	48	70	6	4
7	11.14	166.70	10.67	340	120	50	110	16	2
8	22.60	116.60	18.70	480	144	46	90	7	10
9	5.51	158.40	13.33	260	72	58	90	10	6
10	13.42	208.40	15.33	240	108	51	100	10	2
11	24.30	108.30	32.04	260	84	48	80	4	21
12	18.78	233.40	53.30	380	144	42	80	4	13
13	9.05	166.70	56.10	400	96	56	100	1	13
14	15.70	216.70	26.70	460	144	36	120	10	11
15	20.96	200.04	15.33	440	132	49	80	5	17
16	11.27	66.64	37.38	420	168	44	80	10	5
17	13.54	49.98	12.67	220	108	52	80	17	6
18	12.91	74.97	26.70	300	108	46	80	20	7
19	25.40	274.90	18.66	380	108	59	80	4	12
20	17.40	191.70	10.67	280	108	52	70	3	11
21	2.84	133.30	10.67	320	96	50	70	8	11
22	22.44	116.60	7.99	380	96	49	70	8	9
23	5.51	216.70	5.33	380	120	48	80	8	11
24	5.32	233.40	21.32	280	132	49	90	9	6
25	12.54	83.30	5.33	300	60	40	50	8	11

Table 12. Available nutrient status in mg kg^{-1}soil. (Pre-monsoon surface samples - Low yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
26	21.50	300.10	26.65	560	60	49	90	6	11
27	21.84	291.70	69.30	560	96	35	90	4	3
28	18.50	350.10	23.90	330	180	42	80	8	9
29	19.70	141.60	34.71	440	132	30	80	13	5
30	20.30	150.03	45.39	440	60	34	60	5	6
31	11.65	183.37	5.33	500	216	33	120	5	6
32	30.10	191.70	5.33	500	216	38	70	4	9
33	21.96	191.70	32.04	400	120	53	70	7	5
34	23.30	150.03	21.32	320	84	44	60	4	2
35	8.80	183.40	21.47	720	96	51	90	11	6
36	20.89	108.30	5.33	380	108	33	80	6	10
37	20.32	83.30	5.33	260	132	42	60	6	1
38	12.85	266.60	10.67	360	108	49	90	1	2
39	15.58	166.70	10.67	540	72	22	80	11	9
40	10.48	108.30	45.39	480	144	41	50	5	6
41	22.30	258.20	18.66	260	96	40	50	10	10
42	17.47	116.60	5.33	320	108	44	60	6	4
43	12.40	150.03	77.40	560	216	18	70	8	1
44	20.70	116.60	26.70	280	144	25	60	7	7
45	7.34	141.60	26.70	580	192	33	40	6	4
46	12.85	99.96	69.30	640	96	39	70	6	7
47	13.27	116.60	37.40	460	72	38	50	7	3
48	24.80	74.97	5.33	460	84	41	50	8	10
49	19.90	133.30	10.67	460	132	33	60	13	3
50	5.95	141.60	7.99	520	96	34	40	4	13

Table 13. Available nutrient status in mg kg^{-1}soil. (Pre-monsoon subsurface samples - High yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
1	8.23	150.03	26.70	320	168	46	70	27	26
2	12.60	200.04	21.32	360	120	50	110	6	3
3	5.63	158.40	29.33	400	108	44	90	7	7
4	5.50	158.36	10.67	820	96	40	100	10	11
5	4.49	150.03	26.70	440	168	40	90	3	16
6	4.05	158.36	12.67	680	132	49	80	5	11
7	7.22	175.00	15.99	420	144	41	100	3	15
8	17.30	141.60	23.99	420	156	47	70	8	9
9	7.85	124.95	21.32	280	216	55	80	11	8
10	12.15	250.04	5.33	280	132	41	80	4	10
11	15.71	74.97	29.33	280	120	47	80	6	7
12	7.30	225.04	58.60	380	132	34	80	3	2
13	5.44	141.60	18.66	640	192	54	80	6	8
14	20.70	150.03	39.98	400	96	33	130	5	22
15	5.89	158.40	10.67	480	96	42	90	10	2
16	12.73	99.96	34.71	300	108	43	70	5	4
17	9.60	91.63	10.67	320	144	47	80	9	7
18	12.30	116.60	26.70	280	132	47	50	9	21
19	5.24	258.20	15.99	320	132	46	90	4	24
20	19.75	150.03	2.67	180	84	47	60	6	18
21	17.40	99.96	37.38	540	204	41	50	11	7
22	12.53	124.95	10.67	400	60	47	70	5	8
23	3.38	208.37	18.66	280	144	49	60	7	10
24	3.86	208.37	21.32	300	156	48	100	4	5
25	9.50	74.97	2.67	260	132	42	60	7	12

The data on available nutrients (mg kg^{-1}) are presented in table 14. The values for P ranged between 1.27 and 19.75. The values for K ranged between 66.64 and 250.04. Na ranged from 2.67 to 63.96. The available Ca values were in between 220 and 760. The available Mg values were in between 60 and 228. Regarding available micronutrients, Fe ranged from 19 to 49, Mn from 40 to 90. Available Cu varied from 1 to 9, and Zn from 1 to 14.

4.3.3 Post-monsoon Surface Samples

4.3.3.1 High Yielding Population

As in table 15, the available nutrient ions (mg kg^{-1}) ranged as follows. P from 2.57 to 28.14. K varied between 49.98 and 350.06. Na values ranged from 2.67 to 69.3. Calcium values ranged from 180 to 600. The values for Mg were in between 36 and 180. The available Fe content ranged from 38 to 63. The values for Mn ranged between 70 and 120. Cu ranged from 2 to 23 and Zn from 1 to 34.

4.3.3.2 Low Yielding Population

The data on available nutrients (mg kg^{-1}) are presented in table 16. The P values were in between 3.67 and 30.57. Available K ranged from 74.97 to 241.6. The Na values, varied between 2.67 and 63.96. The values for Ca ranged from 180 to 640. The Mg content varied between 60 and 204. Available Fe ranged from 19 to 71. The available Mn values were in between 60 and 100. The values for available Cu were in between 4 and 18 and Zn between 1 and 22.

4.3.4 Post-monsoon Subsurface Samples

4.3.4.1 High Yielding Population

Table 17 indicates the available nutrients in mg kg^{-1}. The values for P ranged between 1.49 and 26.33. K values were in between 49.98 and 274.90. Available Na values ranged between 2.67 and 63.96. The Ca showed values ranging from 180 to 620 and the Mg values were in between 48 and 168. Available Fe content ranged between 37 and 56 and available Mn ranged from 70 to 120. Available Cu ranged between 4 and 13 and Zn between 5 and 25.

Table 14. Available nutrient status in mg kg^{-1}soil. (Pre-monsoon subsurface samples - Low yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
26	6.37	250.04	29.33	380	132	35	70	7	8
27	18.79	208.40	42.64	760	132	40	80	4	4
28	11.80	166.70	10.67	760	96	41	90	3	6
29	5.50	124.95	32.04	580	144	38	80	1	6
30	2.70	158.40	32.04	460	132	38	50	6	7
31	1.62	141.60	29.33	330	96	37	90	9	6
32	12.53	233.30	2.67	560	192	44	70	3	11
33	18.33	233.30	18.66	520	180	33	60	6	3
34	10.32	158.36	42.64	280	144	40	40	6	1
35	19.50	158.38	39.98	480	132	49	80	6	5
36	14.94	91.63	10.67	360	132	25	60	5	14
37	10.38	83.30	5.33	220	84	41	50	5	13
38	13.42	158.40	7.99	440	156	47	80	9	8
39	11.46	175.00	13.33	560	168	45	60	5	1
40	10.19	99.96	26.70	460	108	38	80	4	6
41	19.75	150.03	37.38	420	72	38	60	4	3
42	13.04	116.60	10.67	340	108	39	50	5	2
43	4.30	174.90	39.98	480	192	28	60	6	4
44	19.70	66.64	29.33	500	84	26	80	4	2
45	11.65	133.30	21.32	600	228	19	40	5	8
46	6.37	158.36	63.96	400	60	38	50	6	8
47	10.63	108.30	32.04	380	96	36	60	9	4
48	19.62	83.30	7.99	440	96	30	50	7	2
49	14.12	150.03	5.33	560	60	31	50	7	2
50	1.27	116.60	7.99	340	132	33	40	4	9

Table 15. Available nutrient status in mg kg^{-1}soil. (Post-monsoon surface samples - High yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
1	13.61	133.30	18.66	320	108	58	110	15	14
2	16.70	166.70	69.30	380	132	61	120	10	18
3	12.10	158.40	58.60	340	84	59	120	11	14
4	11.67	250.04	7.99	600	180	63	110	20	16
5	14.12	150.03	21.32	360	96	49	110	11	34
6	6.79	91.63	21.47	520	108	51	80	11	13
7	10.57	175.00	21.32	260	96	52	120	13	13
8	10.32	58.31	2.67	460	108	57	120	9	13
9	3.86	141.60	10.67	240	48	63	100	13	9
10	6.52	183.40	5.33	220	96	49	110	13	16
11	17.60	99.96	23.99	220	72	49	100	9	16
12	20.32	200.04	47.99	320	96	45	80	7	2
13	8.36	141.60	29.33	440	72	60	110	13	18
14	16.85	350.06	29.33	520	36	38	100	2	1
15	11.10	191.70	5.33	540	48	50	90	5	8
16	20.95	116.60	29.33	380	72	52	110	12	9
17	28.14	49.98	5.33	180	96	54	90	8	11
18	20.30	91.60	21.32	240	72	49	90	23	23
19	21.80	291.60	13.33	420	132	63	100	7	18
20	21.30	150.03	10.67	220	84	57	90	12	12
21	2.57	141.60	13.33	260	60	50	100	11	9
22	19.49	99.96	7.99	300	72	50	100	10	13
23	6.77	191.70	10.67	400	96	51	90	12	16
24	5.76	191.70	29.33	240	108	51	110	7	12
25	10.57	74.97	2.67	260	72	51	70	7	14

Table 16. Available nutrient status in mg kg^{-1} soil. (Post-monsoon surface samples - Low yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
26	18.61	216.70	10.67	280	108	50	90	8	9
27	21.08	233.40	63.96	460	108	41	100	4	8
28	19.80	200.04	23.99	420	96	71	90	4	1
29	3.99	133.30	29.33	260	108	39	100	15	16
30	25.00	133.30	32.04	420	60	44	70	11	10
31	7.56	175.00	18.66	440	144	46	90	9	14
32	2.22	175.00	10.67	320	84	44	90	6	11
33	23.42	83.30	5.33	340	72	47	80	9	13
34	19.75	158.40	29.33	180	120	49	80	13	1
35	7.85	166.70	32.04	500	72	56	90	18	8
36	12.72	99.96	5.33	340	84	34	90	7	13
37	14.18	99.96	5.33	280	120	47	50	9	1
38	10.69	150.03	2.67	420	168	54	80	12	7
39	3.67	116.70	7.99	640	132	39	80	8	6
40	9.75	83.30	42.60	440	60	50	70	6	5
41	17.97	241.60	13.33	340	84	43	70	9	10
42	30.57	124.95	7.99	240	72	46	70	9	1
43	11.96	150.03	29.33	380	204	31	90	8	4
44	12.10	99.96	23.99	260	120	19	80	9	9
45	9.18	133.30	23.99	420	144	39	50	8	9
46	11.27	91.63	32.04	500	180	35	80	8	9
47	13.23	83.30	42.60	360	96	39	70	5	5
48	22.56	74.97	7.99	380	108	48	60	13	13
49	12.91	133.30	7.99	400	96	39	80	11	10
50	4.94	108.30	2.67	480	60	39	60	5	22

Table 17. Available nutrient status in mg kg^{-1}soil. (Post-monsoon subsurface samples - High yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
1	2.41	158.40	21.32	180	144	53	100	8	18
2	5.32	166.70	23.99	260	108	47	110	8	11
3	4.11	258.23	23.99	360	60	48	90	8	12
4	4.94	216.70	13.33	330	114	41	120	13	5
5	6.26	133.30	18.66	380	132	46	100	13	19
6	6.20	224.90	5.33	620	144	50	80	7	15
7	5.45	183.40	18.66	400	108	48	100	11	11
8	10.20	116.60	15.99	380	120	56	80	9	12
9	7.34	116.60	15.99	240	144	56	80	12	11
10	4.24	216.70	10.67	260	108	46	90	9	12
11	11.84	91.63	21.32	220	96	48	80	7	18
12	2.78	216.70	53.30	300	108	37	90	5	7
13	1.49	133.30	23.99	520	132	55	110	9	9
14	18.30	233.30	63.96	440	120	41	110	8	13
15	6.37	166.70	5.33	280	156	44	90	5	6
16	14.18	58.31	34.71	240	48	45	90	8	8
17	9.30	83.30	15.99	240	120	51	70	9	12
18	13.55	99.96	23.99	220	120	46	70	12	13
19	10.25	274.90	15.99	260	60	51	90	6	25
20	26.33	233.30	5.33	400	168	49	70	13	13
21	10.60	133.30	5.33	560	108	46	70	9	7
22	19.05	124.95	13.33	360	148	51	80	12	7
23	7.09	183.40	13.33	320	108	50	70	7	9
24	3.35	175.00	23.99	280	144	50	110	4	6
25	13.92	49.98	2.67	220	72	46	70	4	9

4.3.4.2 Low Yielding Population

Table 18 reveals the available nutrient contents in mg kg^{-1}. Available P ranged from 4.12 to 23.78. Potassium ranged between 66.64 and 233.40. Available Na ranged between 2.67 and 61.41. The Ca content ranged from 220 to 700. Available Mg values varied from 36 to 240. Available Fe values ranged between 27 and 52. Mn ranged from 40 to 110. Available Cu varied between 2 and 14 and Zn between 1 and 18.

4.4 EXCHANGEABLE IONS AND CEC

The exchangeable ions in soil at pre and post monsoon seasons, from surface and subsurface samples were estimated and these cations viz., Ca, Mg, K, Na, Al, Fe and Mn were expressed in cmol (+) kg^{-1}. The sum of these exchangeable ions computed on equivalent basis represent the cation exchange capacity of the soil samples.

4.4.1 Pre monsoon Surface Samples

4.4.1.1 High Yielding Population

The data in table 19 show the exchangeable ions expressed in mg kg^{-1} soil and CEC of the soils. Exchangeable Ca ranged between 380 and 760. The Mg values varied from 96 to 168. The exchangeable K varied between 199.8 and 483.1. The exchangeable Na ranged from 61.09 to 133.30. The exchangeable Al varied between 8.8 and 49.6. Exchangeable Fe varied from 41 to 60 and Mn ranged between 60 and 140. The cation exchange capacity of these soil samples ranged from 4.67 to 7.71 cmol(+)kg^{-1}.

4.4.1.2 Low Yielding Population

As depicted in table 20 the exchangeable ions are expressed in mg kg^{-1} soil. Exchangeable Ca values varied between 320 and 840. The Mg values varied from 72 to 132. The exchangeable K values ranged between 216.5 and 449.6 and Na between 66.7 and 199.9. The exchangeable Al varied from 15.2 to 102.6. Fe values ranged between 38 and 58. The exchangeable Mn values varied from 40 to 180. The cation exchange capacity of these soils ranged from 4.39 to 6.77 cmol(+)kg^{-1} soil.

Table 18. Available nutrient status in mg kg^{-1}soil. (Post-monsoon subsurface samples - Low yielding population)

Sample No.	Available P	Available K	Available Na	Available Ca	Available Mg	Available Fe	Available Mn	Available Cu	Available Zn
26	8.10	233.40	15.99	260	108	44	80	14	8
27	16.89	216.70	39.98	440	168	43	90	5	17
28	9.52	158.40	5.33	500	156	44	70	5	7
29	10.83	99.96	32.04	360	96	41	90	12	9
30	10.12	141.60	29.33	380	84	42	80	7	9
31	5.76	66.64	18.66	540	108	47	110	9	12
32	23.78	133.30	26.70	380	108	41	80	4	18
33	4.49	74.97	15.99	240	132	41	70	8	8
34	4.12	191.70	23.99	360	36	41	60	8	1
35	17.20	233.30	32.04	440	84	52	100	9	7
36	12.53	83.30	7.99	240	108	36	70	6	11
37	10.83	83.30	5.33	240	120	36	70	8	3
38	15.38	208.40	13.33	380	132	50	50	6	12
39	11.33	108.40	10.67	560	72	38	70	7	6
40	9.94	124.95	26.70	460	108	49	60	6	7
41	12.34	124.95	15.99	380	84	41	70	5	17
42	14.12	91.63	5.33	220	120	41	60	7	6
43	5.76	158.36	32.04	420	168	36	50	9	6
44	12.80	91.63	26.70	420	108	33	90	6	6
45	5.64	108.30	15.99	700	240	27	40	7	5
46	11.52	191.70	61.41	420	72	42	70	7	9
47	9.43	66.64	37.38	320	72	31	60	8	8
48	21.96	66.64	7.99	420	72	42	40	9	9
49	11.84	158.40	10.67	420	60	29	70	5	3
50	7.73	124.95	2.67	320	96	38	50	2	11

Table 19. Exchangeable ions in mg kg^{-1} soil and CEC of pre-monsoon surface samples (High yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
1	640	168	299.70	88.86	12.96	60	100	6.48
2	560	144	349.68	133.30	31.84	52	110	6.42
3	640	156	349.70	122.20	24.96	54	120	6.84
4	760	156	432.90	105.52	34.60	51	130	7.71
5	580	180	283.10	61.10	49.60	56	100	6.51
6	600	156	316.40	122.20	8.80	54	80	6.22
7	460	132	299.70	105.52	35.20	56	110	5.62
8	520	144	283.03	83.30	44.80	49	100	5.93
9	380	132	316.40	88.90	30.60	59	100	5.11
10	520	132	432.90	99.96	44.80	54	110	6.34
11	440	156	266.40	94.40	43.40	56	100	5.64
12	480	168	333.00	83.30	23.36	41	100	5.79
13	690	132	249.80	99.96	31.70	57	110	6.58
14	510	132	432.90	127.70	48.00	52	140	6.54
15	480	144	349.68	94.40	24.96	53	110	5.77
16	440	132	483.10	99.60	37.76	58	90	5.93
17	400	108	266.43	111.10	19.52	57	90	4.81
18	480	144	283.08	94.40	11.84	54	90	5.39
19	420	144	449.60	77.80	102.40	56	100	6.49
20	440	108	316.40	66.70	13.28	46	80	4.80
21	440	96	266.43	88.86	19.84	50	80	4.76
22	420	108	266.40	133.30	25.92	48	80	5.01
23	380	120	366.34	116.60	32.16	50	70	5.14
24	620	132	283.08	61.09	9.60	49	110	5.87
25	400	132	199.80	88.90	23.40	53	60	4.67

Table 20. Exchangeable ions in mg kg^{-1} soil and CEC of pre-monsoon surface samples (Low yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
26	520	132	416.30	72.19	44.50	58	100	6.15
27	600	84	449.60	94.40	17.92	42	100	5.98
28	460	108	366.34	111.10	25.40	46	100	5.43
29	460	120	216.50	72.19	17.44	41	90	4.84
30	400	108	316.40	116.60	28.80	48	70	4.96
31	480	108	316.40	66.70	18.90	44	180	5.42
32	620	108	283.08	77.80	102.60	49	90	6.71
33	420	108	333.00	72.20	42.72	49	80	5.11
34	360	108	283.10	72.20	16.32	51	80	4.39
35	580	96	400.00	127.70	15.68	52	100	6.01
36	400	96	349.70	88.90	19.40	43	80	4.74
37	320	120	283.10	77.80	31.80	52	70	4.46
38	380	108	382.90	94.40	27.40	50	110	5.08
39	620	120	316.40	94.40	28.16	44	100	6.16
40	460	108	216.50	199.90	19.68	44	60	5.22
41	380	108	316.40	72.19	25.92	43	60	4.59
42	360	108	449.60	88.86	15.20	44	60	4.78
43	560	96	349.70	99.60	22.60	41	90	5.66
44	400	96	299.70	77.80	28.64	44	70	4.64
45	580	108	266.43	83.30	18.24	42	40	5.34
46	840	96	233.13	88.86	32.16	49	70	6.77
47	480	84	266.43	83.30	21.76	41	60	4.75
48	440	96	233.13	88.86	28.96	47	60	4.69
49	520	72	266.43	99.96	30.08	40	60	5.01
50	560	72	316.40	77.80	21.40	38	60	5.14

4.4.2.1 High Yielding Population

The data in table 21 show the exchangeable ions (mg kg^{-1} soil) and CEC of the soils. Exchangeable Ca values varied between 360 and 800. The exchangeable Mg values ranged from 84 to 168. The K ranged between 216.5 and 416.3 and the exchangeable Na values ranged from 72.19 to 122.2. Exchangeable Al values were in between 11.68 and 78.4. The exchangeable Fe values ranged from 40 to 60. The exchangeable Mn values ranged from 60 to 130. The cation exchange capacity values ranged between 4.68 and 7.90 cmol (+) kg^{-1} soil.

4.4.2.2 Low Yielding Population

As in table 22, the exchangeable ions expressed in mg kg^{-1} soil ranged as follows: Calcium values in this group varied between 320 and 640. The exchangeable Mg values were in between 48 and 132. The values for exchangeable K ranged between 216.5 and 416.3. Exchangeable Na values ranged from 61.09 to 127.70. The exchangeable Al content varied between 6.4 and 99.2. The exchangeable Fe values ranged from 37 to 55 and the exchangeable Mn content varied from 40 to 110. The cation exchange capacity of this group ranged between 4.20 and 6.53 cmol(+)kg^{-1} soil.

4.4.3 Post-monsoon Surface Samples

4.4.3.1 High Yielding Population

Table 23 shows the exchangeable ions in mg kg^{-1} soil and CEC of the soils. Calcium values ranged between 420 and 970. The values for Mg ranged between 108 and 192. The exchangeable K values ranged from 133.13 to 416.30. Exchangeable Na values varied between 66.7 and 122.2. The values for exchangeable Al were in between 8 and 81.92. Iron content varied from 45 to 67 and Mn from 90 to 160. The cation exchange capacity values ranged between 4.85 and 8.00 cmol (+) kg^{-1} soil.

4.4.3.2 Low Yielding Population

The exchangeable ions are expressed in mg kg^{-1} soil. As given in table 24, the exchangeable Ca for the group varied from 360 to 660. The values for Mg ranged between 61 and 144. The K values ranged from 216.5 to 482.9. The exchangeable Na ranged between 55.54 and 177.70. The exchangeable Al ranged between 8.16 and 76.96.

Table 21. Exchangeable ions in mg kg^{-1} soil and CEC of pre-monsoon subsurface samples (High yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
1	680	156	316.40	99.60	20.96	58	90	6.71
2	620	144	349.70	94.40	22.56	54	110	6.45
3	520	144	266.43	94.40	29.92	53	110	5.82
4	800	132	382.99	83.33	78.40	40	120	7.90
5	600	168	299.70	72.20	41.76	54	100	6.50
6	720	144	233.13	88.86	21.44	58	110	6.63
7	480	120	316.40	88.90	28.64	60	100	5.49
8	460	132	266.43	77.80	38.90	48	80	5.32
9	440	132	316.40	94.40	28.50	57	90	5.37
10	420	132	299.70	72.20	51.80	53	100	5.41
11	420	132	266.43	72.20	11.68	52	90	4.84
12	400	144	266.43	77.80	28.16	43	90	5.02
13	550	144	283.10	94.40	32.80	55	100	6.01
14	490	108	349.70	105.50	13.12	51	130	5.51
15	540	144	366.34	105.50	25.76	57	120	6.23
16	480	108	316.38	105.52	43.40	57	80	5.55
17	360	120	283.10	99.96	48.20	56	90	5.02
18	420	144	216.50	72.19	13.92	56	60	4.74
19	440	132	416.30	94.40	71.68	57	90	6.11
20	400	96	282.90	96.70	24.32	49	80	4.68
21	540	84	299.70	83.30	17.92	47	70	5.15
22	420	96	299.70	122.20	30.24	43	70	4.94
23	400	132	349.70	116.60	29.44	51	70	5.27
24	600	156	333.00	111.10	23.36	51	110	6.48
25	400	120	266.40	99.96	26.24	46	70	4.83

Table 22. Exchangeable ions in mg kg^{-1} soil and CEC of pre-monsoon subsurface samples (Low yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
26	460	132	366.34	83.30	37.76	52	70	5.56
27	640	72	333.00	72.20	19.36	45	110	5.74
28	620	108	349.70	116.63	49.60	50	110	6.53
29	520	122	216.50	83.30	35.40	45	100	5.45
30	420	84	266.43	88.86	12.96	47	60	4.40
31	400	96	316.40	83.30	11.04	46	100	4.62
32	540	108	299.70	61.09	99.20	48	70	6.16
33	540	108	382.99	122.20	48.20	44	70	6.06
34	320	96	349.70	94.40	24.50	49	60	4.37
35	420	84	299.70	94.40	17.92	54	90	4.70
36	380	108	316.40	94.40	29.44	45	70	4.76
37	320	96	283.10	88.90	38.60	49	60	4.34
38	480	120	416.30	94.40	38.24	49	60	5.70
39	580	120	233.13	105.52	22.08	48	70	5.63
40	480	96	299.70	105.50	29.44	42	90	5.23
41	460	84	349.70	77.80	28.96	44	70	4.97
42	380	84	283.10	66.70	29.40	44	50	4.28
43	500	96	266.43	88.86	8.16	39	80	4.89
44	420	96	233.13	94.40	35.40	55	90	4.83
45	600	96	283.10	94.40	20.96	40	40	5.46
46	600	96	316.40	127.70	31.40	47	70	5.94
47	400	60	233.13	99.96	23.04	44	70	4.20
48	460	72	233.13	94.40	23.68	45	50	4.51
49	580	48	283.08	83.30	6.40	37	40	4.74
50	420	96	333.00	94.40	29.12	40	50	4.81

Table 23. Exchangeable ions in mg kg^{-1} soil and CEC of post-monsoon surface samples (High yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
1	720	168	283.10	77.80	19.84	64	130	6.99
2	640	168	316.40	116.60	28.80	67	130	6.95
3	720	192	316.40	94.40	21.44	58	140	7.38
4	640	192	400.00	105.50	62.40	58	160	7.77
5	620	180	283.10	72.20	45.92	59	120	6.80
6	620	168	299.70	72.19	17.28	57	100	6.34
7	520	132	333.00	99.96	8.00	59	130	5.76
8	580	144	249.80	83.30	51.40	53	120	6.30
9	480	120	283.10	77.80	34.60	61	110	5.47
10	460	144	349.70	88.90	56.32	58	120	6.05
11	480	144	299.70	77.80	22.56	57	110	5.56
12	420	144	333.00	72.20	21.12	45	120	5.30
13	970	144	233.13	94.40	27.40	56	120	8.00
14	480	168	400.00	122.20	34.24	58	120	6.38
15	620	156	316.40	77.80	21.80	56	130	6.47
16	460	144	249.80	94.40	28.16	60	110	5.48
17	420	120	249.80	77.80	17.12	61	100	4.85
18	400	144	266.40	77.80	12.48	56	100	4.92
19	460	156	366.34	66.70	81.92	59	110	6.35
20	460	108	416.30	66.70	80.56	55	100	6.01
21	480	108	233.13	99.96	18.56	51	110	5.12
22	460	120	133.13	116.60	24.50	51	110	5.00
23	440	144	333.00	105.52	19.36	49	90	5.43
24	720	156	382.90	72.19	25.80	52	120	7.11
25	420	132	199.80	77.80	24.32	56	90	4.85

Table 24. Exchangeable ions in mg kg^{-1} soil and CEC of post-monsoon surface samples (Low yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
26	420	120	333	66.70	32.50	54	90	5.13
27	520	120	366.34	77.80	19.04	47	110	5.66
28	580	108	333	88.90	62.40	49	120	6.35
29	420	108	216.5	72.19	8.16	44	110	4.52
30	440	96	299.7	105.52	25.76	46	80	4.97
31	460	120	349.7	72.19	35.40	48	110	5.48
32	440	108	299.7	77.80	76.96	45	100	5.59
33	440	84	216.5	55.54	38.72	47	90	4.62
34	380	120	266.4	99.96	13.76	49	90	4.67
35	360	108	333	172.20	40.20	56	110	5.35
36	380	108	299.7	88.86	30.88	46	90	4.79
37	380	120	283.1	72.20	36.16	57	60	4.76
38	440	144	283.1	72.19	19.84	51	90	5.17
39	660	144	299.7	88.90	19.52	49	90	6.37
40	520	132	266.43	72.20	20.96	48	90	5.43
41	400	96	299.7	66.70	22.90	49	80	4.58
42	380	96	482.9	83.30	26.72	48	80	5.06
43	420	96	349.7	105.52	21.12	44	120	5.08
44	380	108	266.43	72.19	19.36	49	90	4.52
45	540	120	249.8	83.30	10.88	44	60	5.20
46	620	96	249.8	177.70	27.80	51	90	6.13
47	400	72	249.8	77.80	20.00	46	80	4.26
48	440	96	266.3	66.70	20.20	50	70	4.63
49	460	96	349.7	88.90	23.40	41	80	5.08
50	580	61	283.1	72.20	20.96	40	80	5.12

The values for Fe varied from 40 to 57 and the exchangeable Mn varied between 60 and 120. The cation exchange capacity values ranged between 4.26 and 6.37 cmol(+)kg^{-1} of soil.

4.4.4 Post-monsoon Subsurface Samples

4.4.4.1 High Yielding Group

The data presented in table 25 indicate the exchangeable ion concentrations expressed in mg kg^{-1} soil. Exchangeable Ca content ranged from 420 to 940. The values for exchangeable Mg content varied between 108 and 168. The exchangeable K ranged between 203.1 and 382.9 and the exchangeable Na varied from 66.7 to 133.29. The values for exchangeable Al varied from 11.04 to 108.9. The exchangeable Fe varied between 42 and 60. Exchangeable Mn varied between 80 and 140. The cation exchange capacity values varied from 4.48 to 7.73 cmol (+) kg^{-1} soil.

4.4.4.2 Low Yielding Group

The exchangeable ions are presented in mg kg^{-1} soil . As in table 26, the values for exchangeable calcium varied between 300 and 680. The Mg values ranged from 72 to 144. The exchangeable K ranged between 199.8 and 366.34. The values for exchangeable Na ranged between 66.7 and 183.3 and exchangeable Al ranged from 9.12 to 56. The exchangeable Fe content ranged between 39 and 60 and the exchangeable Mn content ranged from 50 to 120. The cation exchange capacity values ranged between 4.32 and 6.23 cmol(+)kg^{-1} soil.

4.5 NET IONIC EQUILIBRIUM RATIOS OF EXCHANGEABLE IONS IN SOIL

The data on the NIE ratios viz., $K/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$, $K/(Ca+Mg+Fe+Mn)^{1/2}$, $Na/[(Ca+Mg+Fe+Mn)^{1/2} + Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$ are presented in tables 27 to 34.

4.5.1 Pre-monsoon Surface Samples

4.5.1.1 High Yielding Population

The ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ varied from 0.204 to 0.458. The values for the ratio $K/(Ca + Mg + Fe + Mn)^{1/2}$ ranged between 0.274 and 0.633.

Table 25. Exchangeable ions in mg kg^{-1} soil and CEC of post-monsoon subsurface samples (High yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
1	580	168	233.13	77.80	22.60	57	110	6.09
2	520	156	333.00	83.30	26.72	56	120	6.05
3	580	132	249.80	88.90	32.16	56	100	5.95
4	580	168	366.34	72.20	12.48	42	140	6.35
5	600	156	266.43	66.70	27.20	57	110	6.18
6	600	168	233.13	133.29	22.60	59	90	6.37
7	480	144	266.43	88.90	31.52	58	110	5.63
8	420	156	249.80	88.90	23.40	51	90	5.20
9	520	144	299.70	88.86	11.04	55	100	5.64
10	480	132	233.13	66.70	12.96	52	110	5.12
11	440	132	203.10	72.20	31.70	47	100	5.02
12	480	156	249.80	66.70	25.80	46	110	5.48
13	940	144	266.43	88.90	12.00	54	120	7.73
14	460	108	333.00	88.90	26.90	59	120	5.39
15	520	144	333.00	88.90	17.30	58	110	5.84
16	520	108	299.70	99.60	30.70	59	100	5.62
17	380	108	249.80	83.30	15.20	60	80	4.48
18	380	132	216.50	88.90	12.20	57	90	4.61
19	400	144	283.10	72.20	108.90	60	100	6.03
20	420	108	382.90	127.70	27.52	51	90	5.35
21	520	108	283.10	88.90	17.44	49	80	5.27
22	440	108	266.43	105.52	23.52	47	90	5.00
23	420	120	316.40	111.10	26.72	48	80	5.15
24	580	156	366.34	83.30	17.90	54	130	6.37
25	440	132	249.80	99.96	24.00	51	80	5.12

Table 26. Exchangeable ions in mg kg^{-1} soil and CEC of post-monsoon subsurface samples (Low yielding population)

Sample No.	Ca	Mg	K	Na	Al	Fe	Mn	CEC cmol (+) kg^{-1}
26	400	144	283.10	66.70	36.60	54	80	5.11
27	560	96	366.34	77.80	17.12	56	100	5.63
28	540	120	316.40	183.30	35.84	54	90	6.23
29	400	120	199.80	77.80	18.56	43	100	4.57
30	400	96	249.80	83.30	19.40	48	90	4.52
31	480	108	249.80	122.20	16.80	46	120	5.26
32	520	84	266.43	77.80	83.80	50	90	5.76
33	460	120	233.13	138.84	50.40	46	90	5.55
34	380	84	316.40	88.90	27.40	48	70	4.53
35	400	96	249.80	77.80	19.70	60	110	4.61
36	360	108	266.43	99.90	26.10	48	80	4.57
37	300	108	266.43	77.80	38.10	51	80	4.32
38	400	108	266.43	66.70	56.00	47	90	4.99
39	600	108	233.13	94.40	17.44	51	80	5.58
40	440	108	266.43	88.86	25.90	46	80	4.91
41	440	96	316.40	72.20	19.20	46	80	4.79
42	400	84	349.70	66.70	23.20	46	70	4.56
43	460	108	233.13	72.20	17.92	45	70	4.73
44	360	108	249.80	105.50	22.60	47	110	4.62
45	620	108	266.43	88.90	9.44	43	50	5.51
46	680	84	299.70	116.63	33.92	48	80	6.22
47	420	72	266.40	111.10	21.44	48	70	4.53
48	440	96	216.50	83.30	21.33	46	60	4.54
49	500	72	233.13	72.20	9.12	39	70	4.51
50	400	108	299.70	88.90	12.48	42	70	4.60

$Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ values ranged between 0.087 and 0.230. $Na/(Ca+Mg+Fe+Mn)^{1/2}$ values ranged between 0.119 and 0.311 (Table 27).

4.5.1.2 Low Yielding Population

For this group, as in table 28, the values for $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ values ranged from 0.197 to 0.500. The ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$ has got values in between 0.257 and 0.657. The values for $Na/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ ranged between 0.107 and 0.349. $Na/(Ca+Mg+Fe+Mn)^{1/2}$ values ranged from 0.143 to 0.460.

4.5.2 Pre-monsoon Subsurface Samples

4.5.2.1 High Yielding Population

The values of the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ ranged from 0.203 to 0.370. The ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$ has got values between 0.257 and 0.545. The values of the ratio $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ ranged from 0.105 to 0.211 and the values of $Na/(Ca+Mg+Fe+Mn)^{1/2}$ ranged between 0.141 and 0.292 (Table 29).

4.5.2.2 Low Yielding Population

For the low yielding population of coconuts the soil samples taken from 60 cm depth at the pre monsoon season had values for the ratios of exchangeable ions as shown in table 30. It indicates that the value for $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ varied from 0.201 to 0.395. The same ratio excluding Al, showed a range between 0.273 and 0.548. The values of the ratio $Na/(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}$ were in between 0.087 and 0.201. The same ratio without Al showed a range between 0.132 and 0.270.

4.5.3 Post-monsoon Surface Samples

4.5.3.1 High Yielding Population

The ratios presented in table 31 shows that the values for the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ varied between 0.130 and 0.368. The same ratio without Al showed a range from 0.231 to 0.550. The ratio $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ showed values between 0.096 and 0.194. The same ratio without Al showed values in between 0.134 and 0.257.

Table 27. Net Ionic Equilibrium ratios in soil (Pre-monsoon surface samples - High yielding population)

Sample No.	K/[(Ca+Mg+Mn+Fe)$^{1/2}$ + Al$^{1/3}$]	K/(Ca+Mg+Mn+Fe)$^{1/2}$	Na/[(Ca+Mg+Mn+Fe)$^{1/2}$ + Al$^{1/3}$]	Na/(Ca+Mg+Mn+Fe)$^{1/2}$
1	0.274	0.338	0.138	0.170
2	0.315	0.419	0.203	0.271
3	0.307	0.396	0.182	0.235
4	0.355	0.463	0.147	0.191
5	0.238	0.326	0.087	0.119
6	0.306	0.371	0.201	0.243
7	0.281	0.384	0.168	0.229
8	0.252	0.348	0.126	0.174
9	0.313	0.429	0.149	0.204
10	0.387	0.536	0.152	0.210
11	0.244	0.339	0.147	0.204
12	0.315	0.411	0.133	0.174
13	0.215	0.282	0.146	0.191
14	0.383	0.532	0.192	0.266
15	0.332	0.438	0.152	0.201
16	0.458	0.633	0.160	0.221
17	0.278	0.369	0.197	0.261
18	0.286	0.358	0.162	0.202
19	0.383	0.586	0.112	0.172
20	0.336	0.430	0.120	0.154
21	0.277	0.367	0.157	0.207
22	0.271	0.367	0.230	0.311
23	0.370	0.514	0.200	0.278
24	0.273	0.332	0.100	0.122
25	0.204	0.274	0.154	0.206

Table 28. Net Ionic Equilibrium ratios in soil (Pre-monsoon surface samples - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	0.374	0.516	0.110	0.152
27	0.437	0.562	0.156	0.200
28	0.363	0.486	0.187	0.250
29	0.220	0.286	0.124	0.162
30	0.323	0.445	0.202	0.278
31	0.309	0.400	0.111	0.143
32	0.229	0.342	0.107	0.159
33	0.323	0.459	0.119	0.169
34	0.309	0.407	0.134	0.176
35	0.391	0.497	0.212	0.269
36	0.373	0.498	0.161	0.215
37	0.296	0.416	0.138	0.194
38	0.391	0.534	0.163	0.223
39	0.287	0.377	0.145	0.191
40	0.223	0.294	0.349	0.460
41	0.332	0.455	0.129	0.176
42	0.500	0.657	0.167	0.220
43	0.338	0.444	0.163	0.215
44	0.310	0.429	0.137	0.189
45	0.262	0.338	0.139	0.179
46	0.197	0.257	0.127	0.166
47	0.275	0.367	0.146	0.195
48	0.237	0.325	0.153	0.210
49	0.265	0.362	0.168	0.230
50	0.317	0.419	0.132	0.175

Table 29. Net Ionic Equilibrium ratios in soil (Pre-monsoon subsurface samples - High yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	0.279	0.355	0.149	0.189
2	0.315	0.405	0.144	0.186
3	0.245	0.326	0.147	0.196
4	0.294	0.412	0.109	0.152
5	0.256	0.345	0.105	0.141
6	0.203	0.257	0.131	0.166
7	0.303	0.407	0.144	0.194
8	0.251	0.348	0.124	0.172
9	0.307	0.414	0.156	0.210
10	0.277	0.397	0.113	0.162
11	0.281	0.354	0.129	0.163
12	0.263	0.356	0.130	0.176
13	0.256	0.342	0.145	0.193
14	0.355	0.448	0.181	0.229
15	0.337	0.441	0.164	0.215
16	0.297	0.416	0.168	0.235
17	0.275	0.398	0.165	0.238
18	0.225	0.288	0.127	0.163
19	0.370	0.545	0.142	0.210
20	0.296	0.401	0.171	0.233
21	0.303	0.393	0.143	0.185
22	0.306	0.422	0.211	0.292
23	0.349	0.477	0.197	0.270
24	0.300	0.386	0.170	0.219
25	0.272	0.369	0.173	0.235

Table 30. Net Ionic Equilibrium ratios in soil (Pre-monsoon subsurface samples - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	0.347	0.479	0.134	0.185
27	0.318	0.409	0.117	0.150
28	0.303	0.419	0.171	0.237
29	0.201	0.273	0.131	0.178
30	0.296	0.383	0.167	0.216
31	0.349	0.445	0.156	0.199
32	0.253	0.383	0.087	0.132
33	0.349	0.490	0.189	0.265
34	0.387	0.536	0.177	0.246
35	0.319	0.422	0.171	0.225
36	0.327	0.452	0.165	0.229
37	0.299	0.434	0.159	0.231
38	0.395	0.548	0.152	0.211
39	0.221	0.287	0.170	0.221
40	0.295	0.401	0.176	0.239
41	0.354	0.485	0.134	0.183
42	0.302	0.423	0.121	0.169
43	0.287	0.354	0.162	0.200
44	0.231	0.323	0.159	0.222
45	0.275	0.359	0.156	0.203
46	0.294	0.395	0.201	0.270
47	0.255	0.350	0.186	0.255
48	0.245	0.332	0.168	0.228
49	0.315	0.384	0.157	0.191
50	0.344	0.475	0.165	0.229

Table 31. Net Ionic Equilibrium ratios in soil (Post-monsoon surface samples - High yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	0.243	0.304	0.113	0.142
2	0.271	0.352	0.170	0.220
3	0.266	0.334	0.134	0.169
4	0.316	0.434	0.141	0.194
5	0.235	0.317	0.102	0.137
6	0.272	0.341	0.111	0.139
7	0.336	0.408	0.171	0.208
8	0.213	0.295	0.121	0.167
9	0.266	0.362	0.124	0.169
10	0.310	0.440	0.134	0.190
11	0.287	0.375	0.126	0.165
12	0.330	0.432	0.121	0.159
13	0.183	0.231	0.126	0.159
14	0.362	0.487	0.188	0.252
15	0.282	0.360	0.118	0.150
16	0.237	0.316	0.152	0.202
17	0.257	0.334	0.136	0.176
18	0.278	0.352	0.138	0.174
19	0.311	0.458	0.096	0.141
20	0.368	0.550	0.100	0.150
21	0.233	0.303	0.170	0.221
22	0.130	0.173	0.194	0.257
23	0.332	0.432	0.178	0.232
24	0.326	0.418	0.104	0.134
25	0.199	0.265	0.131	0.175

4.5.3.2 Low Yielding Population

As in table 32 the values for the ratio K/[(Ca+Mg+Fe+Mn)^{½} +(Al)$^{1/3}$] ranged from 0.214 to 0.506. The same ratio without Al showed a range between 0.294 and 0.696. The values for the ratio Na/[(Ca+Mg+Fe+Mn)^{½} + (Al)$^{1/3}$] ranged between 0.093 and 0.290. The values for the ratio Na/(Ca+Mg+Fe+Mn)^{½} were in between 0.131 and 0.412.

4.5.4 Post-monsoon Subsurface Samples

4.5.4.1 High Yielding Population

Table 33 shows that the ratio K/[(Ca+Mg+Fe+Mn)^{½} + (Al)$^{1/3}$] has got values in between 0.195 and 0.385. The same ratio without Al has got values ranging from 0.266 to 0.524. The values of the ratio Na/[(Ca+Mg+Fe+Mn)^{½} + (Al)$^{1/3}$] were in between 0.100 and 0.218 and without Al this ratio showed a range between 0.131 and 0.296.

4.5.4.2 Low Yielding Population

As in table 34 the ratio K/[(Ca+Mg+Fe+Mn)^{½} + (Al)$^{1/3}$] showed a range from 0.208 to 0.373. The values of the ratio K/(Ca+Mg+Fe+Mn)^{½} were in between 0.273 and 0.508. The ratio Na/[(Ca+Mg+Fe+Mn)^{½} + (Al)$^{1/3}$] showed values in between 0.108 and 0.286 and the ratio Na/(Ca+Mg+Fe+Mn)^{½} had values from 0.151 to 0.388.

4.6 IONIC CONCENTRATIONS IN SOIL SOLUTION

From the surface soil samples collected in both seasons, soil solutions were extracted and these solutions were analysed for the estimation of nutrients, pH and EC. P, Cu and Zn were not detectable.

4.6.1 Pre-monsoon Samples

4.6.1.1 High Yielding Population

The results in table 35 shows that the pH values varied between 3.50 and 6.07. The electrical conductivity values ranged from 0.246 to 1.860 dSm^{-1}. All the nutrient concentrations mentioned below are expressed in mg kg^{-1}. Potassium concentration ranged from 1.04 to 38.48. The concentration of Na ranged between 5.72 and 25.48. The Ca concentration ranged from 4.68 to 37.44 and the Mg concentration was found to vary

Table 32. Net Ionic Equilibrium ratios in soil (Post-monsoon surface samples - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	0.327	0.449	0.111	0.152
27	0.356	0.460	0.128	0.166
28	0.286	0.406	0.129	0.184
29	0.238	0.294	0.134	0.166
30	0.305	0.413	0.182	0.247
31	0.332	0.456	0.116	0.160
32	0.269	0.404	0.119	0.178
33	0.214	0.301	0.093	0.131
34	0.287	0.370	0.183	0.236
35	0.331	0.470	0.290	0.412
36	0.306	0.424	0.154	0.213
37	0.283	0.398	0.123	0.172
38	0.281	0.367	0.122	0.159
39	0.271	0.344	0.136	0.173
40	0.256	0.333	0.118	0.153
41	0.315	0.425	0.119	0.160
42	0.506	0.696	0.148	0.204
43	0.361	0.480	0.185	0.245
44	0.283	0.376	0.130	0.173
45	0.255	0.317	0.144	0.179
46	0.231	0.305	0.278	0.368
47	0.272	0.366	0.144	0.193
48	0.277	0.368	0.118	0.156
49	0.356	0.477	0.153	0.205
50	0.282	0.370	0.122	0.160

Table 33. Net Ionic Equilibrium ratios in soil (Post-monsoon subsurface samples - High yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	0.210	0.270	0.119	0.153
2	0.305	0.401	0.129	0.170
3	0.225	0.300	0.136	0.181
4	0.342	0.422	0.114	0.141
5	0.237	0.308	0.100	0.131
6	0.210	0.269	0.203	0.261
7	0.248	0.333	0.140	0.188
8	0.245	0.324	0.148	0.195
9	0.297	0.368	0.149	0.185
10	0.235	0.296	0.114	0.143
11	0.195	0.266	0.118	0.160
12	0.235	0.310	0.106	0.140
13	0.223	0.267	0.126	0.151
14	0.325	0.435	0.147	0.197
15	0.319	0.407	0.144	0.184
16	0.283	0.381	0.159	0.215
17	0.270	0.352	0.153	0.199
18	0.232	0.295	0.162	0.206
19	0.241	0.373	0.104	0.161
20	0.385	0.524	0.218	0.296
21	0.282	0.364	0.150	0.194
22	0.269	0.360	0.181	0.242
23	0.318	0.430	0.189	0.256
24	0.337	0.426	0.130	0.164
25	0.248	0.330	0.168	0.224

Table 34. Net Ionic Equilibrium ratios in soil (Post-monsoon subsurface samples - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	0.273	0.378	0.109	0.151
27	0.359	0.460	0.129	0.166
28	0.291	0.395	0.286	0.388
29	0.208	0.273	0.137	0.180
30	0.265	0.353	0.150	0.199
31	0.252	0.324	0.209	0.269
32	0.233	0.350	0.116	0.173
33	0.216	0.307	0.218	0.310
34	0.336	0.466	0.160	0.222
35	0.261	0.347	0.138	0.183
36	0.280	0.384	0.178	0.244
37	0.279	0.403	0.138	0.200
38	0.253	0.371	0.108	0.157
39	0.224	0.286	0.154	0.196
40	0.268	0.362	0.152	0.205
41	0.330	0.436	0.128	0.169
42	0.373	0.508	0.121	0.164
43	0.241	0.314	0.126	0.165
44	0.263	0.354	0.188	0.254
45	0.267	0.328	0.151	0.186
46	0.269	0.360	0.177	0.237
47	0.286	0.386	0.202	0.273
48	0.226	0.302	0.147	0.197
49	0.256	0.320	0.134	0.168
50	0.329	0.423	0.165	0.213

Table 35. pH, EC and nutrient concentrations in soil solution in pre-monsoon samples (High yielding population)

Sample No.	pH	EC (dSm^{-1})	K ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)
1	3.84	0.720	9.36	13.00	7.49	10.12	1.66	3.54
2	4.94	0.468	9.36	11.44	14.98	10.12	6.29	4.45
3	4.14	1.160	15.08	24.96	14.98	14.61	4.97	4.78
4	4.12	1.260	17.16	15.08	33.70	15.73	2.11	3.33
5	4.45	0.723	10.92	12.48	22.47	4.49	1.98	3.12
6	4.70	0.898	4.68	9.36	7.49	10.12	2.03	4.06
7	5.26	0.450	6.76	6.76	19.66	13.36	2.42	3.54
8	4.74	1.050	5.20	12.48	16.85	11.24	2.05	2.84
9	4.12	0.291	12.48	8.32	29.95	21.36	1.54	2.32
10	3.88	0.537	10.92	11.44	12.17	7.90	1.92	3.69
11	4.27	0.446	9.88	10.92	18.72	10.68	1.51	2.84
12	4.24	1.860	18.20	25.48	30.89	19.67	1.98	2.49
13	4.71	0.364	7.80	7.28	20.59	10.68	2.13	3.07
14	3.59	0.432	38.48	19.76	27.15	10.68	1.64	2.76
15	4.20	0.365	9.88	9.88	36.50	10.12	1.62	2.57
16	4.64	1.090	14.56	9.36	37.44	19.11	1.51	2.55
17	5.23	0.308	1.04	5.72	12.17	1.69	2.24	2.76
18	4.54	0.511	11.44	12.48	14.98	11.80	1.59	3.31
19	4.38	0.440	19.76	13.52	29.95	17.42	1.35	2.76
20	6.07	0.983	9.88	9.36	13.11	12.93	7.51	4.08
21	5.69	0.246	15.60	24.44	5.62	4.496	1.51	3.33
22	5.07	0.340	5.72	8.32	21.53	16.86	2.03	2.63
23	5.01	0.627	8.32	5.72	15.91	13.49	3.69	3.85
24	4.40	1.040	17.68	13.00	29.95	10.12	1.30	2.83
25	3.50	0.378	3.12	6.76	4.68	10.12	1.79	4.34

between 1.69 and 21.36. The concentration of Fe ranged from 1.3 to 7.51 and the Mn concentration ranged between 2.32 and 4.78. The Cu and Zn concentrations were not detectable from the solution samples.

4.6.1.2 Low Yielding Population

From table 36 it is evident that the pH values ranged between 3.99 and 6.10. Electrical conductivity ranged from 0.286 to 2.390 dSm^{-1}. All the nutrient concentrations mentioned below are expressed in mg kg^{-1}. The K concentration ranged from 2.60 to 17.16. The values for Na were found between 6.24 and 24.44. The concentration of Ca ranged between 3.75 and 31.80. The Mg concentration ranged between 2.25 and 23.04. The concentration of Fe ranged between 0.624 to 3.870 and the Mn concentration ranged from 2.03 to 4.58. Cu and Zn were not detectable.

4.6.2 Post-monsoon Samples

4.6.2.1 High Yielding Population

Table 37 shows that the pH values were in between 3.80 and 6.02. EC values ranged from 0.207 to 1.75 dSm^{-1}. All the nutrient concentrations mentioned below are expressed in mg kg^{-1}. The concentrations of K were varying between 2.08 and 19.24. Sodium concentration was found ranging between 4.16 and 17.68. The Ca concentration was found varying between 3.75 and 35.57 and the Mg concentration varied between 2.25 and 17.42. The concentration of Fe was found between 1.35 and 12.17and the Mn concentration was found between 2.44 and 4.92. Cu and Zn in the samples were not detectable.

4.6.2.2 Low Yielding Population

The parameters given in table 38 show that the pH of this class ranged from 4.1 to 6.18. The EC values ranged between 0.217 and 3.92 dSm^{-1}. All the nutrient concentrations mentioned below are expressed in mg kg^{-1}. The concentration of K ranged from 2.60 to 24.44 and the Na concentration ranged between 5.72 and 16.64. The Ca concentration ranged between 3.75 and 29.02 and the Mg concentrations were found between 0.876 and 16.29. The concentration of Fe was found to be ranging from 1.07 to 3.95 and Mn from 2.13 to 4.76.

Table 36. pH, EC and nutrient concentrations in soil solution in pre-monsoon samples (Low yielding population)

Sample No.	pH	EC (dSm^{-1})	K ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)
26	4.82	0.679	16.12	14.56	29.02	13.49	1.04	2.29
27	4.60	1.190	17.16	11.44	31.80	12.36	1.07	2.03
28	5.08	0.641	11.44	14.56	25.27	10.68	1.14	2.44
29	4.26	0.930	7.80	11.44	12.17	6.74	1.82	2.76
30	4.42	0.799	9.88	9.88	14.98	8.99	1.14	2.49
31	5.16	0.406	7.28	7.80	11.23	7.87	2.13	4.37
32	6.10	0.402	7.80	7.80	13.11	10.12	3.87	3.67
33	3.99	0.763	15.08	15.08	19.66	10.68	1.33	3.48
34	4.80	0.780	9.36	14.04	12.17	10.68	1.54	2.76
35	4.86	2.090	16.12	24.44	26.21	16.29	1.01	2.44
36	5.28	0.483	5.20	8.84	3.75	6.74	1.14	2.96
37	5.48	0.417	17.16	10.92	5.62	7.31	1.19	2.71
38	5.15	0.408	10.40	9.36	20.60	10.12	1.22	2.57
39	5.01	0.810	11.44	10.40	31.80	17.98	1.29	3.09
40	4.86	0.649	6.76	9.36	9.36	8.99	1.59	3.62
41	5.81	0.512	6.24	8.84	7.49	6.74	1.06	2.49
42	4.98	0.286	10.92	9.36	11.23	10.12	1.85	3.22
43	4.42	0.422	8.32	9.88	8.43	7.87	1.33	2.81
44	4.50	0.600	8.32	11.96	11.23	6.18	1.35	2.83
45	4.98	0.621	3.64	10.92	10.29	6.74	1.40	4.37
46	4.91	0.834	6.24	8.32	7.49	2.25	1.66	3.15
47	4.72	2.390	13.00	19.76	27.14	23.04	1.07	2.76
48	4.67	0.424	2.60	8.84	4.68	8.43	1.25	2.49
49	4.76	0.668	10.92	9.88	10.29	10.68	0.62	4.58
50	4.24	0.561	2.60	6.24	19.66	17.98	1.38	2.96

Table 37. pH, EC and nutrient concentrations in soil solution in post-monsoon samples (High yielding population)

Sample No.	pH	EC (dSm^{-1})	K ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)
1	4.01	0.565	9.88	10.92	8.43	7.87	1.82	3.67
2	5.09	0.412	11.44	11.96	16.85	10.12	5.02	4.24
3	4.87	1.090	14.04	17.68	11.23	11.24	5.09	4.92
4	4.08	1.370	19.24	17.16	26.21	12.36	2.18	3.82
5	4.80	0.624	9.36	9.88	19.66	2.25	2.11	4.19
6	6.02	0.459	3.12	7.80	8.75	6.74	2.11	4.58
7	4.99	0.392	5.72	7.80	17.80	10.68	2.55	3.67
8	5.41	1.160	2.60	7.80	13.11	9.55	2.11	3.22
9	4.08	0.284	9.88	7.28	28.08	17.42	1.59	2.55
10	4.75	0.486	9.36	9.88	6.55	5.62	2.11	4.00
11	4.38	0.421	7.28	8.32	16.85	9.55	1.64	3.22
12	5.78	1.750	5.72	6.24	26.21	11.24	2.11	2.44
13	5.98	0.284	2.08	7.80	17.78	8.99	2.26	3.22
14	5.65	0.419	10.92	8.32	29.02	8.99	1.69	2.96
15	3.80	0.243	8.32	8.84	22.47	6.18	1.85	2.81
16	4.99	1.020	14.04	6.76	35.57	16.29	1.56	2.63
17	4.89	1.530	4.68	4.68	9.36	5.62	2.37	2.96
18	4.21	0.336	9.36	9.36	13.11	10.12	1.66	3.48
19	5.18	0.284	8.32	5.20	27.15	15.73	1.38	2.81
20	5.20	0.769	8.84	8.32	7.49	11.81	12.17	4.84
21	4.01	0.189	13.52	4.44	3.75	5.06	1.59	3.67
22	4.22	0.221	8.32	12.48	23.4	15.17	2.11	2.71
23	5.10	0.414	4.68	4.16	11.23	12.36	4.84	4.81
24	4.10	1.010	9.36	6.76	27.15	6.18	1.35	2.89
25	4.36	0.207	4.16	6.24	7.49	8.99	2.00	4.71

Table 38. pH, EC and nutrient concentrations in soil solution in post-monsoon samples (Low yielding population)

Sample No.	pH	EC (dSm^{-1})	K ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)
26	4.91	0.488	14.56	10.92	28.08	11.82	1.07	2.44
27	4.40	1.120	15.08	9.88	29.02	9.55	1.09	2.13
28	6.18	0.252	24.44	6.24	20.60	7.87	1.25	2.49
29	4.89	0.412	4.16	9.88	10.29	6.18	1.25	2.89
30	4.56	0.831	8.32	8.84	13.11	7.87	1.89	2.57
31	5.35	0.411	4.16	8.84	9.36	7.87	2.24	4.52
32	5.20	0.411	10.92	7.28	11.23	6.74	3.95	4.63
33	4.70	0.254	13.00	14.56	14.98	7.87	1.51	3.43
34	4.97	0.621	7.80	8.84	9.36	7.87	1.77	2.96
35	4.10	1.910	12.48	16.64	21.53	14.61	1.07	2.63
36	4.59	0.398	5.72	6.24	4.68	5.62	1.30	3.15
37	5.10	0.329	13.52	9.36	6.55	6.18	1.35	2.94
38	4.21	0.399	8.32	6.24	17.78	8.99	1.30	2.63
39	5.13	0.670	9.88	9.36	27.15	14.05	3.43	3.69
40	5.40	0.609	3.64	12.48	8.43	6.74	1.77	3.69
41	4.84	0.217	7.28	5.72	5.62	6.18	1.19	2.55
42	4.72	0.247	9.36	10.40	8.43	9.55	2.13	3.67
43	4.61	0.361	5.20	7.28	3.75	6.74	1.54	3.15
44	4.26	0.517	6.24	10.92	9.36	5.06	1.27	2.91
45	5.71	0.495	5.72	9.36	8.43	5.62	1.66	4.53
46	5.09	2.020	8.84	11.44	11.23	7.87	1.87	3.54
47	4.68	1.890	10.92	15.08	19.66	15.73	1.35	2.89
48	4.48	0.316	5.72	7.28	3.74	6.74	1.35	2.91
49	4.55	0.594	9.36	8.32	8.42	0.87	2.42	4.76
50	4.81	3.920	2.6	5.72	16.85	16.29	1.56	3.43

4.7 NET IONIC EQUILIBRIUM RATIOS OF CATIONS IN SOIL SOLUTION

4.7.1 Pre-monsoon Samples

4.7.1.1 High Yielding Population

The ratio of K/(Ca + Mg + Fe + Mn)$^{1/2}$ varied between 0.009 and 0.201 and the ratio Na/(Ca+ Mg + Fe + Mn)$^{1/2}$ varied from 0.053 to 0.369 (Table 39).

4.7.1.2 Low Yielding Population

Table 40 shows that the values of the ratio K/(Ca + Mg + Fe + Mn)$^{1/2}$ varied between 0.013 and 0.137 and that of Na/(Ca+Mg+Fe+Mn)$^{1/2}$ ranged between 0.053 and 0.201.

4.7.2 Post-mosoon Samples

4.7.2.1 High Yielding Population

As in table 39 the values of the ratio K/(Ca+Mg+Fe+Mn)$^{1/2}$ ranged between 0.012 and 0.123 and the ratio Na/(Ca+Mg+Fe+Mn)$^{1/2}$ ranged from 0.041 to 0.178.

4.7.2.2 Low Yielding Population

As in table 40 the values of the ratio K/(Ca+Mg+Fe+Mn)$^{1/2}$ ranged from 0.014 to 0.147. Na/(Ca+Mg+Fe+Mn)$^{1/2}$ ratio had values in between 0.051 and 0.159.

4.8 NUTRIENT CONCENTRATIONS IN INDEX LEAF SAMPLES

4.8.1 Pre-monsoon Samples

4.8.1.1 High Yielding Population

Table 41 shows that the plant N varied from 0.63 to 3.15 per cent. Phosphorus concentration ranged between 0.010 and 0.088 per cent. The K concentrations in between 0.62 and 1.74 per cent. Na concentration ranged between 0.1 and 0.3 per cent. The concentrations of Ca were found in between 0.34 and 0.95 per cent and that of Mg ranged from 0.17 and 0.54 per cent. The nutrient concentrations mentioned below are expressed in mg kg^{-1}. Iron concentration ranged between 200 and 800 and Mn

Table 39. Net Ionic Equilibrium ratios in soil solution (Pre-monsoon and post-monsoon samples - High yielding population)

Sample No.	Pre-monsoon samples		Post-monsoon samples	
	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	0.064	0.151	0.071	0.133
2	0.054	0.112	0.065	0.116
3	0.080	0.225	0.083	0.178
4	0.078	0.116	0.098	0.148
5	0.068	0.132	0.064	0.115
6	0.032	0.107	0.023	0.096
7	0.036	0.061	0.033	0.076
8	0.030	0.123	0.016	0.084
9	0.055	0.062	0.046	0.058
10	0.073	0.130	0.075	0.135
11	0.057	0.107	0.044	0.085
12	0.081	0.192	0.030	0.055
13	0.044	0.069	0.012	0.079
14	0.201	0.175	0.058	0.074
15	0.048	0.081	0.050	0.090
16	0.062	0.068	0.063	0.051
17	0.009	0.082	0.036	0.061
18	0.067	0.124	0.058	0.099
19	0.091	0.106	0.040	0.043
20	0.055	0.088	0.051	0.081
21	0.139	0.369	0.123	0.068
22	0.028	0.070	0.042	0.106
23	0.046	0.053	0.027	0.041
24	0.091	0.113	0.053	0.065
25	0.022	0.082	0.029	0.073

Table 40. Net Ionic Equilibrium ratios in soil solution (Pre-monsoon and Post-monsoon samples - Low yielding population)

Sample No.	Pre-monsoon samples		Post-monsoon samples	
	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	0.080	0.122	0.074	0.095
27	0.084	0.095	0.080	0.088
28	0.061	0.132	0.147	0.064
29	0.055	0.136	0.031	0.125
30	0.063	0.106	0.056	0.100
31	0.049	0.089	0.029	0.104
32	0.048	0.081	0.074	0.084
33	0.085	0.145	0.084	0.159
34	0.059	0.150	0.056	0.107
35	0.078	0.201	0.065	0.147
36	0.045	0.128	0.050	0.092
37	0.137	0.148	0.110	0.129
38	0.059	0.091	0.051	0.064
39	0.051	0.079	0.048	0.077
40	0.046	0.109	0.027	0.158
41	0.049	0.118	0.061	0.081
42	0.070	0.102	0.064	0.120
43	0.061	0.123	0.044	0.104
44	0.061	0.148	0.050	0.147
45	0.026	0.132	0.044	0.122
46	0.059	0.133	0.060	0.132
47	0.057	0.147	0.057	0.133
48	0.020	0.117	0.049	0.105
49	0.070	0.108	0.087	0.132
50	0.013	0.053	0.014	0.051

Table 41. Plant nutrient concentrations (Pre-monsoon samples - High yielding population)

Sample No.	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Al (mg kg^{-1})
1	1.26	0.041	1.38	0.130	0.76	0.32	800	990	20	250
2	1.89	0.034	1.22	0.120	0.73	0.27	400	650	10	90
3	2.52	0.033	0.78	0.200	0.59	0.29	400	710	20	230
4	1.47	0.016	1.46	0.140	0.60	0.35	200	360	10	260
5	1.58	0.010	1.70	0.270	0.48	0.49	300	850	20	210
6	1.68	0.088	1.36	0.120	0.34	0.35	500	380	20	170
7	1.68	0.088	1.18	0.230	0.53	0.29	400	360	30	180
8	2.52	0.044	1.22	0.150	0.51	0.17	300	460	10	190
9	2.31	0.019	1.06	0.130	0.50	0.20	200	460	20	250
10	1.37	0.013	1.80	0.240	0.95	0.35	500	670	10	250
11	2.31	0.025	0.62	0.120	0.48	0.24	500	690	20	250
12	2.31	0.033	0.72	0.160	0.34	0.46	300	430	20	200
13	1.05	0.011	1.22	0.120	0.79	0.36	600	710	20	240
14	1.47	0.025	1.54	0.140	0.42	0.27	600	260	10	200
15	1.68	0.060	1.02	0.235	0.73	0.31	300	550	20	220
16	2.73	0.040	1.58	0.210	0.67	0.3	300	440	10	180
17	1.89	0.080	0.68	0.300	0.84	0.46	400	830	30	180
18	2.04	0.055	0.62	0.165	0.67	0.32	200	680	10	210
19	2.10	0.070	1.14	0.170	0.42	0.50	400	350	10	67
20	1.26	0.060	1.18	0.175	0.48	0.32	500	470	20	110
21	1.16	0.034	1.12	0.215	0.81	0.24	300	450	20	300
22	0.95	0.033	1.14	0.100	0.73	0.54	300	750	10	240
23	1.68	0.016	1.46	0.215	0.59	0.29	400	640	30	260
24	0.63	0.013	1.74	0.180	0.48	0.45	300	630	10	130
25	3.15	0.049	1.20	0.230	0.48	0.24	700	890	20	260

concentration ranged from 260 to 990. The Zn values varied from 10 to 30 and the concentrations of Al ranged between 67 and 300. Copper in all the plant samples were found not detectable.

4.8.1.2 Low Yielding Population

The nutrient composition in index leaves, depicted in table 42 shows that the N concentration ranged between 0.95 and 3.15 per cent. The concentration of P ranged from 0.010 to 0.105 per cent. The values for K ranged between 0.58 and 1.42 per cent. The Na concentrations ranged between 0.080 and 0.255 per cent. The values for Ca were between 0.19 and 1.20 per cent and the Mg concentration ranged between 0.22 and 0.70 per cent. The nutrient concentrations mentioned below are expressed in mg kg^{-1}. Iron varied between 200 and 900 and Mn varied from 310 to 770. The values for Zn varied between 10 and 30 and Al between 67 and 480. Copper was not detectable in any of the samples.

4.8.2 Post-monsoon Samples

4.8.2.1 High Yielding Population

Table 43 shows that the concentration of N in post-monsoon index leaf samples of the high yielding population ranged between 0.95 and 3.15 per cent. Phosphorus concentration ranged between 0.011 and 0.083 per cent and K concentration varied from 0.54 per cent to 2.08 per cent. The Na concentration ranged from 0.115 to 0.445 per cent and the Ca concentration of the samples ranged from 0.26 to 1.12 per cent. The Mg concentration ranged from 0.19 to 0.49 per cent. The nutrient concentrations mentioned below are expressed in mg kg^{-1}. The concentrations of Fe in the samples ranged between 300 and 800 and Mn ranged from 400 to 1110. Zinc concentrations ranged between 10 and 30 and Al concentrations ranged between 72 and 370. Copper was not detectable.

4.8.2.2 Low Yielding Population

The data on the nutrient composition in index leaves for this group are presented in table 44. The N concentration of the samples ranged between 0.84 and 3.36 per cent. The P concentrations ranged between 0.013 and 0.156 per cent and K ranged from 0.74 to 2.08 per cent. The concentration of Na in the samples ranged from 0.140 to 0.385 per cent. Calcium concentration of the samples varied from 0.28 to 1.32 per cent. There was

Table 42. Plant nutrient concentrations (Pre-monsoon samples - Low yielding population)

Sample No.	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Al (mg kg^{-1})
26	2.10	0.018	1.02	0.165	0.19	0.31	600	310	20	120
27	1.05	0.071	1.02	0.185	0.45	0.30	200	510	10	210
28	1.37	0.041	1.24	0.160	0.95	0.46	500	560	10	210
29	1.68	0.010	0.82	0.140	1.10	0.50	400	710	30	230
30	2.31	0.015	0.78	0.120	0.84	0.29	300	770	10	150
31	3.15	0.041	0.82	0.170	1.20	0.42	500	520	30	170
32	2.10	0.019	1.10	0.135	0.36	0.37	400	640	20	200
33	1.47	0.048	1.18	0.145	0.62	0.32	300	710	10	230
34	1.26	0.018	1.08	0.160	0.42	0.46	500	650	20	210
35	1.05	0.069	1.20	0.190	0.23	0.36	200	700	10	240
36	1.05	0.030	0.94	0.185	0.45	0.30	400	600	20	230
37	1.58	0.040	1.08	0.125	0.31	0.27	700	730	10	190
38	1.47	0.033	1.26	0.090	0.98	0.29	300	590	30	300
39	0.95	0.054	1.02	0.170	0.68	0.31	900	590	20	480
40	2.73	0.045	0.72	0.245	0.37	0.28	400	580	10	140
41	0.95	0.011	0.68	0.190	0.96	0.24	400	650	20	180
42	1.26	0.055	1.42	0.080	0.59	0.37	300	520	10	260
43	2.52	0.071	1.08	0.200	0.73	0.27	500	620	10	240
44	1.26	0.025	1.16	0.145	0.53	0.22	400	590	20	250
45	2.31	0.034	1.26	0.215	0.34	0.24	300	420	20	210
46	1.58	0.06	0.96	0.155	0.59	0.44	400	450	10	67
47	2.52	0.029	0.92	0.210	0.56	0.64	400	330	20	160
48	1.47	0.076	0.58	0.120	0.59	0.28	500	560	20	230
49	2.73	0.055	0.66	0.155	0.56	0.70	400	690	20	123
50	1.05	0.105	1.24	0.255	0.79	0.29	500	700	20	240

Table 43. Plant nutrient concentrations (Post-monsoon samples - High yielding population)

Sample No.	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Al (mg kg^{-1})
1	1.58	0.020	1.32	0.140	0.65	0.28	600	810	20	250
2	1.47	0.014	1.24	0.160	0.79	0.31	400	710	20	220
3	2.73	0.030	1.02	0.260	0.73	0.37	300	800	20	210
4	1.26	0.015	1.52	0.165	0.39	0.30	600	500	20	230
5	1.78	0.048	1.60	0.190	0.39	0.46	500	860	10	250
6	2.10	0.020	1.26	0.175	0.37	0.37	500	600	20	180
7	2.10	0.090	1.16	0.190	0.87	0.46	500	850	30	150
8	1.79	0.045	1.62	0.170	0.53	0.19	300	690	20	190
9	2.73	0.025	0.86	0.235	0.67	0.48	700	820	20	250
10	1.37	0.083	0.78	0.190	1.12	0.34	500	790	20	190
11	2.31	0.038	0.86	0.135	0.70	0.27	600	570	10	210
12	1.68	0.036	1.26	0.215	0.45	0.49	300	540	20	160
13	1.16	0.028	1.42	0.155	0.67	0.32	700	720	10	220
14	2.10	0.063	1.44	0.175	0.89	0.22	400	400	10	144
15	1.37	0.044	0.78	0.150	0.26	0.40	300	620	10	210
16	3.15	0.034	1.18	0.195	0.62	0.27	500	580	10	190
17	2.52	0.029	0.70	0.260	0.79	0.47	500	970	20	180
18	2.13	0.011	0.54	0.175	0.65	0.33	600	800	20	210
19	2.10	0.026	1.08	0.260	0.46	0.47	500	600	10	72
20	1.37	0.156	2.08	0.445	0.53	0.34	700	730	20	370
21	1.26	0.029	1.08	0.265	0.79	0.27	400	790	20	140
22	0.95	0.033	1.72	0.115	0.70	0.48	400	1110	10	200
23	2.10	0.054	1.68	0.125	0.65	0.30	700	470	20	220
24	1.26	0.023	1.90	0.265	1.10	0.34	800	670	10	300
25	2.10	0.044	0.74	0.160	0.65	0.40	700	920	20	240

Table 44. Plant nutrient concentrations (Post-monsoon samples - Low yielding population)

Sample No.	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Al (mg kg^{-1})
26	2.10	0.065	1.58	0.140	0.42	0.33	500	590	20	240
27	0.84	0.056	0.88	0.330	0.62	0.31	400	800	20	320
28	2.52	0.076	0.90	0.180	0.39	0.51	400	420	10	180
29	1.68	0.033	2.08	0.235	1.20	0.56	600	900	20	240
30	2.73	0.129	1.30	0.160	0.65	0.32	200	910	10	220
31	3.36	0.028	0.92	0.255	1.06	0.37	500	790	20	230
32	2.31	0.033	1.18	0.180	0.42	0.45	400	710	20	190
33	1.99	0.039	1.08	0.175	0.53	0.27	500	820	20	210
34	1.47	0.046	0.90	0.155	0.84	0.29	400	740	10	250
35	1.16	0.156	1.36	0.235	0.28	0.37	200	660	20	210
36	1.47	0.038	1.04	0.160	0.81	0.47	500	840	20	290
37	1.16	0.08	1.10	0.180	0.50	0.39	600	590	10	180
38	1.58	0.019	1.84	0.175	0.89	0.40	400	660	20	290
39	1.68	0.075	1.24	0.195	0.65	0.34	700	550	10	140
40	2.31	0.070	1.28	0.385	0.39	0.31	600	750	20	210
41	1.16	0.068	0.78	0.235	0.70	0.27	400	620	20	230
42	1.47	0.013	1.50	0.275	0.67	0.45	600	700	20	320
43	2.31	0.038	0.98	0.165	0.62	0.34	600	710	20	250
44	1.26	0.024	1.68	0.240	0.89	0.25	500	720	20	270
45	2.10	0.054	1.08	0.275	0.39	0.28	400	330	10	190
46	1.79	0.029	1.46	0.230	0.98	0.51	600	630	20	190
47	2.10	0.022	0.74	0.200	0.65	0.77	500	360	20	120
48	1.47	0.036	0.92	0.180	0.65	0.29	600	640	20	180
49	2.52	0.101	1.44	0.210	0.99	0.81	500	530	10	190
50	0.95	0.086	1.68	0.275	1.32	0.29	700	640	20	240

a variation from 0.25 to 0.81 per cent in the case of Mg concentrations. The nutrient concentrations mentioned below are expressed in mg kg^{-1}. Iron content varied from 200 to 700 and the Mn from 330 to 910. Zinc varied between 10 and 20 and Cu was non-detectable. Aluminium concentrations ranged between 140 and 320.

4.9 NET IONIC EQUILIBRIUM RATIOS IN INDEX LEAF SAMPLES

4.9.1 Pre-monsoon Samples

4.9.1.1 High Yielding Group

The plant nutrient contents were converted into cmol(+)kg^{-1} leaf and then the ratios were computed. As in table 45, the values of the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ ranged from 1.666 to 4.858. $K/(Ca+Mg+Fe+Mn)^{1/2}$ has got values ranging between 1.894 and 5.785. The ratio $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ varied between 0.409 and 1.246 and $Na/(Ca+Mg+Fe+Mn)^{1/2}$ ranged from 0.471 to 1.418.

4.9.1.2 Low Yielding Group

The ratios in table 46 indicates that the values of $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ varied from 1.595 to 4.240 and the same ratio without Al showed values in between 1.781 and 5.134. The values of the ratio $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ were in between 0.371 and 1.349. There was a variation from 0.448 to 1.581 in the case of the ratio $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

4.9.2 Post-monsoon Samples

4.9.2.1 High Yielding Group

Table 47 reveals that the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ ranged between 1.474 and 5.705 and the values of $K/(Ca+Mg+Fe+Mn)^{1/2}$ varied from 1.717 to 6.885. $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ values varied from 0.487 to 2.070 and there was a variation from 0.557 to 2.498 in the case of ratio $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

4.9.2.2 Low Yielding Group

As in table 48, the values of the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ ranged between 1.711 and 4.695 and the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$ has got values between 1.900 and 5.595. The samples showed a variation from 0.652 to 1.990 in the ratio

Table 45. Net Ionic Equilibrium ratios in index leaf samples (Pre-monsoon - High yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	3.596	4.195	0.574	0.670
2	3.505	3.947	0.609	0.686
3	2.232	2.633	0.970	1.145
4	4.049	4.786	0.658	0.778
5	4.525	5.248	1.219	1.413
6	4.222	4.964	0.632	0.743
7	3.531	4.140	1.167	1.368
8	4.013	4.803	0.837	1.001
9	3.379	4.095	0.730	0.884
10	4.438	5.132	1.024	1.184
11	1.903	2.287	0.624	0.751
12	2.070	2.425	0.780	0.914
13	3.127	3.631	0.543	0.631
14	4.856	5.785	0.749	0.892
15	2.772	3.234	1.083	1.263
16	4.461	5.180	1.005	1.167
17	1.666	1.894	1.246	1.417
18	1.712	1.997	0.773	0.901
19	3.251	3.615	0.822	0.914
20	3.590	4.111	0.903	1.034
21	3.041	3.612	0.990	1.176
22	2.752	3.165	0.409	0.471
23	4.158	4.940	1.038	1.234
24	4.858	5.540	0.852	0.972
25	3.630	4.363	1.180	1.418

Table 46. Net Ionic Equilibrium ratios in index leaf samples (Pre-monsoon - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	3.575	4.208	0.981	1.154
27	3.113	3.696	0.957	1.137
28	2.945	3.358	0.644	0.735
29	1.844	2.095	0.534	0.607
30	2.093	2.390	0.546	0.623
31	1.882	2.117	0.662	0.744
32	3.296	3.889	0.686	0.809
33	3.289	3.864	0.685	0.805
34	2.979	3.475	0.748	0.873
35	3.809	4.599	1.023	1.235
36	2.830	3.371	0.944	1.125
37	3.526	4.215	0.692	0.827
38	3.157	3.697	0.382	0.448
39	2.663	3.239	0.753	0.915
40	2.338	2.741	1.349	1.581
41	1.791	2.058	0.849	0.975
42	3.882	4.576	0.371	0.437
43	2.969	3.488	0.932	1.095
44	3.556	4.275	0.754	0.906
45	4.240	5.134	1.227	1.485
46	2.668	2.958	0.730	0.810
47	2.274	2.574	0.880	0.996
48	1.672	1.976	0.587	0.693
49	1.595	1.781	0.635	0.709
50	3.301	3.856	1.151	1.344

Table 47. Net Ionic Equilibrium ratios in index leaf samples (Post-monsoon - High yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
1	3.674	4.336	0.661	0.780
2	3.286	3.818	0.719	0.835
3	2.677	3.097	1.157	1.339
4	4.679	5.598	0.861	1.030
5	4.398	5.179	0.886	1.043
6	3.774	4.425	0.889	1.042
7	2.833	3.194	0.787	0.887
8	5.154	6.130	0.917	1.091
9	2.142	2.481	0.993	1.150
10	1.866	2.120	0.771	0.876
11	2.401	2.807	0.639	0.747
12	3.452	3.966	0.999	1.147
13	3.862	4.506	0.715	0.834
14	3.980	4.555	0.820	0.939
15	2.388	2.838	0.779	0.925
16	3.415	3.994	0.957	1.119
17	1.722	1.959	1.084	1.233
18	1.474	1.717	0.810	0.943
19	3.056	3.405	1.248	1.390
20	5.705	6.885	2.070	2.498
21	2.977	3.401	1.239	1.415
22	4.292	4.916	0.487	0.557
23	4.681	5.483	0.591	0.692
24	4.466	5.175	1.056	1.224
25	1.926	2.241	0.706	0.822

Table 48. Net Ionic Equilibrium ratios in index leaf samples (Post monsoon - Low yielding population)

Sample No.	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Mn+Fe)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Mn+Fe)^{1/2}$
26	4.695	5.595	0.705	0.841
27	2.414	2.885	1.535	1.834
28	2.476	2.863	0.840	0.971
29	4.454	5.037	0.853	0.965
30	3.586	4.193	0.748	0.875
31	2.189	2.508	1.029	1.179
32	3.292	3.827	0.852	0.990
33	3.198	3.776	0.879	1.038
34	2.357	2.752	0.688	0.804
35	4.226	5.036	1.238	1.475
36	2.499	2.901	0.652	0.757
37	3.092	3.588	0.858	0.996
38	4.487	5.221	0.724	0.842
39	3.440	3.933	0.917	1.049
40	3.901	4.632	1.990	2.362
41	2.176	2.557	1.112	1.306
42	3.761	4.421	1.169	1.374
43	2.670	3.139	0.762	0.896
44	4.398	5.158	1.065	1.249
45	3.450	4.107	1.490	1.773
46	3.379	3.822	0.903	1.021
47	1.711	1.900	0.784	0.871
48	2.598	3.017	0.862	1.001
49	3.009	3.361	0.744	0.831
50	3.869	4.420	1.074	1.227

$Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and there was a variation from 0.757 to 2.362 in the ratio $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

4.10 CORRELATION STUDIES

In the correlation studies, each nutrient ion concentration in soil samples, soil solutions and in plant samples collected at pre-monsoon and post-post monsoon seasons were correlated with the nut yield of the palms.

4.10.1 Correlation of Available Nutrient Ions with Yield

The correlation coefficients of available nutrient ions in soil with the yield of palms are presented in table 49. Available P has got a negative correlation with yield, both at the surface and subsurface samples for both the seasons, but were not significant. In the case of available K, yield at the post-monsoon subsurface samples was positively and significantly correlated at 5 per cent level. Available Ca showed a negative correlation with yield but it was significant only in the case of pre-monsoon surface samples. Available Fe, Mn and Zn showed positive and highly significant correlation with yield with regard to all the cases. Available Cu showed significant positive correlation with yield at 5 per cent level, both at pre and post-monsoon seasons, in the case of subsurface samples only.

4.10.2 Correlation of Exchangeable Ions with Yield

The date in table 50 shows that the correlation coefficients of exchangeable Ca with yield was positive in all cases but it was significant only in the post-monsoon season. In surface samples it was highly significant at 1 per cent level and in subsurface samples, the values were significant only at 5 per cent level. Magnesium showed positive and significant correlation at 1 per cent level, in the case of surface and subsurface samples of both seasons. Iron and Mn were positively and significantly correlated with yield in all the samples in both seasons. The cation exchange capacity in all cases also showed significant positive correlation with yield.

Table 49. Correlation coefficients of available nutrient ions in soil with nut yield

Particulars	Yield (Pre-monsoon surface samples)	Yield (Pre-monsoon sub-surface samples)	Yield (Post-monsoon surface samples)	Yield (Post-monsoon sub-surface samples)
Available P	-0.133	-0.176	-0.024	-0.276
Available K	-0.006	0.120	0.180	0.292*
Available Ca	-0.314*	-0.200	-0.134	-0.271
Available Mg	0.037	0.138	-0.205	0.118
Available Fe	0.633**	0.593**	0.573**	0.621**
Available Mn	0.537**	0.528**	0.716**	0.582**
Available Cu	0.263	0.288*	0.276	0.321*
Available Zn	0.456**	0.452**	0.412**	0.347*
pH	0.028	-0.158	0.003	-0.149
EC	-0.232	-0.251	-0.264	-0.168

* Significant at 5% level   ** Significant at 1% level

Table 50. Correlation coefficients of exchangeable ions in soil with yield

Particulars	Yield (Pre-monsoon surface samples)	Yield (Pre-monsoon sub-surface samples)	Yield (Post-monsoon surface samples)	Yield (Post-monsoon sub-surface samples)
Exchangeable Ca	0.150	0.214	0.424**	0.289*
Exchangeable Mg	0.790**	0.737**	0.772**	0.760**
Exchangeable K	0.118	0.076	0.038	0.122
Exchangeable Na	0.149	-0.016	0.026	-0.076
Exchangeable Al	0.096	0.096	0.147	-0.022
Exchangeable Fe	0.680**	0.592**	0.771**	0.565**
Exchangeable Mn	0.433**	0.570**	0.711**	0.589**
CEC	0.459**	0.460**	0.613**	0.524**

* Significant at 5% level   ** Significant at 1% level

4.10.3 Correlation Coefficients of Net Ionic Equilibrium Ratios of Exchangeable Ions with Yield

As in table 51 $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ showed negative correlation with yield in all cases but these were not significant. The ratio $Na/(Ca+Mg+Fe+Mn)^{1/2}$ was negatively correlated in the case of subsurface samples but was not significant.

4.10.4 Correlation Coefficients of Soil Nutrients with Net Ionic Equilibrium Ratios

4.10.4.1 Pre-monsoon Surface Samples

Table 52 shows that the nutrient ions Ca and Mg were negatively correlated with all the ratios viz. $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$, $K/(Ca+Mg+Fe+Mn)^{1/2}$, $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Only one significant value in these cases, was the correlation coefficient of Ca with the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$. Potassium showed positive and highly significant correlation with the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and it was negatively correlated with the other two ratios. Sodium showed positive correlation with all the ratios and the coefficients were highly significant in the ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

4.10.4.2 Pre-monsoon Subsurface Samples

Table 53 indicates that the nutrient ions Ca and Mg showed negative correlation with the ratios in all the cases. Calcium showed significant negative coefficients for the ratios $K/(Ca+Mg+Fe+Mn)^{1/2}$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$ and Mg showed significant negative correlation with the ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Potassium showed positive correlation in all the cases and it was highly significant for the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and Na showed highly significant positive correlation in $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. The cation exchange capacity showed negative correlation with all the ratios, but it was significant only with the ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

Table 51. Correlation coefficients of Net Ionic Equilibrium of exchangeable ions with yield

Particulars	Yield (Pre-monsoon surface samples)	Yield (Pre-monsoon sub-surface samples)	Yield (Post-monsoon surface samples)	Yield (Post-monsoon sub-surface samples)
$K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$	-0.047	-0.164	-0.219	-0.083
$K/(Ca+Mg+Fe+Mn)^{1/2}$	-0.058	-0.177	-0.238	-0.149
$Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$	0.021	0.223	0.149	0.203
$Na/(Ca+Mg+Fe+Mn)^{1/2}$	0.004	-0.238	-0.180	-0.240

Table 52. Correlation coefficients of Net Ionic Equilibrium in soil with exchangeable nutrient ions and CEC (Pre-monsoon surface samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
Ca	-0.254	-0.324*	-0.144	-0.210
Mg	-0.086	-0.087	-0.141	-0.159
K	0.929**	0.931**	-0.027	-0.003
Na	0.029	0.006	0.361**	0.953**
Al	-0.007	0.034	-0.029	-0.017
Fe	-0.004	-0.034	-0.029	-0.017
Mn	0.181	0.162	-0.162	-0.174
CEC	0.033	0.025	-0.107	-0.126

* Significant at 5% level ** Significant at 1% level

Table 53. Correlation coefficients of Net Ionic Equilibrium in soil with exchangeable nutrient ions and CEC (Pre-monsoon subsurface samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
Ca	-0.228	-0.305*	-0.269	-0.362*
Mg	-0.200	-0.174	-0.326*	-0.315*
K	0.855**	0.867**	0.074	0.133
Na	0.244	0.208	0.887**	0.879**
Al	-0.006	0.227	-0.373**	-0.173
Fe	-0.098	-0.067	-0.126	-0.101
Mn	-0.095	-0.139	-0.204	-0.241
CEC	-0.067	-0.056	-0.303*	-0.306*

* Significant at 5% level ** Significant at 1% level

4.10.4.3 Post-monsoon Surface Samples

The data depicted in table 54 shows that Ca and Mg were negatively correlated with the ratios, and for Ca, this was significant in $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$. Potassium showed highly significant positive correlation with the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and was negatively correlated with $Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Sodium showed highly significant positive correlation in the ratios involving Na^+ as monovalent ion and was negatively correlated with the ratios where K^+ was the monovalent ion. The cation exchange capacity was found negatively correlated with all the ratios.

4.10.4.4 Post-monsoon Subsurface Samples

Calcium and Mg showed negative correlation with all the ratios but it was significant only in one case ie. Ca with $K/(Ca+Mg+Fe+Mn)^{1/2}$ (Table 55). Potassium showed highly significant positive correlation with the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and Na was positively and highly significantly correlated with the two ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. CEC was found negatively correlated with all the ratios, though not significant.

4.11 CORRELATION STUDIES IN PLANT SAMPLES

4.11.1 Correlation Coefficients of Plant Nutrient Contents with Yield

The correlation coefficients in table 56 shows that K was positively and significantly correlated with yield at the pre-monsoon season, but it was negatively correlated with yield during post-monsoon season. Calcium and Mg were negatively correlated with yield at both seasons, though not significant.

4.11.2 Correlation of Plant Net Ionic Equilibrium Ratios with Yield

The correlation coefficient depicted in table 57 indicates that the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ were positively and significantly correlated with yield at the pre-monsoon season and the relation was positive but not significant at the post-monsoon season. The ratios

Table 54. Correlation coefficients of Net Ionic Equilibrium in soil with exchangeable nutrient ions and CEC (Post-monsoon surface samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
Ca	-0.317*	-0.371**	-0.158	-0.214
Mg	-0.112	-0.159	-0.187	-0.225
K	0.910*	0.911**	-0.061	-0.008
Na	-0.019	-0.024	0.952**	0.945**
Al	0.108	0.296*	-0.198	-0.062
Fe	-0.173	-0.165	-0.031	-0.039
Mn	-0.058	-0.078	-0.002	-0.015
CEC	-0.071	-0.081	-0.103	-0.115

* Significant at 5% level ** Significant at 1% level

Table 55. Correlation coefficients of Net Ionic Equilibrium in soil with exchangeable nutrient ions and CEC (Post-monsoon subsurface samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
Ca	-0.158	-0.299*	-0.084	-0.170
Mg	-0.239	-0.311	-0.238	-0.275
K	0.917**	0.886**	0.063	0.064
Na	0.049	0.063	0.960**	0.950**
Al	-0.186	0.055	-0.116	0.031
Fe	-0.050	-0.032	-0.067	-0.062
Mn	-0.006	-0.072	-0.215	-0.241
CEC	-0.087	-0.158	-0.048	-0.087

* Significant at 5% level ** Significant at 1% level

Table 56. Correlation coefficients of plant nutrient contents with yield

Nutrient element	Yield (Pre-monsoon leaf samples)	Yield (Post-monsoon leaf samples)
K	0.345*	-0.004
Na	0.106	-0.173
Ca	-0.035	-0.138
Mg	-0.131	-0.204
Fe	-0.070	0.037
Mn	0.020	0.196
Zn	-0.013	-0.004
Al	-0.043	-0.113

Table 57. Correlation coefficients of plant Net Ionic Equilibrium ratios with yield

Nutrient Ratios	Yield (Pre-monsoon leaf samples)	Yield (Post-monsoon leaf samples)
$K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$	0.333*	0.0808
$K/(Ca+Mg+Fe+Mn)^{1/2}$	0.320*	0.084
$Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$	0.103	-0.120
$Na/(Ca+Mg+Fe+Mn)^{1/2}$	0.099	-0.116

$Na/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$ showed positive correlation with yield at the pre-monsoon season, but it was negative in post-monsoon season.

4.11.3 Correlation Coefficients of Nutrient Contents and Net Ionic Equilibrium Ratios in Plant Samples

4.11.3.1 Pre-monsoon Samples

The values of correlation coefficients in table 58 shows that the nutrient ion K was positively and significantly correlated with ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and Na was positively and significantly correlated with the ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Calcium was negatively correlated with all the ratios and it was significant for all the ratios except $Na/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$. Magnesium was negatively correlated with all the ratios but it was significant only for $K/(Ca+Mg+Fe+Mn)^{1/2}$.

4.11.3.2 Post-monsoon Samples

Potassium was positively and significantly correlated with the two ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ and Na showed highly significant positive correlation with the ratios $Na/[(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Calcium, Mg and Mn were negatively correlated with all the ratios. Aluminium showed positive and significant correlation with the ratios, $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ (Table 59).

4.12 CORRELATION STUDIES IN SOIL SOLUTIONS

4.12.1 Correlation of Soil Solution Nutrients with Yield

Table 60 indicates that K, Ca, Mg and Mn were positively correlated with yield at both seasons, though not significant. Iron was positively and significantly correlated with yield at both seasons. pH showed negative and significant correlation with yield in the pre-monsoon samples.

Table 58. Correlation coefficients of Net Ionic Equilibrium ratios in plant with plant nutrients (Pre-monsoon samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
K	0.936**	0.919**	0.085	0.092
Na	0.052	0.049	0.932**	0.911**
Ca	-0.353*	-0.376**	-0.275	-0.304*
Mg	-0.261	-0.302*	-0.184	-0.233
Fe	-0.002	0.002	-0.063	-0.057
Mn	-0.216	-0.215	-0.038	-0.038
Zn	-0.285*	-0.272	0.111	0.110
Al	0.029	0.076	-0.092	-0.042

* Significant at 5% level ** Significant at 1% level

Table 59. Correlation coefficients of Net Ionic Equilibrium ratios in plant with plant nutrients (Post-monsoon samples)

Particulars	$K/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/[(Ca+Mg+Mn+Fe)^{1/2} + Al^{1/3}]$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
K	0.932**	0.915**	0.109	0.118
Na	0.131	0.139	0.948**	0.936**
Ca	-0.105	-0.140	-0.193	-0.220
Mg	-0.240	-0.267	-0.161	-0.188
Fe	0.072	0.066	0.032	0.028
Mn	-0.096	-0.097	-0.052	-0.050
Zn	-0.048	-0.049	0.143	0.146
Al	0.027	0.325*	0.215	0.250

* Significant at 5% level ** Significant at 1% level

Table 60. Correlation coefficients of soil solution nutrient concentrations with yield

Nutrient element	Yield (Pre-monsoon soil solution)	Yield (Post-monsoon soil solution)
K	0.192	0.011
Na	0.143	-0.039
Ca	0.245	0.264
Mg	0.148	0.173
Fe	0.428**	0.301*
Mn	0.194	0.239
pH	-0.293*	-0.038
EC	-0.057	-0.147

* Significant at 5% level   ** Significant at 1% level

Table 61. Correlation coefficients of soil solution Net Ionic Equilibrium with yield

Nutrient ratios	Yield (Pre-monsoon solution)	Yield (Post-monsoon solution)
$K/(Ca+Mg+Fe+Mn)^{1/2}$	0.100	-0.105
$Na/(Ca+Mg+Fe+Mn)^{1/2}$	0.035	-0.221

4.12.2 Correlation of Solution Net Ionic Equilibrium Ratios with Yield

The coefficients presented in table 61 reveals that for the pre-monsoon season the ratios $K/(Ca+Mg+Fe+Mn)^{1/2}$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$ were positively correlated with yield and at the next season these ratios showed negative correlation with yield.

4.12.3 Correlation of Nutrient Concentrations with Net Ionic Equilibrium Ratios in Soil Solution

4.12.3.1 Pre-monsoon Samples

As depicted in table 62, there was a positive and highly significant correlation between K and the ratios $K/(Ca+Mg+Fe+Mn)^{1/2}$ and $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Sodium also showed highly significant positive correlation with both of these ratios. Magnesium and Fe were negatively correlated with the ratios.

4.12.3.2 Post-monsoon Samples

From table 63, it is evident that K was positively correlated with both the ratios and correlation with $K/(Ca+Mg+Fe+Mn)^{1/2}$ was highly significant. Sodium also showed positive correlation with both the ratios and it was significant only in the second ratio viz., $Na/(Ca+Mg+Fe+Mn)^{1/2}$. Calcium and Mg were negatively and significantly correlated with the ratio $Na/(Ca+Mg+Fe+Mn)^{1/2}$.

4.13. CORRELATION MATRIX OF NUTRIENTS AND NET IONIC EQUILIBRIUM (NIE) IN SOIL, SOIL SOLUTION AND PLANT

4.13.1 Pre-monsoon Season

Table 64 indicates that exchangeable Ca in soil was significantly correlated with CEC. Exchangeable Mg was significantly correlated with exchangeable Fe, exchangeable Mn, CEC and soil solution concentration of Fe. It was also significantly correlated with the ratio, $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in plant and also with yield of palms.

Exchangeable K in soil was significantly correlated with exchangeable Mn, CEC and the ratio, $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in soil. Exchangeable K was also significantly correlated with soil solution concentration of K, Ca and Mg and with the ratio $K/((Ca+Mg+Fe+Mn)^{1/2}$ in soil solution. It was significantly correlated with the plant

Table 62. Correlation coefficients of Net Ionic Equilibrium ratios in soil solution with soil solution nutrients (Pre-monsoon samples)

Particulars	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
K	0.913**	0.386**
Na	0.600**	0.826**
Ca	0.205	-0.198
Mg	-0.005	-0.205
Fe	-0.102	-0.082
Mn	-0.156	0.023

* Significant at 5% level ** Significant at 1% level

Table 63. Correlation coefficients of Net Ionic Equilibrium ratios in soil solution with soil solution nutrients (Post-monsoon samples)

Particulars	$K/(Ca+Mg+Fe+Mn)^{1/2}$	$Na/(Ca+Mg+Fe+Mn)^{1/2}$
K	0.900**	0.164
Na	0.239	0.846**
Ca	0.024	-0.335*
Mg	-0.205	-0.287*
Fe	-0.063	-0.035
Mn	-0.078	0.234

* Significant at 5% level ** Significant at 1% level

Table 64. Correlation matrix of nutrients and Net Ionic Equilibrium in soil, soil solution and index leaf samples (Pre-monsoon samples)

	Soil factors										Soil solution factors							Plant factors											Yield
	Soil Ex.Ca	Ex.Mg	Ex.K	Ex.Na	Ex.Al	Ex.Fe	Ex.Mn	CEC	A	B	Soln.K	Na	Ca	Mg	Fe	Mn	B	Plant K	Na	Ca	Mg	Fe	Mn	Zn	Al	Total	A	B	
Soil Ex.Ca	1	0.191	-0.003	-0.06	0.047	0.048	0.270	0.806**	-0.254	-0.324	0.067	0.147	0.174	-0.01	0.158	0.11	-0.014	0.206	0.025	-0.09	0.113	0.052	-0.085	-0.201	0.059	0.1	0.167	0.173	0.15
Ex.Mg.		1	0.117	0.006	0.187	0.639**	0.446**	0.549**	-0.086	-0.087	0.219	0.176	0.259	0.065	0.407*	-0.01	0.11	0.263	-0.055	-0.14	-0.142	0.069	0.036	-0.021	0.008	-0.054	0.281*	0.275*	0.790**
Ex.K			1	0.044	0.225	0.151	0.376**	0.369**	0.929**	0.931**	0.522**	0.209	0.535**	0.334*	-0.1	-0.17	0.372**	0.434**	-0.068	-0.06	-0.112	-0.2	-0.386**	-0.327*	0.020	0.076	0.427**	0.420**	0.118
Ex.Na				1	-0.129	0.083	-0.010	0.158	0.029	0.006	0.003	0.052	-0.002	0.084	0.197	0.064	-0.012	0.090	0.050	-0.064	-0.105	-0.064	0.009	-0.250	-0.015	-0.139	-0.067	-0.067	0.149
Ex.Al					1	0.275*	0.156	0.403**	-0.007	-0.167	0.238	-0.057	0.211	0.088	-0.074	-0.106	0.180	0.129	-0.068	-0.200	-0.048	0.017	-0.170	-0.128	-0.183	-0.071	0.161	0.149	0.098
Ex.Fe						1	0.353*	0.391**	-0.004	-0.034	0.144	0.009	0.184	0.001	0.246	-0.118	0.117	0.282*	0.008	-0.145	-0.188	0.089	0.102	-0.008	-0.063	-0.071	0.316*	0.309*	0.680**
Ex.Mn							1	0.560**	0.181	0.162	0.411**	0.193	0.426**	0.102	0.287	0.073	0.294**	0.192	-0.081	0.257	-0.004	0.022	-0.180	0.065	0.048	0.247	0.123	0.110	0.433**
CEC								1	0.033	0.025	0.332*	0.213	0.422**	0.138	0.240	0.023	0.187	0.366**	0.032	-0.145	0.008	0.011	-0.197	-0.281*	-0.010	0.062	0.361*	0.345*	0.459**
A									1	0.978**	0.405**	0.141	0.389**	0.284*	-0.156	-0.192	0.304*	0.340*	-0.085	-0.002	-0.120	-0.234	-0.319*	-0.258	0.063	0.063	0.330*	0.329*	-0.047
B										1	0.427**	0.108	0.394**	0.287*	-0.201	-0.210	0.329*	0.331*	-0.089	-0.013	-0.119	-0.217	-0.332*	-0.258	0.032	0.051	0.324*	0.322*	-0.058
Soln.K											1	0.601**	0.537**	0.277	-0.061	0.146	0.667**	0.250	-0.147	-0.237	0.039	-0.061	-0.385**	-0.367**	-0.068	-0.059	0.292*	0.287*	0.172
Na												1	0.270	0.278	-0.059	-0.006	0.608**	0.011	-0.005	-0.245	0.102	-0.183	-0.221	-0.224	0.083	-0.116	0.048	0.057	0.148
Ca													1	0.661**	-0.108	-0.259	0.208	0.264	0.037	-0.123	0.150	-0.271	-0.382**	-0.208	0.066	0.107	0.243	0.234	0.244
Mg														1	-0.021	-0.092	-0.011	0.050	-0.087	-0.222	0.120	-0.091	-0.321*	-0.120	0.129	-0.079	0.066	0.072	0.124
Fe															1	0.213	-0.134	0.090	0.014	0.026	-0.012	0.021	0.061	0.122	-0.198	0.047	0.066	0.069	0.659**
Mn																1	-0.138	-0.146	0.082	0.074	0.047	0.064	0.140	0.156	-0.152	0.019	-0.118	-0.118	0.026
B																	1	0.217	-0.172	-0.215	-0.015	0.002	-0.274	-0.387	-0.038	-0.086	0.267	0.268	0.083
Plant K																		1	0.172	-0.077	-0.078	0.013	-0.085	-0.245	0.108	0.381**	0.936**	0.919**	0.345*
Na																			1	0.012	0.023	-0.044	0.088	0.203	-0.040	0.161	0.062	0.048	0.106
Ca																				1	0.092	0.039	0.293*	0.256	0.211	0.709**	-0.353*	-0.376**	-0.035
Mg																					1	-0.077	0.048	0.060	-0.300*	0.584**	-0.261	-0.303*	-0.131
Fe																						1	0.210	0.164	0.226	0.036	-0.002	0.003	-0.070
Mn																							1	0.091	0.238	0.248	0.216	0.216	0.019
Zn																								1	0.217	0.137	-0.265*	-0.272	-0.014
Al																									1	0.063	0.027	0.075	-0.943
Total																										1	0.064	0.010	0.076
A																											1	0.997**	0.333*
B																												1	0.319*
Yield																													1

A - $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ B - $K/(Ca+Mg+Fe+Mn)^{1/2}$ Total - Total cations in plant

K content and also with the ratios $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and $K/(Ca+Mg+Fe+Mn)^{1/2}$ in plant, ie. NIE in plant. Exchangeable K was also significantly correlated with plant Mn and Zn contents, but these relations were negative. Exchangeable Al in soil was significantly correlated with Fe and CEC of soils.

Exchangeable Fe in soil was significantly correlated with exchangeable Mn and CEC of soil. It was also significantly correlated with plant K content, the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in plant and with the yield of palms.

Exchangeable Mn in soil was significantly correlated with CEC of soil, soil solution concentrations of K and Ca and with the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$ in soil solution. It was also significantly correlated with the yield of palms.

The cation exchange capacity of the soil was significantly correlated with the soil solution concentrations of K and Ca. It was also significantly correlated with the plant K and NIE in plant, ie. $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ and with the yield of palms. The CEC was negatively and significantly correlated with the plant Zn content.

The NIE in soil ie., $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ was significantly correlated with the soil solution concentrations of K, Ca and Mg and also with the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$ (ie. NIE) in soil solution. NIE in soil was also significantly correlated with the plant K content and NIE in plant ie., $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$. It was negatively and significantly correlated with plant Mn content.

Soil solution concentration of K was significantly correlated with soil solution concentrations of Na and Ca and with NIE in soil solution. It was also significantly correlated with NIE in plant. Solution K content was also significantly correlated with plant Mn and Zn contents, but these relations were negative.

Soil solution concentration of Ca was significantly correlated with the solution Mg concentration. Solution concentrations of Ca and Mg were negatively and significantly correlated with the plant Mn content. Solution Fe was significantly correlated with yield.

The plant K content was significantly correlated with the total cation concentration in plant and also with the yield of the palms. It was also significantly correlated with the NIE in plant (ie. with the ratio $K/[(Ca+Mg+Fe+Mn)^{½})+(Al)^{1/3}]$.

Plant Ca was significantly correlated with the plant Mn content and also with the total cations in plant. It was significantly correlated with the NIE in plant but the relation was negative.

Plant Mg content was significantly correlated with the total cation concentration in plant. It was also significantly correlated with the plant Al content and net ionic equilibrium (NIE) in plant but these relations were negative. Plant Zn concentration was negatively and significantly correlated with the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ in plant ie. NIE in plant.

The ratio $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$ in plant ie. NIE in plant was significantly correlated with yield.

4.13.2 Post-monsoon Season

As in table 65, exchangeable Ca in soil was significantly correlated with exchangeable Mg, exchangeable Fe, exchangeable Mn and also with the CEC of soil and was significantly correlated with NIE in soil, but this relation was negative. Exchangeable Ca was significantly correlated with the yield of palms. Exchangeable Mg was significantly correlated with exchangeable Fe, exchangeable Mn and CEC of soil. Exchangeable Mg was significantly correlated with soil solution Ca and also with the yield of palms.

Exchangeable K in soil was significantly correlated with exchangeable Al, CEC of soil, and with the NIE in soil. It was significantly correlated with the plant Na, and plant Mn contents, but the correlation with plant Mn was negative and significant. Exchangeable Na was significantly correlated with the solution Na concentration.

Exchangeable Al in soil was significantly correlated with the CEC of soil and also with the ratio $K/(Ca+Mg+Fe+Mn)^{1/2}$. It was also significantly correlated with the solution K and with the NIE in solution. It was negatively and significantly correlated with the plant Ca content.

Table 65. Correlation matrix of nutrients and Net Ionic Equilibrium in soil, soil solution and index leaf samples (Post-monsoon samples)

	Soil factors										Soil solution factors							Plant factors											Yield
	Soil Ex.Ca	Ex.Mg	Ex.K	Ex.Na	Ex.Al	Ex.Fe	Ex.Mn	CEC	A	B	Soln.K	Na	Ca	Mg	Fe	Mn	B	Plant K	Na	Ca	Mg	Fe	Mn	Zn	Al	Total	A	B	
Ex.Mg.		1	0.180	0.018	0.107	0.680**	0.660**	0.741**	-0.112	-0.159	0.135	0.110	0.323*	-0.009	0.260	0.073	-0.027	0.057	-0.217	-0.236	-0.269	-0.042	-0.034	-0.175	-0.090	-0.279	0.176	0.182	0.772**
Ex.K			1	0.006	0.358*	0.051	0.227	0.315*	0.910**	0.911**	0.197	0.080	0.129	-0.003	0.196	0.095	0.186	0.122	0.291*	-0.047	-0.015	0.048	-0.356*	0.062	0.262	0.059	0.143	0.153	0.038
Ex.Na				1	-0.038	0.130	0.200	0.186	-0.019	-0.024	0.126	0.280*	0.098	0.170	0.136	-0.106	0.102	0.098	-0.174	0.050	0.028	-0.252	-0.047	-0.021	-0.155	0.051	0.100	0.089	0.026
Ex.Al					1	0.164	0.241	0.336*	0.108	0.296*	0.326*	0.030	0.161	0.146	0.166	0.118	0.291*	0.126	0.150	-0.315'	0.015	-0.035	-0.108	-0.106	-0.022	-0.101	0.234	0.244	0.147
Ex.Fe						1	0.517**	0.523**	-0.173	-0.165	0.230	0.084	0.247	0.168	0.245	-0.149	0.064	-0.144	-0.180	-0.199	-0.231	0.041	0.181	0.001	-0.109	-0.313*	-0.036	-0.024	0.771**
Ex.Mn							1	0.715**	-0.058	-0.078	0.247	0.196	0.380**	0.115	0.234	-0.151	0.082	0.050	-0.143	-0.066	-0.114	-0.131	0.160	0.095	-0.021	-0.089	0.095	0.097	0.711**
CEC								1	-0.071	-0.081	0.198	0.164	0.337*	0.062	0.335*	0.044	0.048	0.198	-0.045	-0.151	-0.194	0.086	-0.127	-0.200	-0.017	-0.102	0.282*	0.285*	0.813*
A									1	0.976**	0.066	0.023	-0.030	-0.049	0.071	0.064	0.124	0.047	0.297*	0.046	0.066	0.018	-0.316*	0.164	0.293*	0.119	0.022	0.030	-0.219
B										1	0.120	-0.032	-0.032	-0.015	0.078	0.081	0.161	0.060	0.318*	-0.015	0.082	-0.000	-0.306*	0.139	0.289*	0.101	0.054	0.064	-0.238
Soln.K											1	0.407*	0.394**	0.189	-0.138	-0.170	0.654**	-0.112	-0.044	-0.270	-0.010	-0.213	-0.246	-0.154	-0.078	-0.232	-0.031	-0.023	0.032
Na												1	0.111	0.162	0.017	-0.081	0.270	0.072	0.027	-0.159	0.070	-0.190	-0.063	0.107	0.090	-0.025	0.124	0.138	0.070
Ca													1	0.600**	-0.155	-0.328	0.007	0.136	-0.106	-0.188	0.017	-0.072	-0.214	-0.317*	-0.144	-0.065	0.186	0.177	0.264
Mg														1	0.127	-0.132	-0.226	0.055	-0.000	-0.092	-0.036	0.107	-0.714	0.068	-0.146	-0.051	0.104	0.100	0.144
Fe															1	0.464*	-0.179	0.178	0.248	-0.026	-0.141	0.135	0.089	0.073	0.193	0.041	0.217	0.231	0.422**
Mn																1	-0.118	0.039	0.176	-0.069	0.127	0.056	-0.111	0.073	0.080	0.063	0.047	0.054	0.040
B																	1	-0.210	-0.041	-0.171	0.116	-0.230	-0.175	-0.159	-0.071	-0.157	-0.181	-0.175	-0.107
Plant K																		1	0.161	0.196	-0.033	0.182	0.003	-0.027	0.361*	0.591**	0.932**	0.915**	-0.004
Na																			1	0.074	0.014	0.136	0.030	0.198	0.261*	0.269*	0.131	0.139	-0.173
Ca																				1	0.094	0.295*	0.237	0.143	0.150	0.739**	-0.104	-0.141	-0.136
Mg																					1	0.012	-0.023	-0.015	-0.191	-0.617**	-0.240	-0.267	-0.204
Fe																						1	-0.005	0.056	0.250	0.306*	0.072	-0.067	0.036
Mn																							1	0.257	0.314	0.167	0.097	0.097	0.196
Zn																								1	0.177	0.103	-0.047	-0.038	-0.006
Al																									1	0.240	0.297*	0.325*	-0.114
Total																										1	0.275*	0.235	-0.200
A																											1	0.998**	0.079
B																												1	0.064
Yield																													1

A - $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ B - $K/(Ca+Mg+Fe+Mn)^{1/2}$ Total - Total cations in plant

Exchangeable Fe in soil was significantly correlated with exchangeable Mn and CEC of soil, and with the yield of palms. It was negatively and significantly correlated with the sum of cations in plant.

Exchangeable Mn in soil was significantly correlated with the CEC of soil and with the solution Ca concentration and also with the yield of palms. The CEC of soil was significantly correlated with the solution concentrations of Ca and Fe and with the NIE in plant. The NIE in soil was significantly correlated with the Na and Al content in plant and was negatively correlated with the plant Mn content.

Soil solution K was significantly correlated with the solution concentrations of Na and Ca and with the NIE in soil solution. Soil solution Ca was significantly correlated with the solution Mg and was negatively correlated with the solution Mn content. It was negatively and significantly correlated with the plant Zn content. Soil solution Fe was significantly correlated with the solution Mn and also with the yield.

Plant K was significantly correlated with the plant Al content and also with the total cations in plant. It was significantly correlated with the NIE in plant. Plant Na was also significantly correlated with the plant Al content and with the total cations in plant.

Plant Ca was significantly correlated with the plant Fe content and total cation content in plant. Plant Mg was significantly correlated with the total cation concentration in plant but the relation was negative. Plant Fe was positively correlated with the total cation concentration in plant.

Plant Al content was positively and significantly correlated with the NIE in plant (ie. with the ratio $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$. The total cation concentration in plant was significantly correlated with the NIE in plant ie. with the ratio, $K/[(Ca+Mg+Fe+Mn)^{1/2}+(Al)^{1/3}]$.

4.14 CONTRIBUTION OF SOIL FACTORS TO YIELD

The results of detailed regression analysis on contribution of the soil cations and CEC to yield are presented here.

4.14.1 Pre-monsoon Surface Soil Samples

Stepwise regression analysis depicts the improvement in prediction values of yield. The equations developed are:

Yield = 73.197 Ex.Mg + 306.478 Ex.Fe – 79.88 (R^2 = 0.6497*) (4.1)

Yield = 69.961 Ex.Mg + 294.217 Ex.Fe + 21.281 Ex.Mn – 81.43 (R^2 = 0.6472**) (4.2)

Yield = 71.024 Ex.Mg + 295.821 Ex.Fe + 24.01 Ex.Mn – 0.821 CEC – 79.10 (R^2 = 0.6398**) and (4.3)

Yield = 3.273 Ex.Ca + 72.866 Ex.Mg + 312.442 Ex.Fe + 27.58 Ex.Mn - 3.35 CEC – 79.13 (R^2 = 0.6329**) (4.4)

As there is not much variation in the R^2 value in the equations (Eqn.4.1 to Eqn.4.4), the yield can be expressed as equation 4.1 itself.

4.14.2 Pre-monsoon Subsurface Soil Samples

The equations developed through the stepwise regression analysis are,

Yield = 66.094 Mg + 78.718 Mn – 37.88 (R^2 = 0.5735*) (4.5)

Yield = 58.448 Mg + 171.613 Fe + 70.62 Mn – 58.33 (R^2 = 0.5797**) (4.6)

Yield = 62.92 Ex.Mg + 151.732 Ex.Fe + 81.024 Ex.Mn - 2.508 CEC – 48.64 (R^2 = 0.5738**) and (4.7)

Yield = 5.769 Ex.Ca + 67.212 Ex.Mg + 165.456 Ex.Fe + 82.223 Ex.Mn – 6.649 CEC – 47.24 (R^2 = 0.5671**) (4.8)

Here also the yield can be expressed by the equation 4.5 itself.

4.14.3 Post-monsoon Surface Soil Samples

The equations developed through the stepwise regression analysis are,

Yield = 28.704 Ex.Mg + 455.27 Ex.Fe + 95.63 Ex.Mn – 103.8 (R^2 = 0.7354**) (4.9)

Yield = 33.644 Ex.Mg + 455.449 Ex.Fe + 109.543 Ex.Mn

$$-2.857 \text{ CEC} - 98.24 \ (R^2 = 0.7339^{**}) \quad (4.10)$$

$$\text{Yield} = 9.206 \text{ Ex.Ca} + 37.486 \text{ Ex.Mg} + 479.701 \text{ Ex.Fe} + 124.47 \text{ Ex.Mn} - 10.121 \text{ CEC} - 94.62 \ (R^2 = 0.7388^{**}) \quad (.4.11)$$

As there is not much variation in R^2 value from Equations 4.9 to 4.11, the yield is expressed by the equation 4.9 itself.

4.14.4 Post-monsoon Subsurface Soil Samples

The equation developed through the stepwise regression analysis are,

$$\text{Yield} = 70.56 \text{ Ex.Mg} + 406.72 \text{ Ex.Fe} - 95.71 \ (R^2 = 0.6595^{*}) \quad (4.12)$$

$$\text{Yield} = 63.547 \text{ Ex.Mg} + 376.245 \text{ Ex.Fe} + 42.093 \text{ Ex.Mn} - 97.42 \ (R^2 = 0.6612^{**}) \quad (4.13)$$

$$\text{Yield} = 1.49 \text{ Ex.Ca} + 62.882 \text{ Ex.Mg} + 375.954 \text{ Ex.Fe} + 39.829 \text{ Ex.Mn} - 99.53 \ (R^2 = 0.6547^{**}) \text{ and} \quad (4.14)$$

$$\text{Yield} = 6.631 \text{ Ex.Ca} + 67.037 \text{ Ex.Mg} + 398.8 \text{ Ex.Fe} + 46.886 \text{ Ex.Mn} - 5.29 \text{ CEC} - 94.41 \ (R^2 = 0.6499^{**}) \quad (4.15)$$

There is not much variation in the R^2 value from equations 4.12 to 4.15, hence yield can be expressed by the equation 4.12 itself.

4.15 CONTRIBUTION OF SOIL, SOLUTION AND PLANT FACTORS TO YIELD

The results of detailed regression and path coefficient analysis on contribution of soil, solution and plant factors to yield are presented hereunder:

4.15.1 Pre-monsoon Samples

Stepwise regression analysis depicts the improvement in prediction values of yield. The equations developed are,

$$\text{Yield} = 57.661 \text{ Ex.Mg} + 330.271 \text{ Ex.Fe} + 1085.25 \text{ solution Fe} - 75.22 \ (R^2 = 0.7207^{**}) \quad (4.16)$$

$$\text{Yield} = 57.943 \text{ Ex.Mg} + 344.512 \text{ Ex.Fe} + 1052.28 \text{ solution Fe} + 0.170 \text{ total cations in plant} - 95.02 \ (R^2 = 0.7288^{**}) \quad (4.17)$$

Table 66. Path coefficients indicating direct and indirect effects on yield (Pre-monsoon samples)

	Ex. Ca.	Ex. Mg.	Ex. Fe.	Ex. Mn.	CEC	Solution Fe.	Plant K	Total cations in plant	K/[(CA+Mg+ Fe+Mn)$^{1/2}$ + (Al)$^{1/3}$] in plant	Simple correlation coefficient (r)
Ex. Ca.	**-0.0224**	0.0943	0.0154	0.0059	-0.0157	0.0464	0.0230	0.0069	-0.0043	0.150
Ex. Mg.	-0.0043	**0.4936****	0.1638	0.0096	-0.0107	0.1191	0.0294	-0.0037	-0.0064	0.790*
Ex. Fe.	-0.0013	0.3113*	**0.2598**	0.0078	-0.0080	0.0634	0.0342	-0.0068	-0.0081	0.680**
Ex. Mn.	-0.0060	0.2164	0.0922	**0.0219**	-0.0108	0.0794	0.0209	0.0176	-0.0026	0.433**
CEC	0.0180	0.2713*	0.1058	0.0121	**-0.0195**	0.0702	0.0409	0.0043	-0.0083	0.459**
Solution Fe.	-0.0035	0.2008	0.0562	0.0059	-0.0047	**0.2929***	0.0101	0.0033	-0.0020	0.428**
Plant K	-0.0046	0.1300	0.0795	0.0041	-0.0071	0.0265	**0.1117**	0.0264	-0.0214	0.345*
Total cations in plant	-0.0022	-0.0265	-0.0256	0.0055	-0.0012	0.0139	0.0426	**0.0693**	-0.0012	0.075
K/[(CA+Mg+ Fe+Mn)$^{1/2}$ + (Al)$^{1/3}$] in plant	-0.0042	0.1387	0.0921	0.0025	-0.0071	0.0252	0.1045	0.0035	**-0.0229**	0.333*

Yield = 56.787 Ex.Mg + 319.256 Ex.Fe + 1063.897 solution Fe
+ 0.242 plant K + 0.123 total cations in plant – 91.59
($R^2 = 0.7274^{**}$) (4.18)

Yield = -1.001 Ex.Ca + 57.400 Ex.Mg + 311.979 Ex.Fe + 5.956 Ex.Mn – 0.613 CEC + 1067.403 solution Fe + 0.353 plant K + 0.102 total cations in plant – 0.618 $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in plant – 86.03
($R^2 = 0.7017^{**}$) (4.19)

As there is not much variation in the R^2 value from equations 4.16 to 4.19 , the yield can be expressed by the equation 4.16 itself.

Table 66 indicates the path coefficients indicating both direct and indirect effects of different factors on yield. The table indicates that the direct effects of exchangeable Mg and soil solution Fe on yield are significant. Exchangeable Fe and CEC have got significant indirect effects on yield through exchangeable Mg

4.15.2 Post-monsoon Samples

The equations developed through the stepwise regression analysis are,

Yield = 12.38 Ex.Ca + 40.192 Ex.Mg + 442.23 Ex.Fe + 134.44 Ex.Mn – -15.85 CEC + 962.883 solution Fe – 81.79 ($R^2 = 0.8127^{**}$) (4.20)

Yield = 12.56 Ex. Ca + 40.050 Ex. Mg + 447.303 Ex.Fe + 135.429 Ex.Mn – -15.479 CEC + 956.65 solution Fe + 0.323 $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in plant – 82.81 ($R^2 = 0.8084^{**}$) (4.21)

Yield = 13.098 Ex.Ca + 40.883 Ex.Mg + 447.616 Ex.Fe + 136.539 Ex.Mn – 16 CEC + 945.645 solution Fe – 0.476 plant K + 0.082 total cations in plant + 4.168 $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ in plant – 89.35
($R^2 = 0.7992^{**}$) (4.22)

In this case, since there is not much variation in R^2 values from equations 4.20 to 4.22 the yield can be expressed by the equation 4.20 itself.

Table 67. Path coefficients indicating direct and indirect effects on yield (Post-monsoon samples)

	Ex. Ca.	Ex. Mg.	Ex. Fe.	Ex. Mn.	CEC	Solution Fe.	Plant K	Total cations in plant	K/[(CA+Mg+ Fe+Mn)$^{1/2}$ + (Al)$^{1/3}$] in plant	Simple correlation coefficient (r)
Ex. Ca.	**0.3232***	0.2106	0.1321	0.2040	-0.5117**	0.0641	-0.0337	-0.0007	0.0356	0.424**
Ex. Mg.	0.1644	**0.4140****	0.2830*	0.2770*	-0.4389**	0.0730	-0.0107	-0.0192	0.0299	0.772**
Ex. Fe.	0.1047	0.2873*	**0.4078****	0.2223	-0.3223*	0.0735	0.0255	-0.0216	-0.0050	0.771**
Ex. Mn.	0.1577	0.2744*	0.2170	**0.4180****	-0.4247**	0.0633	-0.0105	-0.0062	0.0171	0.711**
CEC	0.2792*	0.3068*	0.2219	0.2997*	**-0.5924****	0.0936	-0.0367	-0.0072	0.0480	0.613**
Solution Fe.	0.0739	0.1078	0.1070	0.0944	-0.1970	**0.2801***	-0.0333	0.0030	0.0369	0.472*
Plant K	0.0583	0.0236	-0.0555	0.0235	-0.1162	0.0499	**-0.1872**	0.0415	0.1583	-0.004
Total cations in plant	-0.0030	-0.1133	-0.1255	-0.0366	0.0603	0.0119	-0.1126	**0.0703**	0.0468	-0.200
K/[(CA+Mg+ Fe+Mn)$^{1/2}$ + (Al)$^{1/3}$] in plant	0.0678	0.0729	-0.0121	0.0422	-0.1673	0.0609	-0.1744	0.0194	**0.1699**	0.080

Table 67 shows the path coefficients indicating both direct and indirect effects of different factors on yield.

From the table it is clear that the direct effects of exchangeable Ca, exchangeable Mg, exchangeable Fe, exchangeable Mn, CEC and solution Fe on yield were significant, but the effect of CEC was negative. The indirect effects of CEC through exchangeable Ca, exchangeable Mg, exchangeable Mn were significant and positive. The indirect effect of exchangeable Ca through CEC was negative and significant. The indirect effects of exchangeable Mg through exchangeable Fe and exchangeable Mn were significant. The indirect effect of exchangeable Mg and exchangeable Fe through CEC were significant and negative. The indirect effect of exchangeable Fe through exchangeable Mg was significant. The indirect effect of exchangeable Mn through exchangeable Mg and CEC were significant, but the effect through CEC was negative. Soil solution Fe concentration had got no significant indirect effects. Plant K content, total cations in plant, and the NIE in plant ie. $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ had got no significant direct or indirect effects in the post monsoon season.

Discussion

5. DISCUSSION

The results of the present study are discussed critically in this section with supporting studies from the literature wherever possible.

5.1 YIELD OF PALMS

The fifty coconut palms included in the present study were selected from a phenotypically identical population of palms. But there was a wide variation in yield among the palms from as low as 14.4 nuts palm^{-1} yr^{-1} (Table 2) to as high as 84.4 nuts palm^{-1} yr^{-1} (Table 1). Considering this wide variability, the palms were selected in such a way to include very low and very high yielders. This was done with an objective to analyse the soil – plant system ie., the nutrient levels and interactions, thereby unravelling the contributing factors to yield. An attempt is made here, to discuss this variability in yield with respect to the soil - solution – plant nutrient equilibrium.

5.2. ELECTROCHEMICAL PROPERTIES

The data on electrochemical properties such as pH, EC and organic carbon content of the soil samples, of both surface and subsurface, taken before and after the monsoon rains are presented in tables 3 to 10. The data reveal that, though there is variation in these properties, among the samples taken in the same season, from same depth, as well as among the samples of different depths taken at different seasons, there was no specific trend in these variations, either season-wise or depth-wise. Also there was not much relations observed among these parameters with yield, except for the pH (Tables 3 and 4). A critical observation with respect to pH is that, for the highest yielding palm (84.4 nuts palm^{-1} yr^{-1}) the pH of the surface sample was 5.10 at pre monsoon season, while that was 3.74 for the lowest yielder (14.4 nuts palm^{-1} yr^{-1}). This variation in rhizosphere pH must have definitely influenced the solubility as well as absorption of different nutrient ions. However, there was no direct significant correlation between these parameters and yield.

5.3 AVAILABLE NUTRIENTS

The data on available P content of the surface samples, taken at pre monsoon season, show high variability. However, this has no direct influence on yield. The rhizosphere soil sample of the palm yielding 66.8 nuts yr^{-1} contained only 2.84 mg P kg^{-1} soil (Table 11), while the sample from the rhizosphere of the palm yielding 68 nuts yr^{-1} showed the highest P status of 25.4 mg kg^{-1}. The data on available P content of surface samples, taken at pre monsoon season, from the rhizosphere of low yielding palms revealed that the sample containing 30.1 mg P kg^{-1} soil yield only 27.4 nuts yr^{-1} whereas the sample from the lowest yielder contained only 5.95 mg P kg^{-1} soil (Table 12). So there is a trend of available P influencing the yield in low yield group. However, there was no significant correlation. In both surface and subsurface samples, content of available P increases irrespective of the yield probably due to the dissolution of native P with the increased availability of water.

The data on subsurface samples do not show any significant trend for available P with yield, either in high yielders or low yielders (Tables 13 and 14). The only noteworthy observation was that the samples from the lowest yielder contained the lowest available P content (1.27 mg kg^{-1}) (Table 14). The data on available P in the post monsoon surface samples also showed wide variation (Table 15). The rhizosphere sample containing 2.57 mg P kg^{-1} soil, yielded 66.8 nuts yr^{-1}. On the other hand, the rootzone of palm yielding 23.6 nuts yr^{-1} contained 30.57 mg P kg^{-1} soil (Table 16). Similar trends are seen in the case of subsurface samples also.

The above data point to the fact that the available P alone is not directly influencing the yield. Probably its interaction with other factors might have some effect. Kanapathy (1977) in a study on dwarf coconut palm showed that there was no yield response to P fertilization.

Available K content of samples taken from the basins of low yielders and high yielders at pre monsoon and post monsoon seasons reveal that there is no specific relation for this parameter with yield (Table 11 to 18).

The data on available Ca and Mg contents from the surface and subsurface samples taken at pre monsoon season from both high and low yielding populations also showed no specific trend in influencing the yield. However, the available Mg content from the surface soil samples of pre monsoon season for the high yielding population (Table 11) showed somewhat a direct relationship with yield with the highest Mg content from the rhizosphere soil of the highest yielding palm and lowest Mg content from the rootzone of the lowest yielding palm. But at the same time, only 84 mg Mg kg^{-1} root zone soil was observed for a palm yielding 81.8 nuts yr^{-1}, whereas 216 mg Mg $kg^{-1}$of rhizosphere soil was there for a palm yielding only 23.6 nuts yr^{-1}, in the case of pre monsoon surface samples (Table 11 and 12).

During post monsoon season, for Ca and Mg there was no direct relationship with yield in any of the cases (Tables 15 to 18). In this season, for the surface soil samples of the low yield group, the available Ca content was only 180 mg kg^{-1} soil for a palm yielding 27.2 nuts yr^{-1} , but it was as high as 640 mg Ca kg^{-1} for a palm with 24.8 nuts yr^{-1} (Table 16). In the case of available Mg also such a trend was noticed. A palm yielding 27.8 nuts yr^{-1} showed only 60 mg Mg kg^{-1} soil, whereas a palm yielding 23.6 nuts yr^{-1} had got 204 mg Mg kg^{-1} root zone soil (Table 16). In the subsurface soil samples also such inverse relationships were got, for these nutrients. The negative correlation, though not significant, of Mg with yield (-0.205) also points towards this fact. In the subsurface soil samples of post monsoon season, the available Ca content was only 180 mg kg^{-1} of rootzone soil for the highest yielding palm (84.4 nuts yr^{-1}) and for a palm of yield 22.6 nuts yr^{-1} the rhizosphere soil showed 700 mg Ca kg^{-1} (Tables 17 and 18).

In the case of available micronutrients, for Fe and Mn during pre and post monsoon seasons, both for surface and subsurface soil samples there was a direct relation with yield both for high yielding and low yielding populations. Available Fe content of the surface samples at pre monsoon season ranged from 18 to 60 mg kg^{-1} (Tables 11 and 12), and this was found to have a direct positive significant correlation ($r = 0.633^{**}$ and 0.593^{**}) as seen in table 49.

Similarly, in the case of samples taken at post monsoon season, the Fe content varied from 19 to 71 mg kg^{-1} soil, which is also significantly correlated with yield. In the case of available Mn, the content varied from 40 to 130 mg kg^{-1} when the samples, both surface and subsurface were taken during both seasons, from the basins of the entire population (Tables 11 to 18). Here also there was a significant positive correlation between the available Mn content and yield (r = 0.537**; 0.528**; 0.716**; 0.582**) (Table 49).

Available Cu showed significant correlation with yield only in the case of samples taken from the subsurface layer, while available Zn showed positive significant correlation with yield in all cases, of samples from both depths during both seasons (Table 49).

The data on available nutrient status and its correlation with yield revealed that micronutrients viz., Fe, Mn, Cu and Zn have got positive influence on yield.

Potassium shows such a trend only in the case of post monsoon subsurface samples while available Ca have got a negative correlation with yield in the case of all samples, but the relation was significant only in the case of pre monsoon subsurface samples (Table 49).

A critical appraisal of the data would lead to the conclusion that available Cu and Zn, which may be limiting under acidic lateritic environment would definitely give response. This might be due to the restricted solubility of these ions due to the over dominance of K and Mg. Vijayaraghavan *et al.* (1988) reported that along with recommended dose of NPK, 200g of $ZnSO_4$ palm^{-1} yr^{-1}, has significantly increased the coconut yield to 122-129 nuts palm^{-1} yr^{-1} which was 69.5% higher than the control.

An interesting observation is that available Fe and Mn, which are expected to be in excess levels in lateritic environment are showing positive significant correlation with yield. This would mean that their availability is restricted probably due to aerobic oxidized condition where Fe and Mn might have been precipitated and got into unavailable forms. Further, the negative relation of available Ca with yield would indicate Ca level must have been raised due to some applied sources which also restricted the Fe and Mn availability. This might be the reason for the positive response of Fe reported earlier. Eschbach and Manciot (1981) found that on adult coconut palms, application of $FeSO_4$ at the rate of 400 g tree^{-1} yr^{-1} increased the number of nuts per tree, and application of Mn increased both growth and number of nuts per tree.

5.4 EXCHANGEABLE CATIONS AND CEC

The data on exchangeable cation content in surface samples of pre monsoon season show that the soil samples from root zone of high yielding palms have in general more exchangeable Ca and Mg and lower content of Al. In other words, as the Ca and/or Mg content decreases it was found replaced to some extent by Al. Exchangeable K and Na variation did not show any specific trend. So also in the case of exchangeable Fe and Mn (Tables 19 and 20). In low yield group, pre-monsoon surface samples, a decrease in yield was observed with low exchangeable Mg content. (Table 20). This shows that Mg is a limitting nutrient for coconut under lateritic environment. Cecil (1988) reported that Mg is one of the limiting nutrient elements in the nutrition of coconut. Mathew (1977) earlier reported the importance of Mg in coconut nutrition. In the case of pre monsoon subsurface samples, the trend was very same as that in pre monsoon surface samples (Tables 21 and 22). So also the case of post monsoon surface and subsurface samples (Tables 23 to 26). Further, figures 2 to 5 show that the response of Mg to yield could be predicted as a linear one which could explain upto 62 per cent variation (R^2 for linear curve 0.6218). Cation exchange capacity was also found to influence the yield in a similar way.

The above said trends were well depicted by the significant correlation coefficients of exchangeable Ca, exchangeable Mg, exchangeable Fe, exchangeable Mn and CEC (Table 50). Similarly the curve showing the relationship of exchangeable Fe (post-monsoon) to yield could be linear (Fig.6) with 59 per cent prediction value. The negative relation of Al with yield though not significant, was observed only in the case of subsurface samples (Table 50). This would further show that, it was the $BaCl_2$ exchangeable ions and the CEC derived from summing up of these exchangeable ions reflects their effect on yield. Such an effect was not observed in the case of available ions, which were extracted by neutral normal ammonium acetate. But in the case of micronutrient cations like Fe and Mn, the available (0.1M HCl extractable) and $BaCl_2$ exchangeable ions seem to come from the same pool which has got significant influence on yield. This would further indicate that, the ammonium acetate solution buffered to neutral pH is not extracting the same exchangeable pool, which is in equilibrium with soil

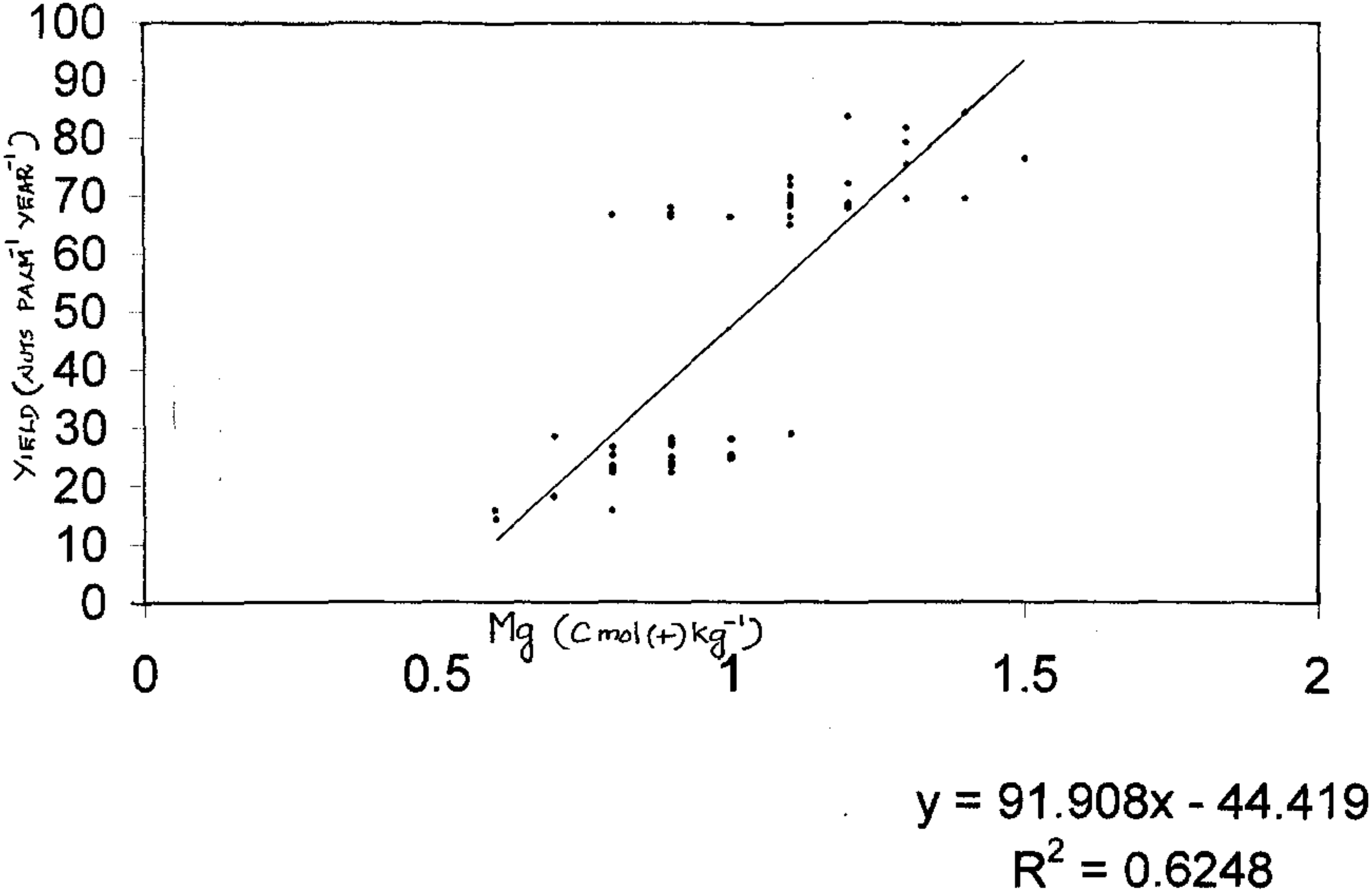


Fig. 2. RESPONSE OF Mg TO YIELD. (pre-monsoon surface samples)

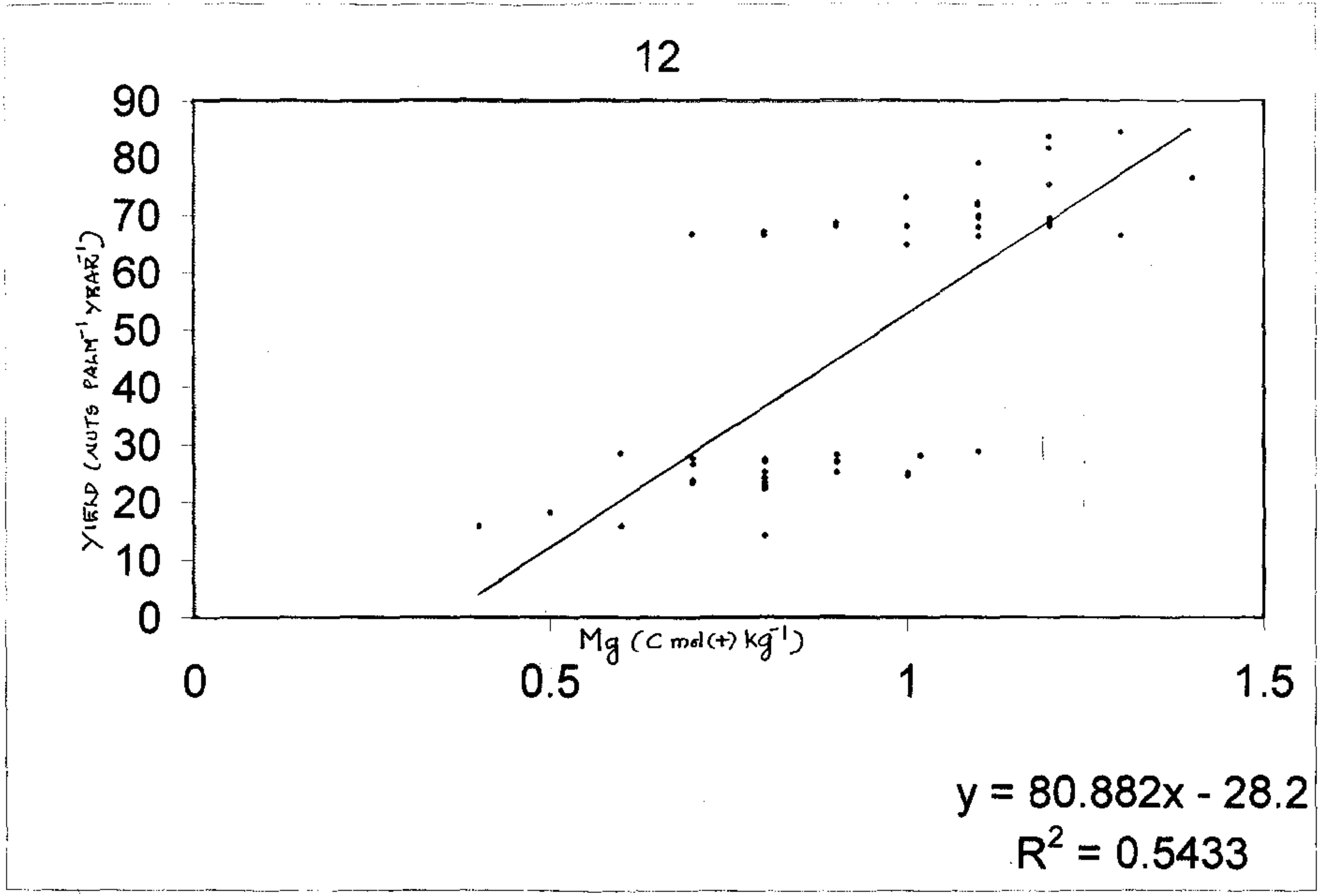


Fig. 3. RESPONSE OF Mg TO YIELD (pre-monsoon subsurface samples)

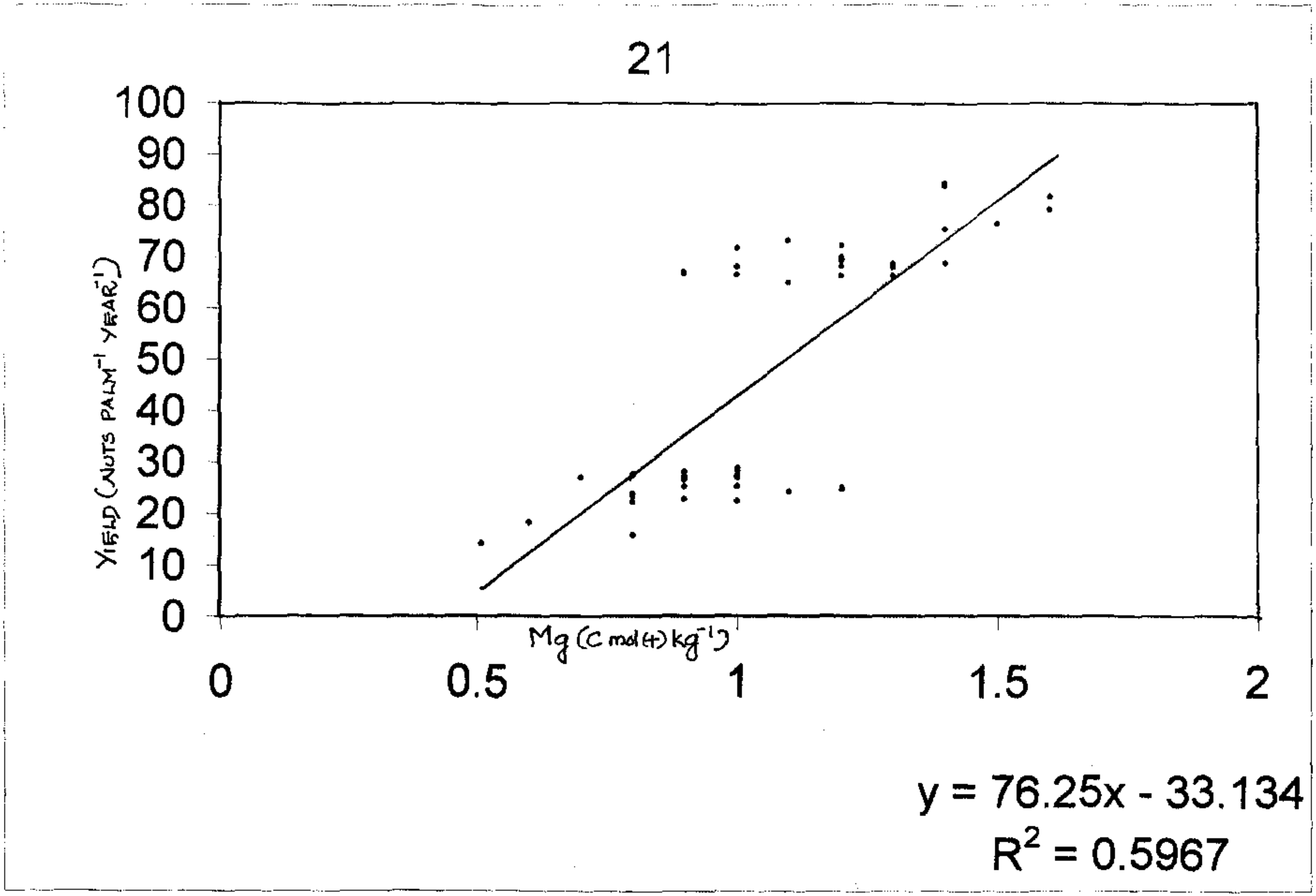


Fig. 4. RESPONSE OF Mg TO YIELD (post monsoon surface samples)

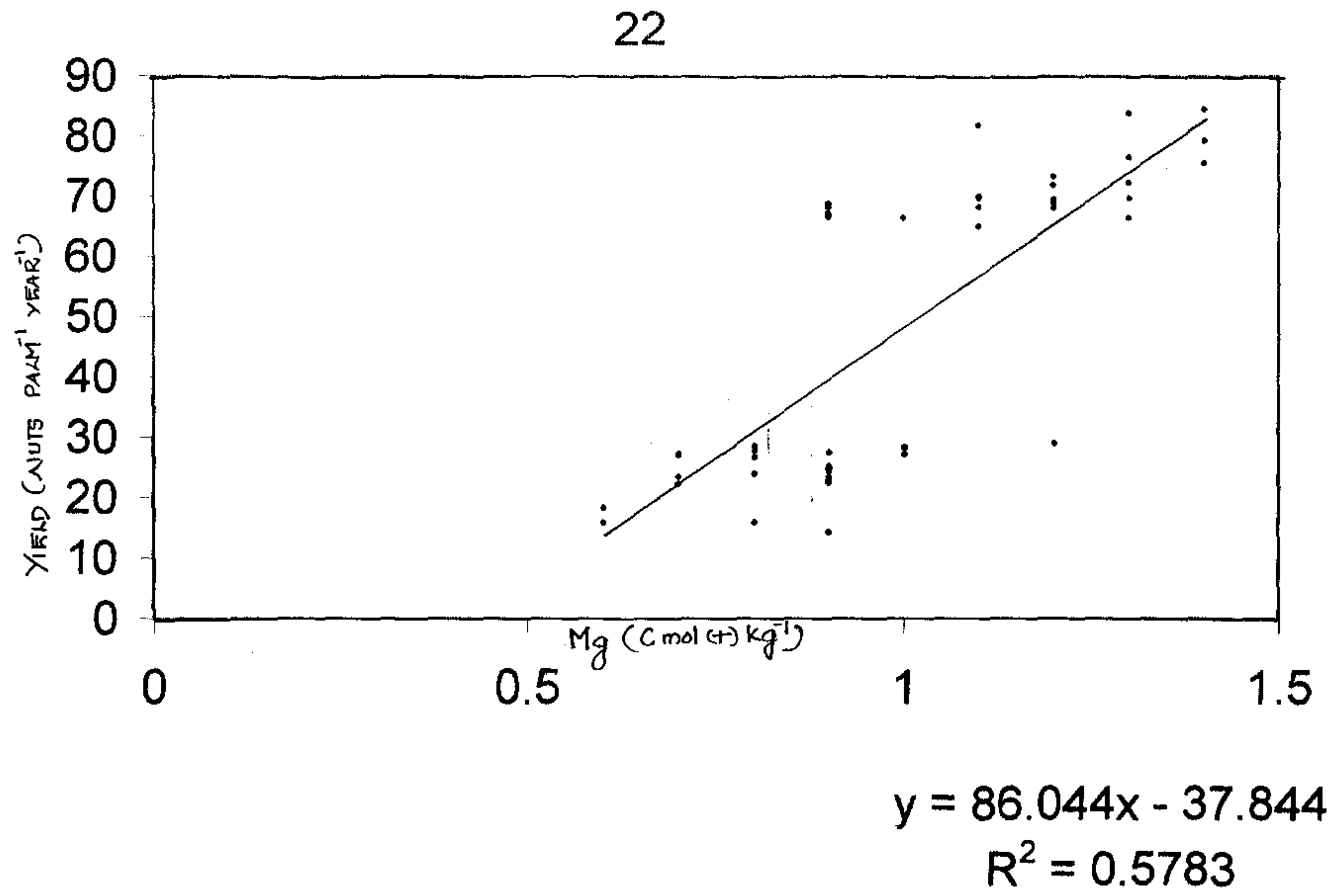


Fig. 5. Response of Mg to yield (Post monsoon subsurface samples)

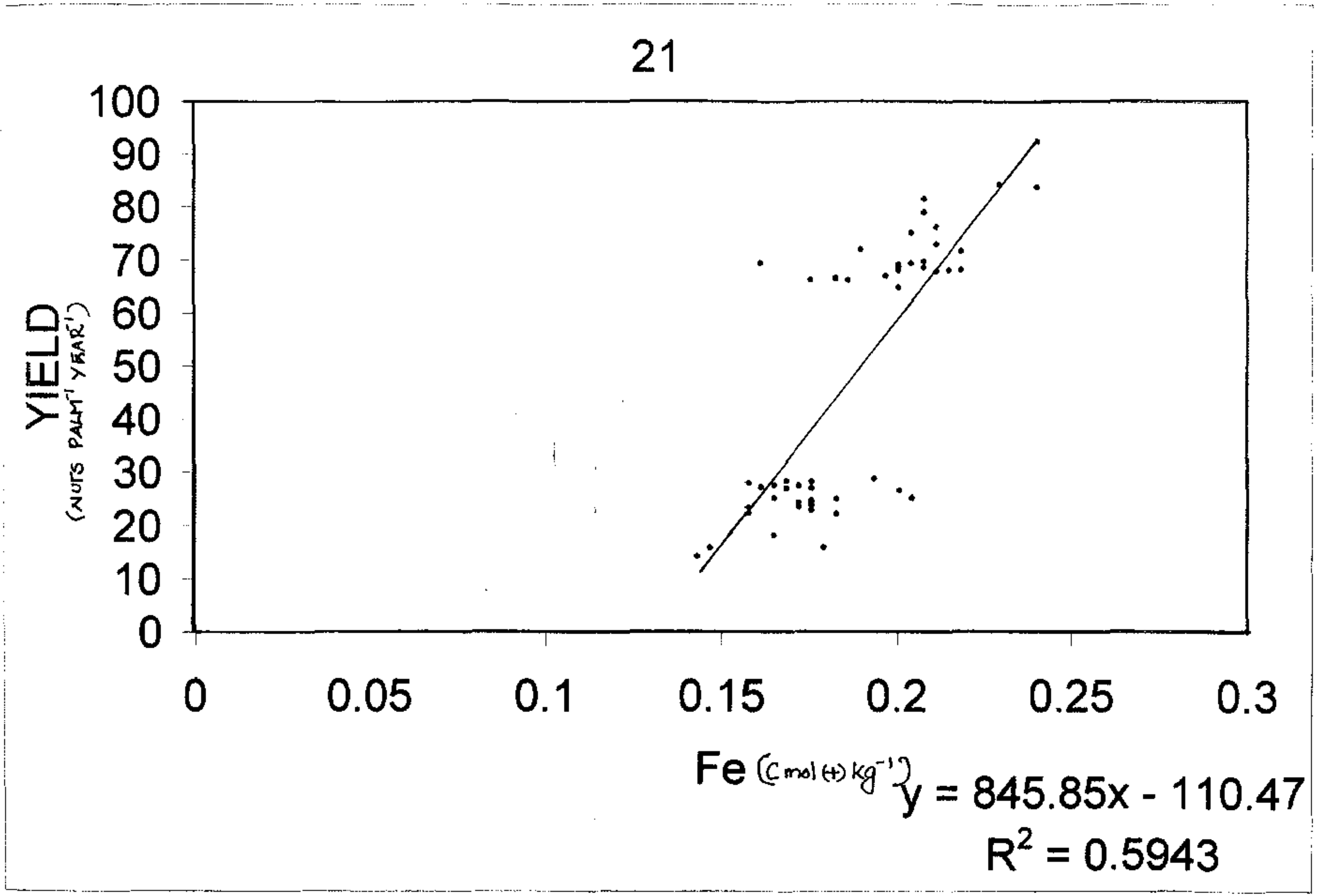


Fig. 6. RESPONSE OF Fe to YIELD (Post monsoon surface samples)

solution pool which in turn is the source for plant uptake. Similar results in the case of exchangeable cations were reported by Seena *et al.* (2001).

5.5 NET IONIC EQUILIBRIUM RATIOS OF EXCHANGEABLE CATIONS

The NIE ratio of exchangeable cations, computed following the ratio law (Schofield, 1947) ie., $K/[(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}]$ varied from 0.130 to 0.550 across the depths and seasons of sampling (Tables 27 to 34). However, this ratio or the ratio excluding Al, ie. $K/(Ca+Mg+Fe+Mn)^{1/2}$, as well as the similar ratios with monovalent Na ion in place of K, failed to give any direct relation with yield (Table 51). This might be due to the failure in obtaining significant relation either for exchangeable K or for exchangeable Na with yield. This would further shows that, K is not limiting in the rhizosphere samples of palms under the present study which in turn may be due to proper K fertilization.

5.6 IONIC CONCENTRATIONS IN SOIL SOLUTIONS

The data on soil solution (Tables 35 to 38) show that pH of soil solution was generally less than that of the corresponding soil. Further, pH has got significant negative correlation with yield in the pre monsoon season (Table 60), which means that there is an yield decrease with increase in pH of the soil solution. The significant positive correlations of available micronutrients and significant negative correlation of available Ca with yield (Table 49) might be viewed in this context. Thus the increase in pH naturally increases the Ca concentration in solution, which in turn adversely affects the solubility of micronutrients. Thus it is clear that, it is the pH of soil solution that reflects the ion absorption environment of plant roots than that of the soil pH. The electrical conductivity of the soil solution was in general more than that of the soil (Tables 35 to 38) and a negative correlation with yield was observed. (Table 60).

The ionic concentration in soil solution (Tables 35 to 38) does not show any specific trend. This is as expected, as the soil solution concentration depends much on the soil moisture status. Moreover, soil solution is highly dynamic and the concentration of each ion is subjected to high variability. Still there is a significant positive correlation for the concentration of Fe with yield, which would support the influence of Ca as well as the pH on solubility of Fe (Table 60).

5.7 NET IONIC EQUILIBRIUM RATIOS IN SOIL SOLUTION

The net ionic equilibrium ratio [K/(Ca+Mg+Fe+Mn)½] appears to have no significant correlation with yield (Table 61). This might be due to the lack of correlation of individual ionic concentrations in soil solution.

5.8 NUTRIENT CONCENTRATIONS IN INDEX LEAF SAMPLES

Table 41 shows the nutrient ion concentrations in the index leaf. Though a high variation in the content of N, 0.63 to 3.1 per cent in high yielding group at the pre monsoon season, 0.95 to 3.15 per cent in pre monsoon low yield group, 0.95 to 3.15 per cent in post monsoon high yield group and 0.84 to 3.36 per cent in post monsoon low yield group), (Tables 41 to 44) was observed in leaf, it failed to give any significant correlation with yield. This is depicted from the data as a palm having 3.36 per cent of N concentration in leaf yields only 27.6 nuts yr^{-1} while a palm with N content of 0.63 per cent yields 66.4 nuts yr^{-1}.

Phosphorus content was found very low in the samples ranging from 0.01 to 0.16% (Tables 41 to 44). However, the P content also doesn't appear to influence the yield.

The content of K was found to have direct influence on yield, in the pre monsoon season. This is substantiated by the significant positive correlation of leaf K content with yield (r = 0.345*) (Table 56). The plant content of other cations did not have any significant effect on yield. Indirakutty and Pandalai (1968) observed a general increase in foliar nutrient content of K_2O with increase in yield of coconut palm.

5.9 NET IONIC EQUILIBRIUM RATIOS IN INDEX LEAF SAMPLES

The NIE ratio with respect to K varied from 1.47 to 5.71 among the samples taken from different yield groups in different seasons (Table 45 to 48). This ratio as well as the ratio excluding Al [ie., K/(Ca+Mg+Fe+Mn)½)] was found to have significant positive correlation with yield.

The data on correlation of different ions and their NIE ratios with respect to K, in soil, solution and in plant clearly unravel the following fact. In the case of exchangeable ions in soil, except exchangeable K all were significantly correlated with yield but the

NIE ratios were not. On the other hand in leaf samples, no cations, other than K shows any significant correlation with yield, while K has, and hence the ratios involving K were significantly correlated with yield. Further in soil solution neither K nor other cations, except Fe showed any significant correlation with yield. There the ratio also failed to correlate significantly with yield. This would indicate that, the influence of ratios on yield is K dependent. The ratios further revealed that the NIE ratios in soil as well as in solution are below unity while that in the leaf samples were above one, which means that the concentrations of exchangeable and solution K are less when compared to the total concentration of other ions included in the ratio, while the situation is just reverse in the leaf samples. Thus, K is absorbed by the plant against a concentration gradient, or it is absorbed actively.

The strong dominance of monovalent K^+ ion in the NIE ratio is also evident from its highly significant correlation coefficients with the respective ratios (Tables 52 to 55).

The NIE ratios with respect to Na (Tables 52 to 55), clearly indicates that it is less than one in soil and solution as well as in more than 50% of the leaf samples. A comparison of the data on K and Na with respect to other cations, points to the fact that though both K and Na are monovalent alkali metals, their nature of movement and absorption are of different nature and hence the equilibrium concentrations are entirely different. Thus as discussed earlier, K required in large amount by the plant is selectively absorbed; but there is no ample evidence for such a behaviour in the case of Na.

5.10 CORRELATION OF NUTRIENT ELEMENTS AND NIE IN SOIL, SOLUTION AND IN PLANT

Table 64 shows the correlation matrix of exchangeable, soil solution and leaf contents of nutrients, in the pre monsoon season. All exchangeable ions except Na, shows significant correlation with CEC. This is as expected since the effective CEC is computed by summation of all the cations.

Exchangeable K shows significant correlations with exchangeable Mn, NIE ratios in soil, soil solution concentrations of K, Ca, Mg, NIE ratio in solution, plant K and NIE ratio in plant (r = 0.375*, 0.929** and 0.931**, 0.522**, 0.535**, 0.334*, 0.372**, 0.434**, 0.427** and 0.420** respectively). Negative significant correlation exists between exchangeable K and plant Mn and Zn (r = -0.385** and –0.327*). The data indicates that exchangeable K status directly controls the soil solution concentration of K as well as the plant K content. As discussed earlier, exchangeable K has a significant dominance in deciding the NIE ratio in soil, solution as well as in plant. Wahid *et al.* (1974) reported a positive correlation of both soil and leaf K contents with yield indicating the role of K in increasing the yield of coconut.

The negative significant correlation of exchangeable K with plant Mn and Zn reveals the antagonistic positive effect of soil K status on restricting the absorption of Mn and Zn by the plant.

Exchangeable Mg showing positive significant correlation with exchangeable Fe and Mn as well as soil solution concentration of Fe and also with the NIE ratios in plant, reveals that the status of Fe and Mn in exchangeable sites and the solubility of Fe are directly related with exchangeable Mg. This might be the influence of Mg being a divalent ion in saturating exchange sites.

Another interesting result is the significant correlation of solution K (Table 64) with NIE ratio in solution as well with the respective ratios in plant (r = 0.887**, 0.292*, 0.287* respectively). This would further emphasize the role of exchangeable K, in controlling the solution concentration of K, which in turn controls the NIE ratio in solution, as well as the ratios in plant. The negative relation of solution K with plant Mn (-0.385**) and Zn (-0.367(*) supports the earlier finding of antagonistic effect of K in the absorption of Mn and Zn. Solution concentrations of Ca and Mg are also antagonistically and significantly related with plant Mn content (r = -0.382** and –0.321*).

Potassium, Ca and Mg are the cations in plant having significant correlation with the total cation concentration in leaf (r = 0.381**, 0.709**, 0.564** respectively). Plant K is positively and significantly correlated with the NIE ratios in plant (r = 0.936** and 0.919**) whereas Ca and Mg are significantly and negatively correlated with the NIE ratios in plant (r = -0.375** and –0.303* respectively), which might be either due to selective and active absorption of monovalent of K from the soil or due to restricted passive entry of Ca and Mg to the leaf. This is further substantiated by the positive correlation of exchangeable Ca and Mg with the NIE in plant (r = 0.187 and 0.281* respectively).

The NIE ratio between the exchangeable ions, between the ions in solution and between the ions in index leaves are mutually, significantly and positively correlated among themselves. This would lead to an important conclusion that, though the ions are absorbed by the palms by different mechanisms, there exists a constancy in their relative proportion in the entire soil – plant system, which means that the fate of an ion starting from the exchangeable surface via. soil solution through the plant roots to the plant top is following a chain of equilibrium reactions as explained by Fried and Broeshart (1967), as given below:

$$\text{Exchangeable Ions} \rightleftharpoons \text{Ions in solution} \rightleftharpoons \text{Ions in plant}$$

The concentration of these ions, in any of the above phases, in the soil – plant system could be more accurately expressed as their relative concentration levels (Beckett, 1964 and Tinker, 1964). This is because the concentration of any ion in any of these phases in equilibrium will be governed by the concentration of other ions in the system on an equivalent basis, which is the basis for ratio law proposed by Schofield (1947). Thus on relative concentration basis, following ratio law, the above equilibrium of soil-plant system can be expressed as,

$$\underbrace{\left[\frac{K}{(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}}\right]}_{\textit{exchangeable}} \rightleftharpoons \underbrace{\left[\frac{K}{(Ca+Mg+Fe+Mn)^{1/2}}\right]}_{\textit{solution}}$$

$$\rightleftharpoons \underbrace{\left[\frac{K}{(Ca+Mg+Fe+Mn)^{1/2} + (Al)^{1/3}}\right]}_{\textit{plant}}$$

It is also important in this context to note that this net ionic equilibrium ratio was significantly correlated with yield only in the case of the ions in the leaf, which means that though the ratios are in equilibrium, the absorption of individual ions from the soil to the plant depends not only on their relative concentration, but the mode of absorption which is controlled by root characters, which in turn depends on the species and varieties. Thus absorption is a genetically controlled character.

It is clear from the above discussion, that neither soil test values of individual ions alone nor the corresponding values in plant alone can give a clear picture of optimum nutrient requirements for the plant. The relative concentration both in soil and plant can give better information.

As in the present study, K in soil and solution becomes dominant due to the sufficient concentration to maintain an optimum equilibrium ratio with respect to other ions, to the tune of controlling the absorption of toxic native elements like Mn. Thus, due to its selective absorption, K accounts for the highest concentration in plant. The soil NIE ratio $[K/(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ in the present study ranges from about 0.2 to 0.5, while that in plant ranges between 1.66 and 4.86 (Table 45), with a mean value of 3.41.

However, the contributions of different soil, solution and plant parameters to yield derived by regression analysis gives the following conclusions:

5.11 CONTRIBUTION OF VARIOUS SOIL, SOLUTION AND PLANT FACTORS TO YIELD

Considering the contributing soil factors alone, in the pre monsoon surface samples, about 65 per cent variation in yield could be predicted by exchangeable Mg and exchangeable Fe. (Equation 4.1). With respect to the pre monsoon subsurface samples, 57 per cent of yield variation could be explained by, exchangeable Mg and exchangeable Mn (Equation 4.5).

In the post monsoon season, considering the surface soil samples almost 74 per cent variation in yield could be attributed to exchangeable Mg, exchangeable Fe, and exchangeable Mn (equation 4.9), while in the subsurface samples of post monsoon season the variation to the tune of 66 per cent was due to exchangeable Mg and exchangeable Fe (equation 4.12). Thus irrespective of depth of sampling and season of sampling, the main contributing soil parameters to yield are exchangeable Mg, exchangeable Mn and exchangeable Fe.

However, in the pre monsoon surface samples, when soil solution concentration of Fe is included along with equation 4.1 the percentage variation that could be predicted improved to 72 per cent (equation 4.16).

In the post monsoon surface samples, when exchangeable Ca and solution Fe concentration were added (equation 4.20) the prediction value improved to 81 per cent from 73 per cent in equation 4.10.

Further the path coefficients as given in table 67 and depicted in fig.7 indicating the direct and indirect effects of soil, solution and plant parameters and NIE ratio in plant, on yield enlighten the following facts. The direct effect of exchangeable Ca is positive and significant, but its effect through CEC is negative and significant which means that under low cation exchange capacity environment like in the present study (CEC 4.20 to 8.00) (Table 19 to 26), exchangeable Ca, being the dominant exchangeable ion, becomes a dominant factor.

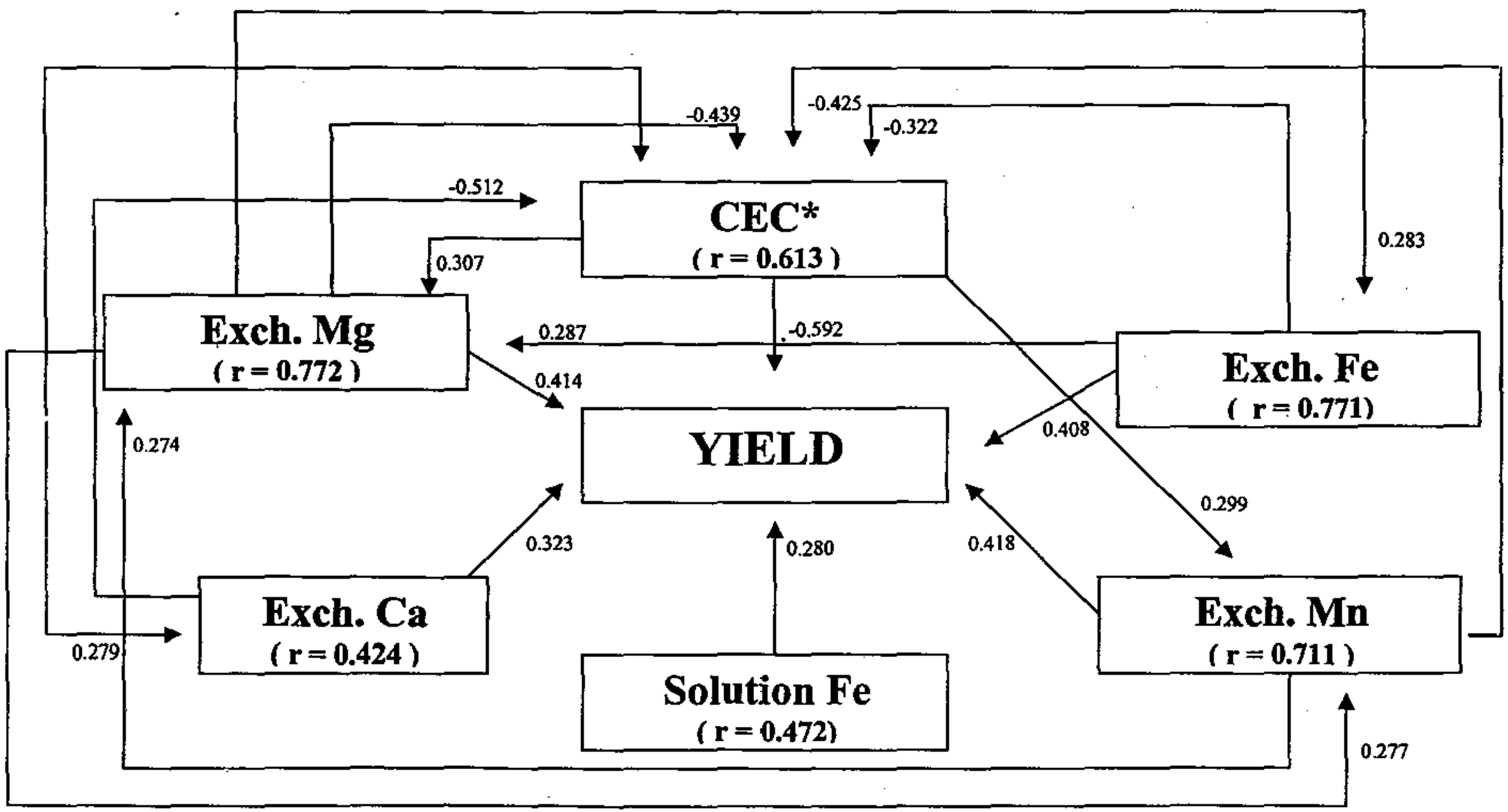
It would also give an indication that under the acidic environment where Al replaces the basic cations like Ca and Mg becoming the dominant ion, might adversely affect the yield. This is supported by the significant positive direct effect of Mg and its significant negative indirect effect through CEC on yield ($r = 0.4140^{**}$ and -0.4387^{**} respectively). The direct effect of exchangeable Fe and its indirect effect through exchangeable Mg are positive and significant. This might be possibly due to the restricted solubility of Fe due to dominance of Ca and Mg. Exchangeable Mn shows the same trend as that of Fe ie., its direct effect as well as indirect effect through Mg are positive and significant. But its indirect effect through CEC is negative and significant.

The direct effect of CEC is negative and significant. However, its indirect effect through exchangeable Ca, exchangeable Mg and exchangeable Mn are significant and positive and these indirect effects together masks the direct negative effect of CEC.

All these negative significant effects of CEC, both direct and indirect points to the fact that either exchangeable K and / or Al might have contributed antagonistically with exchangeable Ca, exchangeable Mg, exchangeable Fe and exchangeable Mn which becomes so significant in the soils under the present investigation, having low cation exchange capacity.

Thus the present study points to the fact that there exists an equilibrium between the relative intensities of K in soil-plant system. Potassium is actively and selectively absorbed by the palms, which influenced the yield positively. Exchangeable K governs

Fig.7 Schematic diagram representing the contribution of various factors to yield



* The direct effect of CEC and indirect effect of various factors through CEC are negative

the activity of K in soil solution. Further, K along with Mg seems to restrict the solubility of Fe and Zn, which in turn influenced the yield. Though not significant exchangeable Al seems to have negative influence on yield, through its dominance on exchange complex under a low CEC lateritic environment. The possible toxic effect of Fe,Mn and Al also might have been restricted by the selective uptake of K.

Summary and Conclusion

6. SUMMARY AND CONCLUSION

The present study was conducted in selected palms, from both high yielding and low yielding populations from the coconut garden of the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University. The objectives of the investigations were to analyse the soil-plant system and the levels and interactions of nutrient ions thereby finding out the contributing factors to yield. For this purpose, index leaf samples were collected during pre and post monsoon seasons from 25 palms each from high yielding and low yielding groups. Soil samples were collected from the basins of these palms during the same seasons at 30 cm (surface samples) and 60 cm (subsurface samples) depths. Soil solution at saturation point were extracted from the surface samples by centrifugation technique. These samples – leaf, soil and solution were analysed for estimation of different nutrient ions. An attempt was made to critically analyse the soil – solution – plant nutrient equilibrium and its relation to yield. The salient results of the present study along with the conclusions are given below:

- The yield of palms varied from 14.4 to 84.4 nuts palm^{-1} year^{-1}.

- No specific relation of yield with pH, EC or organic carbon content of any of the samples was observed.

- The $BaCl_2$ exchangeable ions and the CEC derived from summing up of these exchangeable ions reflected their effect on yield. In the case of available ions extracted by neutral normal ammonium acetate solution, such an effect was not observed.

- In the case of available micronutrients (0.1M HCl extractable) Fe, Mn and Zn were significantly correlated with yield while this relation of Cu was significant only in the case of subsurface samples.

- Among the ionic concentration in soil solutions, only Fe was positively and significantly correlated with yield in both the seasons.

- Of the different elemental composition in plant, only K was found to have significant positive correlation with yield, that too in the pre monsoon season.

- The NIE with respect to K, $[K/(Ca+Mg+Fe+Mn)^{1/2} +(Al)^{1/3}]$ in plant was found to have significant direct relation with yield in pre monsoon season.
- Exchangeable K had got a significant dominance in deciding the NIE ratio in soil, soil solution and in index leaves. Exchangeable K controlled the solution concentration of K which in turn controlled the NIE ratio in solution as well as the ratios in plant.
- Exchangeable K status directly controlled the plant K content and plant K was positively and significantly correlated with the NIE ratios in plant, and these ratios were significantly and positively correlated with yield.
- The negative significant correlation of exchangeable K with plant Mn and Zn revealed the antagonistic effect of soil K status in restricting the absorption of Mn and Zn by plants.
- Soil solution concentrations of Ca and Mg were antagonistically and significantly related with plant Mn content.
- The NIE ratios between the exchangeable ions, the ions in soil solution and the ions in index leaf samples were mutually, positively and significantly correlated among themselves. This leads to the conclusion that though the ions are absorbed by the palms by different mechanisms, there exists a constancy in their relative proportion in the entire soil-plant system which follows ratio law.
- The movement of an ion starting from the exchangeable surface via., soil solution through the plant roots to the plant top could be well explained by the direct significant positive correlation among these ratios in soil, solution and in plant.
- Pótassium, Ca and Mg were the dominant cations in plant deciding the total cation concentration in the index leaves.
- Soil solution pH was generally lower than the corresponding soil pH and the solution EC was higher than the corresponding soil EC. It is the pH of the soil solution that reflects the ion absorption environment of plant roots than the soil pH.

- The concentrations of exchangeable and solution K were less when compared to the total concentration of other ions included in the ratio (Fe, Mn, Ca, Mg and Al), while in leaf samples, it was vice versa.

- Soil test values of the individual ions alone or the plant content of individual ions alone can't give a clear picture of optimum nutrient requirements for the plant. The relative concentration of ions both in soil and in plant can give better information with respect to yield through nutrient interactions.

- In the pre monsoon surface samples, 72 per cent variation in yield could be predicted by exchangeable Mg, exchangeable Fe and soil solution concentration of Fe.

- The direct effect of exchangeable Ca on yield was positive and significant, but its effect through CEC was negative and significant ie., under low CEC environment like that in the present study, exchangeable Ca becomes a dominant factor which was reflected on yield.

References

REFERENCES

Anilkumar, K.S. and Wahid, P.A. 1989. Impact of longterm inorganic fertilization on soil nutrient availability and nutrition of coconut palm. *Oleagineux* 44(6): 281-286

Anon. 1980. Report of the division of soils 1979. *Ceylone Cocon. Q.* 31: 15-35

Barnhisel, R. and Bertsch, P.M. 1982. Aluminium. *Methods of Analysis Part II Chemical and Microbiological properties.* 2nd edition (eds. Page, A.L., Miller, R.H. and Keeneg, D.R.) American Society of Agronomy, Madison, USA, pp. 275- 296

Beckett, P.H.T. 1964. Studies on soil potassium I. confirmation of the ratio law: Measurement of potassium potential. *J. Soil Sci.* 15: 1-8

*Bopaiah, M.G. and Cecil, S.R. 1991. Effect of NPK on coconuts grown in coral soils of Lakshadweep. International Symposium on Coconut Research and Development-II, 26-29 November, 1991. Central Plantation Crops Research Institute, Kasargod, India, *Abstract*: 22

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* 59: 39-45

*Breure, C.J. and Rosenquist, E.A. 1976. An oil palm fertilizer experiment in volcanic soils in Papua New Guinea. *International Developments in Oilpalms* (eds. D.A. Earp. and W. New all). Incorporated Society of Planters, Kuala Lumpur

Breure, C.J. and Rosenquist., E.A. 1977. An oil palm fertilizer experiment in volcanic soils in Papua New Guinea. *Oleagineux* 32(7): 301-310

Cecil, S.R. 1984. Effect of N, P, K, Ca and Mg on leaf nutrient content and yield of young coconut. *Proceedings of PLACROSYM-VI, December 16-20, 1984* (eds.Sethuraj, M.R., Potty, S.N.). Rubber Research Institute of India, Kottayam, pp.331-351

Cecil, S.R. 1988. Ca and Mg nutrition of coconut palm. *Proceedings of National Symposium on Coconut Breeding and Management, November 23-26, 1988* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Kerala Agricultural University, Trichur, pp.219-224

Clarson, D., Damodaran, C. and Mohamed, G.L. 1986. Response of magnesium and borax on coconut yield. *Indian Cocon. J.* 16(11): 6-7

*Cordova, A.S. 1965. The soil chemical status and foliar nutrient composition of coconut trees in some Philippine coconut plantation. B.S. Thesis, UPLB. College, Laguna, p.82

Devi, C.B.K. and Pandalai, K.M. 1968. Note on the leaf composition in relation to poor negative characters and yield in the coconut palm. *Indian J. agric. Sci.* 38: 876-880

Devi, C.B.K, Wahid, P.A., Pillai, N.G. and Sankarannarayanan, M.P. 1975. Effect of NPK fertilizers on tree element nutrition of three coconut genotypes. *J. Plantation Crops* 3: 11-13

Eschbach, J.M. and Manciot, R. 1981. Micronutrients in coconut nutrition. *Oleagineux* 36: 291-304

*Felizardo, B.C. 1965. Bimonthly variation of some of the macro-elements in the leaves of differently fertilized coconut. M.S. thesis, UPCA College, Laguna, p.112

Fremond, Y., Ziller, R. and Lamothe, M.N. 1966. *The coconut palm.* International Potash Institute, Berne, Switzerland p.86

Fried, M.. and Broeshart, H. 1967. *The Soil Plant System in Relation to Inorganic Nutrition.* Academic Press, New York, p.358

Gopi, C.S. 1981. Foliar diagnosis in coconut (*Cocos nucifera* Linn.) in relation to nitrogen, phosphorus and potassium. M.Sc. (Ag.) thesis, Kerala Agricultural University, Trichur, India, p.132

*Goswami, N.N., Bapat, S.R., Leelavathi, C.R. and Singh, R.N. 1975. Potassium deficiency in rice and wheat in relation to soil type and fertility status. *Indian Soil Science Society - Bulletin 10, Potassium in Soil, Crops and Fertilizers.* Indian Soil Science Society, New Delhi, pp.186-194

Government of Kerala, 2001. *Data Book on Agriculture 2000.* Agriculture division, State Planning Board. Trivandrum, p.346

*Grimme, H. 1975. Soil factors of potassium availability. *Indian Soil Science Society - Bulletin 10, Potassium in Soil, Crops and Fertilizers.* Indian Soil Science Society, New Delhi, pp.144-163

Hendershot, W.H. and Duquette, M. 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. *Soil Sci. Soc. Am. J.* 50: 605-608

Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.* John Murry Ltd., London, U.K. p.528

Hsu, P.H. 1963. Effect of initial pH, phosphate and silicate on the determination of aluminium with aluminon. *Soil Sci.* 96: 230-238

Indirakutty, K.N. and Pandalai, K.M. 1968. Influence of soil types in foliar nutrient composition in coconut. *Indian J. agric. Sci.* 38: 492-496

*Jack, H.A. 1965. Potassium content of soils and leaves of coconut in high and low yielding areas in two Tagalog provinces. B.S. thesis, UPCA College, Laguna, p.102

Jackson, M.L. 1958. *Soil Chemical Analysis.* Indian Reprint 1967. Prentice Hall of India Private Ltd., New Delhi, p.498

*Jankovic, M. and Nemeth, K. 1974. The effects of K dynamics on yield. *Potash Research and Agricultural Production.* International Potash Institute, Berne, Switzerland, pp.75-84

Jayman, T.C.Z. and Sivasubramaniam, S. 1974. The use of ascorbic acid to eliminate interferance from iron in the aluminon method for determining aluminium in plant and soil extracts. *Analyst* 99: 296-301

Jose, A.I., Krishnakumar, N. and Gopi, C.S. 1991. Yield prediction in coconut based on foliar nutrient levels. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of the National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Trichur, pp.212-218

Joseph, P.A., Nambiar, P.K.N., Nair, C.S. and Nayar, N.K. 1993. Common salt benefits coconut trees in laterite soils. *Indian Cocon. J.* 24(2): 2-3

Kanapathy, K. 1977. Leaf analysis and fertilizer requirements of coconuts. *Malay. agric. J.* 50: 322-339

Khasawneh, F.E. 1971. Solution ion activity and plant growth. *Soil Sci. Soc. Am. Proc.* 35: 426-436

*Koenig, H.A. and Johnson, G.R. 1942. Colorimetric determination of phosphorus in biological materials. *Ind. Eng. Chem.* (Anal.), 14: 155-156

Krishnakumar, N. 1983. Yield prediction in coconut based on foliar NPK values. M.Sc. (Ag.) thesis, Kerala Agricultural University, Trichur, India, p.129

Loganathan, P. and Atputharajah, P.P. 1986. Effect of fertilizers on yield and leaf nutrient concentrations in coconut. *J. trop. Agric.* 63: 143-148

*Magat, S.S. 1975. Soil and leaf analysis in relation to coconut yield. *Proceedings of National Symposium on Coconut Research, November 17-19, 1975.* Taclob City, pp.120-136

Magat, S.S., Margate, R.K. and Habane J.A. 1988. Effects of increasing rates of sodium chloride (common salt) fertilization on coconut palms grown under an inland soil (Tropudaits) of Mindanao, Philippines. *Oleagineux* 43(1): 13-19

*Mahilum, B.C. 1976. Present status, problems and research needs is nutrition of coconut and oil palm. *Proceedings of the Second Natural Agricultural Resource System Research Congress, Workshop Session No.7, November 10-13, 1976.* Los Banos, Laguna, pp.4-6

Manciot, R., Ollagnier, M. and Ochs, R. 1979. Mineral nutrition and fertilization of the coconut around the world (Part I). *Oleagineux* 34(1): 499-515

Manciot, R., Ollagnier, M. and Ochs, R. 1980. Mineral nutrition and fertilization of the coconut around the world (Part III), *Oleagineux* 35: 13-27

Manikandan, P., Joshi, O.P., Khan, H.H. and Bidappa, C.C. 1986. Available micronutrient status of the coconut tract of Kasargod district, Kerala. *J. Plantation Crops* 14(2): 134-138

Margete, R.K., Maget, S.S., Alfanja, L.M. and Habane, J.A. 1979. A long term KCl fertilization study of bearing coconuts in an inland-upland area of Davao (Phillippines). *Oleagineux* 34(5): 235-242

Mathew, C. 1977. The importance of magnesium in coconut nutrition. *Indian Cocon. J.* 8(8): 3-4

Mathewkutty, T.I. 1994. Applicability of Diagnosis and Recommendation Integrated System (DRIS) in coconut palm (*Cocos nucifera* L.). Ph.D. thesis, Kerala Agricultural University, Trichur, India, p.115

Mohanachandran, S. 1990. Relationship between leaf nutrients and yield in coconut. M.Sc. (Ag.). thesis, Kerala Agricultural University, Trichur, India, p.108

Moris, N. 1991. Cation composition in soil solution of two Malaysian soils. *J.nat. Rubb. Res.* 6(3): 206-214

Muliyar, M.K. and Nelliat, E.V. 1971. Response of coconut palms (*Cocos nucifera* Linn.) to N, P and K fertilizer application on the west-coast of India. *Oleagineax* 26(11): 687-691

Nair, G.C.B., Vijayan, M., Saraswathy, P., Thampi, A.P., Pillari, K.J., Nair, V.R., Nair, G.M., Pushpangadan, K., Sukumaran, K.M., Pillai, G.R., and Koshy, E.P. 1988. Response of coconut palm to N, P and K from seedling stage. *Proceedings of the National Symposium on Coconut Breeding and Management, November 23-26, 1988* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Kerala Agricultural University, Trichur, pp.225-228

Narayanankutty, M.C. 1983. Biochemical characterization of coconut palms in relation to yield. M.Sc. (Ag.) thesis, Kerala Agricultural University, Trichur, India, p.88

*Nartea, R.N. 1969. Potassium supplying capacity of some coconut soils in the Philippines. M.S. thesis, UPLB College, Laguna, p.104

Nazrul – Islam, A.K.M. 1986. Effect of interaction of calcium and manganese on the growth and nutrition of *Epilobium hirsutum* L. *Soil Sci. Pl. Nutr.* 32: 161-168

Nelliat, V. 1973. NPK nutrition of coconut palm - A review. *J. Plantation Crops*-I *(Suppl.)*: 70-80

Ollagnier, M. Ochs, R. and Marton, G. 1970. Manuring of oilpalm in the world. *Fertilite* 36: 33-63

Ollagnier, M. and Ochs, R. 1971. Chlorine a new essential element in oil palm nutrition. *Oleagineux* 26(1): 1-15

Pillai, N.G. and Davis, T.A. 1963. Exhaust of micro nutrients by the coconut palms. A preliminary study. *Indian Cocon. J.* 16: 81-87

Potty, N.N. 1978. Studies on the variation in response of T x D coconut palms of different yield groups to fertilization. *Indian Cocon. J.* 8(12): 4-5

Prabhakumari, P. 1992. Secondary and micronutrient – Interactions in continuously fertilized coconut palms. Ph.D. thesis, Kerala Agricultural University, Trichur, India, p.148

Pratheep, M.S. 1998. Nutrient status of the soil and plant as influenced by spacing and continued manuring in coconut (*C. nucifera L.*). M.Sc. (Ag.) thesis, Kerala Agricultural University, Trichur, India, p.102

-Pushpangadan, K. 1985. Effect of continuous NPK fertilization on the growth and yield behaviour of coconut with special reference to potassium nutrition and its inter relation with other mineral nutrients. Ph.D. thesis, Kerala Agricultural University, Trichur, India, p.198

*Querijero, G.B. 1972. Soil and leaf analysis - a tool in crop production. *Proceedings of Silver Anniversary Celibrations of Soil Science Society of Philippines, September 27-29, 1971.* Manila, Philippines, pp. 26-40

Reddy, S.D.V. and Upadyay, A.K. 1998. Nutritional requirement of coconut palm. *Indian Cocon. J.* 28(12): 2-3

Rehm, G. 1994. Soil cation ratios for crop production. http//: *daneel. mes. umn. edu. Minnesota extension service*, University of Minnesota

*Schofield, R.K. 1947. A ratio law governing the equilibrium of cations in the soil solution. *Proceedings of Eleventh International Congress on Pure and Applied Chemistry*, pp.257-261

Seena, E., Sureshkumar, P. and Saifudeen, N. 2001. An innovative soil test method with Net Ionic Equilibrium (NIE) – a study with respect to potassium availability in laterite soils. *Proceedings of Thirteenth Kerala Science Congress, January, 29-31, 2001*(ed. Das, M.R.). Kerala Institute of Local Administration, Thrissur, pp.423-426

Sims, J.T. and Johnson, G.V. 1991. Micronutrient soil tests. *Micronutrients in Agricultre.* (eds. Mortredt, J.J., Cox, F.R., Shuman, L. and Weleh, R.S.) Second edition, Soil Science Society of America, Madison, USA, pp. 427-472

*Singh, M. and Mishra, M.K. 1991. Response of coconut to potassium application. International Symposium on Coconut Research and Development II, 26-29 November, 1991. Central Plantation Crops Research Insitute, Kasargod, India. *Abstract*: 26

Smith, R.W. 1969. Fertilizer response by coconuts on two contrasting Jamaican soils. *Exp. Agric.* 5: 133-145

Snedecor, G.W. and Cochran, W.G. 1967. *Statistical Methods.* Sixth edition. The Lower State University Press. Ames. Iowa, USA, p.593

*Sparks, D.L. 1980. Chemistry of soil potassium in Atlantic coastal plain soils - A review. *Common. Soil Sci. Plant. Anal.* 11: 435-449

Sreelatha, A.K. 1993. Potassium dynamics in Neyyattinkara soil series under coconut cultivation. M.Sc. (Ag.) thesis, Kerala Agricultural University, Trichur, India, p.102

Thomas, K.M. 1973. Nutrient composition of coconut leaves and its relationships to nut yields in Tanzania. *East Afr. agric. J.* 39(20): 170-175

Thomas, K.M. and Nandra, S.S. 1974. Nutrient composition of coconut leaves and relation to nut yields in Tanzania. *Tor. J.* 39: 170-175

Tinker, P.B. 1964. Studies on soil potassium IV. Equlibrium cation activity ratio and responses to potassium fertilizer of Nigerian oil palms. *J. Soil Sci.*15: 35-41

Vijayaraghavan, H., Manmohanlal, S. and Ramanathan, T. 1988. Effect of Zn on yield of coconut. *Indian Cocon. J.* 18(11): 3-7

Wahid, P.A., Devi, C.B.K. and Pillai, N.G. 1974. Inter relationship among root CEC, yield and mono and divalent cations in coconut. *Pl. Soil* 40: 607-617

Wahid, P.A., Devi, C.B.K., Philip, G. and Pillai, N.G. 1975. Effects of discontinuation of fertilizer application on the NPK nutrition of coconut palm. *J. Plantation Crops* 3: 58-60

Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci.* 31: 29-38

Warrier, S.M. and Piggot, C.J. 1972. Rehabilitation of oil palms by corrective manuring based on leaf analysis. *Advances in Oil Palm Cultivation* (eds. R.L. Wastic and D.A. Earp). Incorporated Society of Planters, Kuala Lumpur, pp.103-112

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Proc. Soil Sci. Soc. Am.* 29: 677-678

Ziller, R. and Prevot, P. 1962. Foliar diagnosis: A mehtod of studying mineral nutrition – Its application to the coconut palm. *Indian Cocon. J.* 15: 156-159

* Originals not seen

AVAILABILITY INDICES FOR STRESSED NUTRIENTS FOR COCONUT (*Cocos nucifera* L.) IN AN ULTISOL

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study was conducted with an objective to analyse the soil-plant system , the levels and interactions of nutrient ions in soil, soil solution and plant thereby finding out the contributing factors to yield. The importance of the term relative intensity lies in the fact that the contribution of mineral elements to growth and yield of plants depend much on the relative amount of one element with respect to the others rather than the absolute content of individual elements. To study the ionic interactions and to unravel the role of Net Ionic Equilibrium based on Ratio Law on soil plant system, a sample of fifty phenotypically identical palms varying in yield from 14.4 to 84.4 nuts palm^{-1} year^{-1} grown under an Ultisol were selected.

Index leaf samples were collected during pre and post monsoon seasons from 25 palms each from high yielding and low yielding groups. Soil samples were also collected from the basins of these palms during the same seasons at 30 cm (surface) and 60 cm (subsurface) depths. Soil solutions at saturation point were extracted from the surface samples by centrifugation technique. These leaf, soil and solution samples were analysed for different nutrient ions, and the NIE ratios in these three phases were worked out with respect to K and Na.

The soil samples were acidic in nature and the variation in rhizosphere pH must have definitely influenced the solubility as well as absorption of different nutrient ions.

In the case of available nutrients, the micro nutrients showed significant direct relation with yield both for high and low yielding populations. This might be due to their restricted availability due to aerobic oxidised condition where Fe and Mn might have been precipitated and got into unavailable forms.

The $BaCl_2$ exchangeable ions and the CEC derived from summing up of these exchangeable ions influenced yield directly.

Exchangeable K had got a significant dominance in deciding the NIE ratio in soil, solution and in index leaves. Exchangeable K controlled the soil solution concentration of K which in turn controlled the NIE ratio in solution and the ratios in plant.

Exchangeable K directly controlled the plant K content and plant K was positively and significantly correlated with the NIE ratios in plant and these ratios were positively and significantly correlated with yield.

The negative significant correlation of exchangeable K with plant Mn and Zn revealed the antagonistic effect of exchangeable K in restricting the absorption of Mn and Zn by plants.

Among the ionic concentrations in soil solution, Fe was positively and significantly correlated with yield in both the seasons. Soil solution concentrations of Ca and Mg were antagonistically and significantly related with plant Mn content. Potassium content and the NIE ratio in index leaves were found to have a significant direct relation with yield in the pre-monsoon season. Potassium, Ca and Mg were the dominant cations in plant deciding the total cation concentration in index leaves.

The NIE ratios between the exchangeable ions, the ions in soil solution and the ions in index leaf samples were mutually, positively and significantly correlated among themselves. This lead to the conclusion that there exists a constancy in the relative proportion of nutrient ions in the entire soil-plant system which followed Ratio Law.

The study lead to the conclusion that the soil test values of the individual ions alone or the plant content of individual ions alone can't give a clear picture of optimum nutrient requirements for the plant. The relative concentration of K in soil through the concentration in soil solution was found to govern the relative concentration in plant which in turn influenced the yield.