POTASSIUM DYNAMICS IN NEYYATTINKARA SOIL SERIES UNDER COCONUT CULTIVATION

By

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THESIS
SUMBITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE
MASTER OF SCIENCE IN AGRICULTURE
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI — THIRUVANANTHAPURAM
1993

DECLARATION

I hereby declare that this thesis entitled **POTASSIUM DYNAMICS IN NEYYATTINKARA SOIL SERIES UNDER COCONUT CULTIVATION,** 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, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **POTASSIUM DYNAMICS IN NEYYATTINKARA SOIL SERIES UNDER COCONUT CULTIVATION** is a record of research work done independently by **Miss. SREELATHA, A. K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ACKNOWLEDGEMENT

I wish to place on record my unboundful indebtedness and deep sense of gratitude to Dr. N. Saifudeen, Associate Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani for his sustained and inspiring guidance, untiring interest, constructive criticism, constant encouragement, ever willing help and kind treatment extended throughout the course of this investigation and preparation of this thesis.

I express my sincere gratitude to Dr. P. Padmaja, Professor and Head, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani for her helpful suggestions and critical scrutiny of the manuscript.

I am extremely thankful to Dr. K. Pushpangadan, Professor of Agronomy, Coconut Research station, Balaramapuram for his valuable help rendered during the course of the study and for critically reviewing the manuscript.

I earnestly express my sincere thanks to Dr. P. Saraswathy, Head, Department of Agricultural statistics, College of Agriculture, Vellayani for her valuable advice and help in statistical analysis of data and subsequent interpretations.

I am grateful to Sri. C.E. Ajith Kumar, Junior Programmer, Department of Agricultural statistics, College of Agriculture, Vellayani for rendering his help in computer analysis of the experimental data.

I owe immense gratitude to Mr. Suraj, Senior Research Fellow, Regional Research Laboratory, Pappanamcode, Thiruvananthapuram for the sincere help rendered during the chemical analysis and mineralogical analysis of the samples.

I am grateful to Chitra. V.G., Suneetha. S, Santhi Kamath, Leena Chandran, Sudha, Roshni, Geetha, Moossa. P.P., Sanjeev. V, Louis Joseph, Noushad. A and all junior P.G. students of the Department of Soil Science and Agricultural Chemistry for their assistance given during the course of this work.

I sincerely thank Kerala Agricultural University for awarding a fellowship for the post graduate programme.

I am infinitely indebted to my beloved mother and sister for their inspiration and encouragement throughout the course of this work.

I gratefully acknowledge M/s. Athira Computers, Devaswom Lane Kesavadasapuram, Thirivananthapuram for neatly printing this thesis.

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VELLAYANI
27-12-93

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INTRODUCTION

Coconut palm is a versatile plant which is valued in the national economy as an important source of vegetable oil and fibre. India is the third largest coconut producing country in the world contributing 18 per cent of the global nut production. The annual production is 6404 million nuts from an area of 1.23 million hectares. Among the fruit and plantation crops, coconut is the Kalpavriksha, the tree which provides food, drink and shelter for human beings, as well as raw materials for industries.

The coconut palm removes large quantities of nutrients from the soil continuously. Coconut palm is a heavy consumer of potassium. Of the primary nutrients, potassium has been found to be the most important for coconut. The beneficial effect of potassium as reflected in the increase in yield and quality of coconut has been reported by several workers. Coconut is generally cultivated in acid laterite soils with low available potassium content. These soils are dominated with Kaolinitic clay mineral which have no interlattice binding sites for potassium and hence available K content is low. The potassium reserves of soils dominant in kaolinite cannot be sufficient for crop production and hence continuous K fertilization may be recommended for coconut. For potassium fertilizers, India depends entirely on import using scarce foreign exchange. Thus it is very essential to maximise the efficient use of these fertilizers and save foreign exchange.

Understanding the dynamics of potassium in the soil will help to optimise the use of K fertilizer which is very much essential for maximising coconut yield.

A long term fertilizer experiment in coconut with 3 levels of N,P and K in 27 combinations applied continuously over 25 years, possibly gives the ideal experimental material to investigate the dynamics of potassium. Thus, samples were derived from such an experiment in Coconut Research Station, Balaramapuram. The study under report was carried out with the following objectives.

1. Investigations on the variation in availability of soil potassium to growing coconut palms after 25 years of continuous nutrition, through the Quantity/Intensity concept.

2. Development of mathematical models to explain yield response of coconut in relation to potassium availability and soil properties.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Potassium is one of the most studied elements among the plant nutrients. Potassium nutrition assumes significance in crop production usually when higher yields are targetted. However, in the tropics where coconut palms are grown, the soils are generally deficient or low in potassium, thus limiting coconut yields. Research output on the behaviour of potassium in the soils with respect to chemical fractions and their interactions, in the context of coconut nutrition are scanned and the review is presented here under.

2.1. Potassium Nutrition of coconut palms

Potassium is a dominant nutrient for coconut. Reports from all over the coconut growing countries suggest that the yield increases obtained by potassium application were outstanding. One of the limiting factors in the economic production of coconut, in most of the coconut growing areas of the world is the deficiency of K, which is mainly attributed to the low K supplying capacity of coconut growing soils.

2.1.1. Benefits from potassium nutrition of Coconut

Potassium application has favourably influenced coconut production as well as soil health under various cropping situations. Potassium was found to increase 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 (Uexkull, 1971; Muliyar and Nelliat, 1971;

Pushpangadan, 1985; Nair *et al.*, 1988; Singh and Mishra, 1991 and Prabhakumari, 1992).,

Improvement in leaf angle, albumin content of nuts etc. are also reported (Uexkull, 1971; Margate *et al.*, 1979).

Potassium could reduce the pre-bearing age of palms and foliar yellowing (Muliyar and Nelliat, 1971; Thampan, 1984).

2.1.2. Functions of potassium

Potassium is important in metabolism of coconut palms by exerting its influence through drought resistance function by accelerating the movements of stomata (Uexkull, 1972; Manciot *et al.*, 1979; Ollagnier, 1985). It is also important in activating enzymes, in the transport of metabolites and in cell division (Manicot *et al.*, 1979).

The major functions of potassium in plants can be summarised as follows. (Beringer, 1978; FAO, 1984, Mengel and Kirkby, 1987).

(i) activation of a number of enzymes (about 60) involved in photosynthesis, metabolism of carbohydrates and proteins.

(ii) assistance in the synthesis and translocation of carbohydrates, protein synthesis, membrane permeability, stomatal regulation and water utilisation.

(iii) improved utilization of N.

(iv) improved utilisation of sunlight during cool and cloudy periods.

(v) enhanced resistance to withstand pests, diseases and stresses such as those created by drought, salinity, sodicity etc.

(vi) improved crop quality in addition to yield increase.

2.1.3. Deficiency symptoms of potassium in coconut

A tall coconut is likely to suffer from potassium deficiency if the potassium content of leaflets in frond 14 falls below 0.8% of dry matter (Manciot *et al.*, 1979).

Nelliat (1978) reported K deficiency symptoms of coconuts as chlorosis, leaf scorch, poor crowns and short fronds.

Uexkull (1983) has also described the deficiency symptoms of potassium in coconut. Visual symptoms first appear on older leaves. Early symptoms are oily looking, olive yellow spots on both sides of midrib. As the deficiency intensifies the spots grow larger, turn yellower and develop rusty spots in the centre. Leaf tips and margins show symptoms of yellowing that is soon followed by necrosis. Fronds are often droopy, especially when N is in excess. Nuts from K-deficient trees are small both in size and number.

Ouvrier (1985) reported that the K deficiency symptom is characterised by yellowing, particularly of the centre of the crown, possibly as a consequence of enzymatic disfunction in leaves and drying of the leaves at the base because of inadequate water supply.

production and marketing costs dictate its efficient use. Understanding the relationships of K with cultural and management practices is essential for increasing the potassium use efficiency.

Ziller and Prevot (1962) observed that by the addition of 1.5 kg muriate of potash resulted in a 62% increase in the yield of nuts. Magat *et al.* (1975) reported that by the application of 1.66 kg KCl, resulted in 25 more nuts/tree/year than control. Sumbak (1976) estimated an annual yield increment of 0.3 and 0.38 ton/ha by the application of 1 and 2 kg KCl per palm respectively.

Reducing potential K^+ loss through leaching is especially critical on coarse textured, well drained soils in areas of high rainfall. These soils usually have low amounts of available K^+ and require large amounts of added K^+ for maximum yields, making efficiency of use particularly important. Liming acid soils can reduce the leaching of exchangeable K^+. Liming improves K^+ retention by increasing the effective cation exchange capacity of acid soils and by increasing the amount of Ca^{2+} on the exchange complex. Substitution of K^+ for Ca^{2+} is easier than for H^+ or Al^{3+}, which dominate the exchange sites of acid soils (Munson and Nelson, 1963).

Ollagnier (1985) reported that drought reduces the efficiency of K fertilizers in coconut. Responses in irrigated trials of coconut were much smaller than was to be expected in view of K levels since, irrigation cancels the water deficits, the effect of K is nil because there is no longer any need to regulate stomatal opening. In non-irrigated soils, KCl exerts its influence through drought resistance function and is involved in stomatal closure.

2.1.4. Potassium uptake and partitioning by coconut palms

Coconut palm is a heavy consumer of K. Pillai and Davis (1963) reported that in sandy soils of average fertility, typical of the West Coast of India, coconut palms removed annually 34.2 kg K_2O per acre of 70 trees.

Potassium uptake by the different components of high yielding hybrid coconuts (138 bearing trees yielding 6700 kg of copra ha^{-1}) were, Spikelet - 14 kg K/ha, stalk - 7.0 kg K/ha, husk - 116.1kg K/ha, Shell - 9.0 kg K/ha, albumin - 47.0 kg K/ha, and the total is 193.1 kg K/ha. Annual uptake of the whole stand including trunks and fronds was 249 kgk/ha (Ouvrier and Ochs, 1978).

Mature, more than ten year old, coconut palms yielding 1.8 tons of copra removed about 90 to 130 kg of K ha^{-1} $year^{-1}$ (Uexkull, 1985).

Potassium distribution in the coconut palms is typically, 63% in the nuts, 12 % in peduncles, 12 % in leaves +stipules, 3% in spathes and 9% in the stem. Potassium uptake requirement for an yield of 1000 nuts was reported to be 10.7 kg K_2O (Thampan, 1984). Rao (1989) reported that 1 ha of coconut garden (70 palms) having yield of 40 nuts/palm/year removed 28.4 kg K/year.

2.1.5. Potasium use efficiency by coconut palms

Potassium is used by the coconut palm in greater quantities than any other nutrient. Since many soils cannot provide adequate K for sustained high yields, fertilizer K must be used. Needs for supplemented K and rising

Leaching loss of potassium occurs in soils with a poor exchange capacity. Therefore splitting of potassic fertilizers help in increasing the potassium use efficiency by coconut palms. Muliyar and Nelliat (1971) reported that split application of recommended dose of potassium fertilizers increased the nut yield by 8.4% and copra yield by 11.7 % compared to single annual application. Quencez and de Taffin (1981) reported the advantage of split application of potassium fertilizers as better development of coconut palms and precocity of flowering.

An increase in K fertilizer is accompanied by an increase in husk K contents (Ouvrier, 1984; Ouvrier, 1987). The husk is responsible for most of mineral exports from coconut garden, 67% in the case of K (IRHO, 1992). Dehusking in the field itself enabled a considerable reduction in exports to be made. Without dehusking in the field, it is seen that tall coconuts export more K than the hybrids/ton of copra produced (Ouvrier, 1987).

Ramanandan and Muliyar (1978) reported that in coconut soils, cultivation alone increased the available K_2O content in the soil in comparison with uncultivated plots.

2.2. Potassium dynamics in soil

2.2.1. Forms of potassium in soil

The forms of potassium in soil in order of their availability are soluble, exchangeable,non exchangeable and mineral K (Sparks and Huang, 1985). Dynamic equilibrial reactions exists between these forms of soil K. A knowledge of different forms of potassium will assist in assessing the long term nutrient availability.

Shanmuganathan and Loganathan (1976) reported that the water soluble K, exchangeable K, difficulty exchangeable K and total K ranged from 20 to 30 ppm, 4 to 128 ppm, 1 to 230 ppm and 350 to 244000 ppm respectively in coconut growing soils of Srilanka covering 20 soil series. Water soluble K, exchangeable K and difficulty exchangeable K contents were positively related to pH, CEC and total exchangeable bases. The water soluble and exchangeable K significantly decreased with depth. Among total, difficulty exchangeable, exchangeable and water soluble K, there was positive correlation with two adjacent forms.

Continuous cropping and continuous addition of potassium with and without other nutrients will affect the different forms of soil potassium and their interactions.

Prabhakumari (1981) observed that in red and lateritic soils of Trivandrum district, the water soluble K ranged between 1.53 and 7.16 meL^{-1}, exchangeable K ranged between 9 and 32 cg kg^{-1}, HNO_3- K range from 10 to 58 cg kg^{-1} and the total K ranged from 1200 to 1290 ppm.

Khan *et al.* (1982) reported that the water soluble K in red sandy loam soil at Pachalloor, Kasargod and Beypore in Kerala were 1.92, 0.95 and 0.79 meL^{-1} respectively. 1N NH_4OAC-K in these soils were 26,32 and 26 ppm respectively and Boiling HNO_3 - K in the soils were 25, 70 and 46 ppm respectively.

Continuous application of K fertilizers to coconut in a red sandy loam soil for 15 years resulted in an increase of available K from 36.4 ppm to 50.9 ppm. Available K decreased with depth and was negatively correlated with pH (Khan *et al.*, 1982).

In sandy and sandy loam soils of India under two long term experiments after 10 and 9 cycles of crop rotation (maize-wheat and maize-wheat-fodder cowpea), non exchangeable K decreased in all plots and exchangeable K was higher in plots receiving K fertilizers (Ganeshamurthy and Biswas, 1985).

Dhillon *et al* (1985) reported that in benchmark soils of North-West India water soluble K, exchangeable K, available K, HNO_3-K and non exchangeable K ranged from 0.004 to 0.244 me $100g^{-1}$, 0.045 to 0.52 me $100^{-1}g$, 0.058 to 0.564 me $100g^{-1}$, 1.19 to 6.4 me $100g^{-1}$ and 1.11 to 6.2 me $100g^{-1}$ respectively. On an average the water soluble K, exchangeable K, available K and boiling 1N HNO_3 - K constituted 0.06, 0.34, 0.40 and 7.75 % of total K.

In 102 soils from continental U.S. and Peurto Rico representing 10 soil orders, Sharpley (1989) reported that water soluble K was related to exchangeable K content ($r^2 = 0.86$ to 0.96) and the exchangeable K was related to HNO_3 extractable K ($r^2 = 0.81$ to 0.83).

Valsaji (1989) reported that the water soluble K, exchangeable K, available K, HNO_3 - K and non exchangeable K of the Neyyattinkara sandy loam soil in the coconut basins ranged from 0.102 to 1.023 me l^{-1} (mean 0.554

me l^{-1}), 1.0 to 13.4 cg kg^{-1} (mean 5.44 cg kg^{-1}), 1.6 to 16.8 cg kg^{-1} (mean 7.61 cg kg^{-1}), 3.2 to 30.4 cg kg^{-1} (mean 11.8 cg kg^{-1}) and 0.8 to 16.00 cg kg^{-1} (mean 4.19 cg kg^{-1}) respectively.

Premakumar (1989) reported that in a long term fertilizer trial on coconut in a red sandy loam soil the water soluble, exchangeable and non exchangeable K, at a distance of 180 cm from the bole of the palm and at a depth of 30-60 cm, varied from 9.3 to 73.8 ppm, 29.8 to 123.6 ppm and 211 to 373.6 ppm respectively.

In a long term fertilizer experiment with maize and wheat in a paleustalf, the water soluble K, exchangeable K, non exchangeable K and total K ranged from 9.86 to 28.56 ppm, 63 to 189 ppm, 611 to 1071 ppm, 2045 to 2864 ppm respectively and all the forms of K correlated significantly and positively with each other (Lal, *et al*, 1990).

Devi *et al* (1990) studied the distribution of various forms of K in two soil series of South Kerala (Vellayani and Neyyattinkara). In Vellayani series water soluble, exchangeable, fixed, lattice, total and available K ranged from 5.2 to 18.9, 10.8 to 72, 22 to 91, 61.8 to 437, 115 to 513 and 18.8 to 82.5 ppm respectively. In Neyyattinkara series, the corresponding values were 2.8 to 26.8, 18.5 to 89.9, 20 to 90, 136 to 432, 186 to 591 and 21.3 to 100 ppm respectively. Water soluble K was significantly and positively correlated to exchangeable and available K. The different forms of K decreased with increasing depth.

Subba Rao and Sekhon (1990) reported that in six soil series from tropical India, significant positive relationships were observed between exchangeable K and water soluble K.

Kher and Minhas (1991) studied the forms of potassium in an alfisol with continuous manuring and cropping with wheat. The water soluble, exchangeable, non exchangeable, HCl soluble and total K ranged from 6.7 to 8.2, 65 to 133, 61 to 693, 211 to 2914 ppm and 1.75 to 2.45 per cent respectively.

Subba Rao and Sekhon (1991) reported that the effect of pH on water soluble and exchangeable K and their relationship was not conspicuous in soils with appreciable amount of organic carbon and when the pH was greater than 5.5, the influence of pH on available K status was negligible.

Mukhopadhyay *et al.* (1992) reported that in five micaceous soils of Punjab growing maize, oats, bajra, jowar and berseem in an exhaustive manner, the available, fixed and total K ranged from 0.012 to 0.024, 2.359 to 5.226 and 12.3 to 18.0 g kg^{-1}.

Sutar *et al.* (1992) reported that in lateritic soils of Phondaghat soil series in South Konkan (Maharastra), water soluble, exchangeable, non-exchageable, lattice and total K ranged from 0.6 to 30.0, 13.9 to 231.0, 76.4 to 373.4, 2975 to 5625 and 3250 to 6250 ppm respectively.

In mollisols of Nainital Tarai Singh *et al.*, (1993) reported that total K, water soluble K, exchangeable K and non exchangeable K varied from

1.58 to 3.00%, 6.6 to 99, 53.85 to 216.2, 533 to 1023 mg kg^{-1} respectively. The exchangeable K was highly correlated with available (r=0.948**), non exchangeable (r = 0.743^{**}) and total K (r = 0.567^{**}). Water soluble and exchangeable K contributed 35.1 and 80 per cent towards available K.

Joseph (1993) reported that in Trivandrum series water soluble, available, exchangeable, nitric acid and non exchangeable K ranged from 0.17 to 0.86 meq l^{-1} (mean 0.47 me l^{-1}), 2.93 to 21.77 cg kg^{-1} (mean 8.39 cg kg^{-1}), 2.82 to 20.1 cg kg^{-1} (mean 7.93 cg kg^{-1}) 5.73 to 22.46 cg kg^{-1} (mean 11.81 cg kg^{-1}) and 0.01 to 11.46 cg kg^{-1} (mean 3.42 cg kg^{-1}) respectively. In Kazhakkuttom series water soluble K, available K, exchangeable K, nitric acid K and non exchangeable K varied from 0.19 to 0.76 meq L^{-1} (mean 0.34 meq L^{-1}), 1.59 to 13.23 cg kg^{-1} (mean 4.69 cg kg^{-1}), 1.38 to 12.99 cg kg^{-1} (mean 4.35 cg kg^{-1}), 5.69 to 18.43 cg kg^{-1} (mean 10.18 cg kg^{-1}) and 0.45 to 10.22 cg kg^{-1} (mean 5.49 cg kg^{-1}) respectively. In Kottoor series water soluble K, available K, exchangeable K, Nitric acid K and non exchangeable K ranged from 0.40 to 0.97 meq L^{-1} (mean 0.58 meq L^{-1}), 11.27 to 26.14 cg kg^{-1} (mean 15.9 cg kg^{-1}); 8.08 to 25.39 cg kg^{-1} (mean 15.34 cg kg^{-1}); 16.22 to 48.46 cg kg^{-1} (mean 31.13 cg kg^{-1}) and 1.69 to 33.44 cg kg^{-1} (mean 15.19 cg kg^{-1}) respectively. The total K contents of Trivandrum, Kazhakkuttom and Kottoor series were 428, 162 and 344 cg kg^{-1} respectively. Available K significantly and positively correlated to all other forms of K.

Prabhakumari (1993) reported that in lateritic/red loam soils of Kerala water soluble K, NH_4OAC- K and HNO_3- K varied from 60 to 220, 80 to 297 and 80 to 580 ppm respectively. NH_4OAC- K was significantly and positively correlated with water soluble K.

2.2.2. Potassium in soil solution and its interaction with other ions

Soil solution potassium is the form taken up directly by the plants and is subject to leaching (Sparks, 1980). The effectiveness of soil solution K for crop nourishment is influenced by the presence of other cations particularly Ca and Mg. In very acid soils Al^{3+} ions and in salt affected soils, Na+ ions have to be considered. Exchangeable Al^{3+} which is present in higher concentration in acid tropical soils than other cations, competes with K^+ for non specific sites of exchange (Sivasubramanian and Talibudeen, 1972).

Patil and Zande (1975) reported that high exchangeable Mg in black soils has been reported to suppress the K uptake of crops. Gerloff (1976) reported that Na has the capacity to substitute partially the metabolic functions of K.

Cation antagonism was brought about by lack of adequate K rather than a surplus of K. Low K^+ levels favoured uptake of Mg and Ca and resulted in lower plant yields than higher K levels (Mengel *et al*, 1976).

Potassium application even at lowest rate, induced Mg deficiency in the absence of Mg fertilizer, shown by the appearance of chlorosis in coconut (Coomans, 1977).

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.

Potassium plays an important role in the efficient utilisation of N. The large quantity of N used in intensive cropping encourage crop uptake of N and K and in turn heavy depletion of soil K. So NK interaction assumes special significance. Significant NK interactionsin coconut have been reported by Murti, (1972); and Khan and Bavappa, (1986). In the absence of K, the response of N was very poor, resulting in poor yield. In the presence of K significant increase in yield was seen with N application.

Fallavier and Olivin (1988) reported that in 4 tropical soils representative of oil palm growing zones, where K was applied, it mainly exchanged with Ca and Mg. Proportionately Mg is displaced more easily than Ca.

In a long term fertilizer experiment with coconut Anilkumar and Wahid, (1989) reported that application of high rates of $(NH_4)_2SO_4$ led to reduction in the exchangeable K due to the removal of K^+ ions from the exchange sites by NH_4^+ ions/H^+ ions generated in nitrification process.

Dhillon and Dhillon (1992) reported that at low K saturation illitic soils showed higher K selectivity than smectite and kaolinite. But at high K saturation, smectite soils maintained high K selectivity. It was found that in K^+ - NH_4+exchange system, all soils preferred NH_4^+ to K^+. Smectite preferred K^+ to Na^+ whereas kaolinitic and illitic soils preferred Na^+ to K^+. The relative escaping tendency of K from adsorbed to solution phase was greater in K^+ - Ca^+ system followed by K^+- NH_4^+ and K^+- Na^+ system.

Prabhakumari (1992) reported that the application of K fertilizers had a depressing effect on Fe, Ca and Mg contents and enhancing effects on Mn content of soil.

Bonneau *et al.* (1993) observed that in hybrid coconut, once the K fertilization is insufficient the Na content of the leaf increases in line with fall in K content. It was found that K fertilizer had a depressive effect on Mg content of leaf.

2.2.3. Potassium reserves in soil which influences long term availability

The bulk of total K in most soils is in mineral form. Mineral K is assumed to be only slowly available to plants (Jackson, 1964; Sparks and Huang, 1985).

Common soil K bearing minerals in order of availability to their K to plants are biotite, muscovite, orthoclase and microcline (Huang *et al*, 1968). It has generally been thought that only small amounts of feldspar and mica K are released over a growing season (Rasmussen, 1972). But Miricki *et al.* (1985), Sadusky and Sparks (1985) have found that a substantial amount of K is being released from sand fraction of Delaware soils.

Sparks (1980) reported that in soils high in total K which occur in micas and feldspars, the K forms are slowly released to solution and exchangeable form available to plant and lack of crop response to K fertilization in the soils was due to high indigenous levels of mineral and non exchangeable K. Non exchangeable K is different from mineral K in that it is not bonded covalently within crystal structure of soil mineral particles. Instead it is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculite and inter grade clay minerals (Rich, 1972; Sparks and

Huang, 1985). It is moderately to sparcely available to plants depending on various soil parameters. (Goulding and Talibudeen, 1979; Sparks and Huang, 1985).

Goulding and Talibudeen (1979) studied the kinetics of K release from soil from Nil and PK treatments of Saxmundham experiment. The Nil plot soil released 0.6 μeq kg^{-1}a^{-1} principally from slow release source. But this was sufficient only for a poor crop (1.6 t ha^{-1} wheat). They suggested that soil could release K at this rate for about 150 years based on its content of micaceous minerals. However for maximum yield some more K from 'fast release' souces and K in solution was needed.

Sekhon and Subha Rao (1980) reviewing the K availability in soils of Southern India, indicated that kaolinite is the dominant mineral group in laterite and most red soils.

Gopalaswamy and Iyer (1982) reported that in Vellayani series the easily weatherable minerals like feldspar and mica are low which speak of their inherent K fertility status.

In sandy soils of Nigeria, Igbo Unamba - oparah (1985) reported that due to high rainfall the soils were very low in K because of the leaching losses. In these highly weathered soils, the fine sand or fine sand plus silt separates were found to be the sources of potassium.

Ganeshamurthy and Biswas (1985) reported that in typic ustochrepts subjected to continuous cropping and fertilizer use, contribution of non-exchangeable K to crops was more in untreated plots than in those receiving fertilizer K. The K removed by the crops was significantly correlated to the non exchangeable K released from the soil.

In alluvial soils of Uttar Pradesh, clay had the highest concentration of K, compared with sand and silt fractions, but its contribution towards total soil K was low due to the low clay content. The non exchangeable K in these soils was found to be more in fine textured soils than coarse textured soils (Sharma and Mishra, 1986).

Maji and Chatterjee (1990 a) reported that the availability of K from non exchangeable sources was found to be higher from smectite dominated black soils compared to illitic red soils.

Sharma *et al* (1992) reported that contribution of mica K dominated over feldspar K in soils of Eastern India and these fractions were also the over all major contributors to total (taking both mica K and feldspar K) K of the soils. Boiling nitric acid (1 N) extractable K, a measure of reserve K in soil available to plants slowly over the cropping period, showed significant correlation with total K estimated by HF dissolution method.

2.2.4. The concept of activity ratios with respect to K

For a greater understanding of the fertility status of soils, it is important to study K - (Ca + Mg) equilibrium relationships. Schofield (1947) proposed that the ratio of the activity of cations such as K^+ and Ca^{2+} was defined by the relation $a^{K} / (a^{Ca})^{1/2}$, where 'a' is the ionic activity. The concept of quantity (Q) and intensity (I) was first applied to the mineral nutrient status of soils by Schofield (1955).

Schofield and Taylor (1955 a) further demonstrated the applicability of law to a Rothamsted soil for ion pairs H-Na, H- K, H-Ca and H-Al and to five other Rothamsted soils for the ion pair H - (Ca+Mg) (1955 b).

Beckett (1964 a), following a consideration of ratio law, opined that the intensity (I) of K in a soil at equilibrium with its soil solution could best be defined by the ratio $a^{K} / (a^{Ca} + a^{Mg})^{1/2}$ of the soil solution. This equilibrium activity ratio for K or AR^{K} (Becktt 1964 a, 1964 b) has often been used as a measure of K^{+} availability.

Below an AR^{K} of 0.001 (mol. $L^{-1})^{1/2}$, the bulk of K was adsorbed at interlattice positions, between AR^{K} values of 0.001 and 0.01 (mol $L^{-1})^{1/2}$ at edge position and 0.01 (mol $L^{-1})^{1/2}$ at planar positions. Also a small percentage of edge positions were being filled at AR^{K} values upto 0.1 (mol $L^{-1})^{1/2}$ (Sparks and Liebhardt, 1981).

The activity ratio may be expected to provide a satisfactory measure of ruling chemical potential of the labile K in a soil provided it is not used to compare soils of widely different Ca (and Mg) status or a few soils of which the activity ratio is not independent of the concentration of soil solution (Beckett, 1964 b).

Moss (1967) and Lee (1973) noted that a soil with a given compliment of exchangeable K^+,Ca^{2+} and Mg^{2+} gives rise to an activity ratio for potassium (AR^K) in the equilibrium soil solution that will be characteristic of that soil and independent of the soil to solution ratio and total electrolyte concentration. The ratio depends only on K^+ saturation and the strength of adsorption of cations.

Beckett (1964 b) noted that different soils showing the same value of AR^K may not possess the same capacity for maintaining AR^K while K^+ is removed by plant roots.

The activity ratio as a measure of the difference in chemical potential of two ionic species in the solution is theoretically independent of soil solution concentration if the ratio law is obeyed. In the use of activity ratio as a measure of potential Ca and Mg are treated as a single ionic species (Le Roux and Sumner, 1968 a).

The AR_e^K value is a measure of availability or intensity of labile K in soil. Beckett (1964 b) and Le Roux and Sumner (1968 b) found that K fertilization has increased the AR_e^K values.

Beckett's activity ratio would provide an adequate comparative measure of the potential of labile K and of the availability of K to plants in a soil, so long as its uptake is not limited by metabolic process or antagonisms at root surfaces. (Van Diest, 1978).

2.2.5 Quantity Intensity relationships in different soils

The relationship between exchangeable K (Q for quantity) and the activity of soil solution potassium (I for intensity) is important because of the major role of exchangeable K in replenishing the soil solution K removed by cropping or leaching. The Q/I studies is based on the fact that the distribution of K between exchange sites and soil solution is a function of the kind and concentration of complimentary ions. In Q/I curves, the ratio of $a^K / (a^{Ca} + a^{Mg})^{1/2}$ is related to change in exchangeable K to obtain the effect of quantity (exchangeable K) on intensity.

For Q/I relationships to be valid in indicating the amount of soil K available for plant uptake during the growing period, they must be unaffected by the amount of K normally released, fixed or added during the growing season. These assumptions have proved to be valid by a number of researchers (Mathews and Beckett, 1962; Beckett *et al.*, 1966, Beckett and Nafady, 1967). The Q/I relations were not greatly affected by K^+ removal. Nafady and Lamm (1973) showed that Q/I relations were unaffected by additions of K upto 1000 kg ha^{-1} and by fixation of upto 600 kg of K ha^{-1}.

For the construction of a typical Q/I curve, a soil is equilibrated with solutions containing a constant amount of $CaCl_2$ and increasing amounts of KCl (Beckett, 1964 a). The soil gains or loses K to achieve the characteristic AR^K of the soil or remains unchanged if its AR^K is the same as the equilibrating solution. The AR^K values are then plotted against the gain or loss of K to form the characteristic Q/I curve. From the Q/I plot several parameters are obtained to characterize the K status of soil. The AR^K when the Q factor or ΔK equals zero is a measure of degree of K^+ availability at equilibrium or ARe^K. The value of ΔK when $AR^K = 0$ is a measure of labile or exchangeable K in soils (ΔK^o). The slope of the linear portion of the curve gives the potential buffering capacity of K (PBC^K) and is proportional to the CEC of the soil. The number of specific sites for K (K_X) is the difference between the intercept of the curved and linear portions of Q/I plots at AR^K=0 (Beckett, 1964 b; Sanvalentin *et al.*, 1973; Sparks and Liebhardt, 1981). The AR^K values are computed from the measured concentration of Ca^{2+}, Mg^{2+} and K^+ corrected to their chemical activities by application of extended Debye - Huckel theory (Sparks and Liebhardt, 1981).

Various interpretations have been made on the parameters that can be derived from a Q/I plot. The linear portion of the curve has been ascribed to non specific sites for K (Beckett, 1964 b) while the curved portion has been attributed to specific sites with a high K affinity. (Beckett, 1964 b; Rich, 1964; Beckett and Nafady, 1967; Le Roux and Sumner, 1968 a). Repoted ranges in Q/I parameters of K are presented in the table on next page.

Patiram and Prasad (1981) observed that in soils of Meghalaya, the measure of Q/I parameters of K did not show any superiority over commonly used Neutral Normal NH_4OAC for predicting plant available K. The PBC^K values were correlated significantly with CEC and Ca + Mg content of the soils but did not represent the intensity of K availability.

Reported ranges in Q/I parameters of potassium

Sl. No.	Soil description	PBC^K	AR_e^k	ΔK_L	ΔK_o	ΔK_x	K potential	ΔG	Reference
1.	Soils of West Bengal (Oxic paleustalf and typic ochraqualf)	3.00 to 67.00 m mole 100 g^{-1} (mole litre^{-1})$^{1/2}$	0.0009 to 0.0108 (mole litre^{-1})$^{1/2}$	0.06 to 0.192 m mole 100 g^{-1}	0.023 to 0.192 m mole 100 g^{-1}	0.028 to 0.094 m mole 100 g^{-1}	N.R	2.67 to 4.14 cal mole^{-1}	Chandi and Sidhu (1983)
2.	Egyption soils	13 to 350 me 100g^{-1} (mole litre^{-1})$^{1/2}$	0.0011 to 0.0301 (mole litre^{-1})$^{1/2}$	0.09 to 2.490 me 100 g^{-1}	N.R	N.R	N.R.	N.R.	Sadik et al. (1986)
3.	Soil of North-West India (Ghabdan, Bhundri,Bains Awans Somana and Palampur series)	9.6 to 720 me 100 g^{-1} (mole litre^{-1})$^{1/2}$	0.4 to 14.75 x 10^{-3} (mole litre^{-1})$^{1/2}$	0.07 to 0.85 me 100 g^{-1}	0.06 to 0.36 me 100 g^{-1}	0.01 to 0.55 me 100 g^{-1}	N.R	2.54 to 4.71 K cal 100 g^{-1}	Dhillon *et al* (1986)
4.	Alluvial soils of Western Uttar Pradesh	3.45 to 66.67 C mole Kg^{-1} litre^{-1})$^{1/2}$	0.002 to 0.0059 (mole litre^{-1})$^{1/2}$	0.18 to 0.52 C mole Kg^{-1}	0.07 to 0.38 C mole Kg^{-1}	0.01 to 0.20 C mole Kg^{-1}	N.R	12.69 to 15.04 KJ mole^{-1}	Sharma and Mishra (1989)
5.	Typic ustochrept under long term fertilization in mango orchards	42.8 to 229.7 C mole kg^{-1} (mole litre^{-1})$^{1/2}$	1.5 to 2.5 m (mole litre^{-1})$^{1/2}$	0.05 to 0.2 C mole kg^{-1}	N.R	N.R	N.R	3.5 to 3.93 K cal mole^{-1}	Biswas et al. (1989)
6.	Neyyattinkara sandy loam soil under coconut cultivation	0.86 to 9.6 me 100 g^{-1} (mole litre^{-1})$^{1/2}$	0.011 to 0.026 (mole litre^{-1})$^{1/2}$	0.048 to 0.540 me 100 g^{-1}	0.013 to 0.120 me 100 g^{-1}	0.035 to 0.420 me 100 g^{-1}	N.R	1420.12 to 1929.58 cal mole^{-1}	Valsaji (1989)

Sl. No.	Soil description	PBC^K	AR_e^k	ΔK_L	ΔK_0	ΔK_X	K potential	ΔG	Reference
7.	Acid soils of Sikkim growing maize	15.72 to 65.22 C mole kg^{-1} (mole $litre^{-1})^{1/2}$	2.20 to 17.20 (mole $litre^{-1})^{1/2}$	0.12 to 0.98 C mole kg^{-1}	N.R	N.R	N.R	N.R	Patiram (1991)
8.	Dune and interdune soils of Rajasthan (Torripsamments)	22 to 223 me kg^{-1} (mole $litre^{-1})^{1/2}$	0.004 to 0.039 (mole $litre^{-1})^{1/2}$	1.3 to 7.7 me kg^{-1}	0.5 to 2.7 me kg^{-1}	1.2 to 7.4 me kg^{-1}	1.9 to 32.6 me kg^{-1} (mole $litre^{-1})^{1/2}$	1937 to 3236 cal e^{-1}	Dutta and Joshi (1991)
9.	Nedumangad series (Oxic Dystropept)	5.8 to 6.0 C mol kg^{-1} (mole $litre^{-1})^{1/2}$	6.0 to 7.5 x 10^{-3} (mole $litre^{-1})^{1/2}$	0.17 C mol kg^{-1}	N.R	N.R	N.R	N.R	Subba Rao *et al.* (1991)
10.	Alluvial soils fo Northern India (Haplusfalf and Ustochrept)	6.3 to 57.7 C mole kg^{-1}	2.0 to 5.0 x 10^{-3} (mole $litre^{-1})^{1/2}$	0.15 to 0.40 C mole kg^{-1}	N.R	N.R	N.R	N.R	Pal and Singh (1991)
11.	Salt affected soils of arid Rajasthan (Camborthids, Calciorthids and Salorthids)	62 to 72.5 me kg^{-1} (mole $litre^{-1})^{1/2}$	2 to 9 x 10^{-3} (mole $litre^{-1})^{1/2}$	1.1 to 6.0 me kg^{-1}	0.2 to 3.7 me kg^{-1}	0.6 to 2.5 me kg^{-1}	1.3 to 210 me kg^{-1} (mole $litre^{-1})^{1/2}$	2883 to 3296 cal e^{-1}	Dutta and Joshi (1992)

N.R. - Not Reported.

Parra and Torrent (1983) developed a procedure for determining Q/I relationships in a continuous manner using a K^+ selective ion electrode. The AR_e^K values calculated by continuous procedure were highly correlated ($r = 0.972$) with those determined with the usual Q/I method in a nearly 1:1 relationship.

Chatterjee *et al.* (1983) observed that PBC^K values were low in kaolinitic soils than illite dominated soils and intermediate in smectite dominated soils. The PBC^K measurement and equilibrium studies indicated that these were being influenced not only by the nature and quantity of clay minerals but also certain physico chemical factors.

Bandopadhyay *et al.* (1985) reported that in some coastal soils of Orissa and West Bengal the PBC^K and Gibb's free energy (ΔF) indicated that the soils had a high potassium supplying capacity. The clay content of the soil was correlated to PBC^K.

Mittal *et al.* (1987a) observed that Q/I relationship of soil determined by Beckett's method and its modification in which total electrolyte concentration was kept constant (25 me/litre) was found to be linear throughout in the modified method, but only so in upper part of the original method. They also found that Q/I parameters in the K desorption region suggested that in original method much less K was released in comparison to modified one and the excess K released, termed strongly bonded K, was absent in original method.

Lime application increased the PBC^K and labile K (ΔK) but decreased the activity ratio of K (AR^K) in some acid soils (Patiram and Rai, 1988).

Sharma and Mishra, (1989) reported that in texturally different alluvial soils of western Uttar Pradesh, K_L was positively correlated to exchangeable K and PBC^K was significantly related with fixed K, total K and mica K.

In 102 soils representing 10 soil orders from continental U.S. and Peurto Rico, Sharpley (1990) observed that the K buffer capacity was significantly greater for smectite soils than mixed and kaolinitic soils and was closely related to clay, CEC and K saturation.

Subba Rao and Sekhon (1990) observed that higher buffer capacity values were recorded in smectite dominant black soils, followed by illitic alluvial soils and lowest in Kaolinite dominated red and lateritic soils. The reverse was observed for AR_0^K. At constant K saturation AR_0^K was higher in kaolinitic than in other soils.

Al Kanani *et al.* (1991) reported that in calcareous soils, the Q/I plots were linear in contrast to curvilinear trends observed in non calcareous soils.

Dutta and Joshi (1992) observed that in salt affected soils of arid Rajasthan. PBC ^{K} was found to be positively related with H_2So_4 - K and negatively with water soluble K.

Lumbanraja and Evangelou (1992) investigated the influence of added NH_4 on K Quantity - Intensity relationships of three Kentucky soils. They reported that the Q/I plot components, K_L, AR_e^K and PBC^K were affected by added NH_4. The addition of NH_4 caused an increase in the quantity of labile K for all soils.

Deshmuk and Khera (1993) observed that the high amount of clay and organic carbon registered the lower value of AR_0^K and higher for LBC in an Ustochrept of Northern India. They also found that values of labile pool (K_L) were found to be more in heavy soils than in the light textured one. AR_0^K and K_L decreased with K depletion, but LBC^K increased. This indicated that the depletion of K was faster in these soils.

2.2.6. Relationship between crop uptake and Q/I parameters

Studies on the 'immediate' Q/I relations of labile K in soils indicate that this technique could be used profitably for quantitative prediction of the K status of soil throughout the growing season (Le Roux and Sumner, 1968 b). They found that the potassium application to Japanese millet lead to an increase in the pool of labile K. Q/I studies on soil samples taken after various periods of plant growth illustrated how the pool of labile K and ARe^K order decrease as increasing amount of K was taken up by plant. Depending on soil type, both the above parameters fall to a given minimum in soils being intensively cropped after which the pool serves as the vehicle by which K from inter lattice sites become available to plant.

Maida (1980) reported that in 27 soils from an NPK factorial experiment on tea, the value for change in free energy, ΔG ranged from -12 to -16 KJ mol^{-1} and the field observation showed that tea plants growing on soils having ΔG. Values less than -15 KJ mol^{-1} responded to K fertilizers. The investigation has indicated that heavily cropped soils are likely to show crop responses if the intensive cropping system does not include supplementation of K.

Sparks and Liebhardt (1981) investigated the effect of long term lime and K applications on Q/I relationship of a typic hapludult from Delaware coastal plain soil cropped to corn and soybean. They observed that AR_e^K decreased with profile depth due to the greater K fixation by specific sites for K. The parameter ΔK_0 which measures labile K became more negative with increased lime and K additions. The number of specifc sites (K_x) was found to increase with K fertilization. The PBC^K parameter increased with lime addition.

Q/I parameters of K in soil were found to be affected by long term intensive cropping system of wheat-bajra and application of N and P fertilizers without addition of K. AR_0^K value, an index of availability of K was drastically reduced in soils of N and P fertilized plots and the K adsorption was also more in such plots indicating greater need to satisfy larger K depletion (Patra and Khera, 1983).

Singh *et al.* (1984) studied the Q/I relationships of a sandy loam soil collected after 5 years of a fertilizer trial with pearl- millet-wheat rotation.

The Q/I isotherm for K in plots not receiving K fertilizer had a curved lower part and linear upper one, whereas for K treated soils these were almost linear throughout. The values of AR_0^K ranged from 4.6 to 11.6 x 10^{-3} $(m/l)^{1/2}$. The linear buffering capacity was higher for K treated plots than for untreated plots.

Biswas *et al.* (1986) studied the K supplying capacity of soils from mango orchards and showed that the relationship between exchangeable K (Q) and soil solution K (I) was more curvilinear towards the origin. The critical supply parameter value $(QI)^{1/2} / (K_1K_2)^{1/4}$ around unity has been reported for these orchards.

In sugarcane growing soils Yadav (1986) estimated the Q/I relationship and found that the labile K constituted 12 to 70% of exchangeable fraction. The readily available K was found to be low as revealed by AR_0^K and change in free energy and the PBC^K were also low.

PBC^K was found to be significantly correlated with K fixation capacity, cation exchange capacity and non-exchangeable K content in 14 soil series from Hissar, in which wheat was grown (Mittal *et al.*, 1987b).

Beegle and Baker (1987) studied the differential potassium buffer behaviour of 3 soils (typic hapludalf, entic haplorthord and typic hapludult) in which alfalfa was grown. The buffer relationships determined indicated very different K behaviour for these soils even though exchangeable K soil test indicated similar K levels. They suggested that the K buffering behaviour of individual soils could be included in K management decisions involving corrective soil treatments.

The Q/I plot components labile K, activity ratio of K at equilibrium and linear PBC^K were affected by tillage and N addition in soils under 16 year continuous maize production with conventional tillage and no tillage management. The K_L and AR_0^K were highest for no tillage soil with and without N addition (Evangelou and Blevins, 1988).

Maji and Chatterjee (1990b) investigated Q/I relation of soil K in four surface soils of India belonging to Plinthustalf, haplustalf, Paleustert and vertic Ustochrept soil taxonomical units cropped to maize and wheat. ΔK_L, PBC^K and - ΔF values were found to be more in montmorillonite dominated black soils compared to illitic red soils but reverse results were observed in case of AR_e^K values. Two new parameters namely buffering capacity of K in saturation extract ($BC^K{}_{se}$) and unified solution Q/I factor were worked out in these soils. But these were found to have no extra advantage over those derived from Beckett's Q/I technique.

Patiram (1991) reported that in acid soils of Sikkim (haplumbrepts and dystropepts) growing maize all the Q/I parameters were found to be significantly and positively correlated with one another except AR_0^K and PBC^K. The dry matter yield, K concentration and K uptake of the maize plant were significantly and positively correlated with AR_0^K, ΔK_L and PBC^K.

Mukhopadhyay *et al.* (1992) reported that on depletion of 0.8 to 6.1 g kg^{-1} K from five micaceous soils of Punjab by growing 18 crops of two months duration, Q/I isotherms were shifted upward. It caused an increase of 0.16 to 1.36 cmol kg^{-1} of sites specific for K and overall selectivity of K over Ca was also increased. ΔK_L in the range of 1.3 to 2.5 m mol kg^{-1} was reduced to 0.4 to 0.6 m mol (K^{+}) kg^{-1} on cropping. AR^{K}_{e}, which was in the range of 0.0003 to 0.0017 $mol^{-1/2}$ $dm^{-3/2}$ reduced to 0.0001 to 0.0003 $mol^{-1/2}$ $dm^{-3/2}$ on cropping. The increased K preference was found to be equivalent to a chemical potential (ΔF) of 2.65 to 4.37 KJ mol^{-1}.

MATERIALS AND METHODS

MATERIALS AND METHODS

Soil samples from a 3^3 confounded factorial experiment at Coconut Research Station, Balaramapuram were used for the study.

Experimental Site

The Coconut Research Station, Balaramapuram lies at 8°29'N latitude and 76° 57' E longitude and at 64 m above mean sea level. Climate is humid tropical. Mean annual rainfall ranges from 1200 to 1500 mm. The average maximum and minimum temperatures are 30.7°C and 23.4°C respectively.

The Soil

The soil is red loam and an acidic alfisol. The soil is classified as Fine Loamy Kaolinitic Isohyperthermic Kandic Haplustalf.

The Experiment

The study was conducted deriving materials from the 25 year old NPK factorial experiment in which coconut palms received N at 0, 340 and 680; P_2O_5 at 0,225 and 450 and K_2O at 0, 450 and 900 g/palm/year. Each plot has four palms per treatment. The palms (West Coast Tall) have been planted at a spacing of 7.5 x 7.5 m each treatment replicated twice. N, P and K were applied as ammonium sulphate (20.5 percent N), super phosphate (16 percent P_2O_5) and muriate of potash (60 per cent K_2O) respectively. There was no organic matter application in any of the treatment.

Collection of soil samples

Soil samples collected from the active root zone (0-60 cm depth) of the experimental palms during 1989 ie., after 25 years of fertilizer application were used for the study. This was to maintain the uniformity of fertilizer sources, which has since been changed from ammonium sulphate, single superphosphate and muriate of potash to urea, rock phosphate and muriate of potash respectively. Soil samples collected from basins of the four experimental palms in each plot (at a distance of 180 cm from the bole and at a depth of 0-60 cm) were used for making composite samples.

Analytical methods

Soil samples collected were analysed for pH, electrical conductivity, organic carbon, cation exchange capacity, exchangeable cations, forms of potassium and Quantity - Intensity parameters of potassium. Mineral composition of the clay fraction of soil collected from uncropped area, was also dertermined.

Analytical procedures adopted for the estimation of physico chemical properties of soils and exchangeable cations were as follows.

Physico chemical characteristics of the soil

Sl. No.	Characteristics	Methods followed .
1.	pH (Soil : water 1:2.5)	pH meter
2.	Electrical conductivity (Soil: Water 1: 2.5)	Conductivity bridge
3.	Organic Carbon	Rapid titration method of Walkley and Black. (Walkley, 1946)
4.	Cation exchange capacity (CEC)	Using neutral normal ammonium acetate (Chapman, 1965)
5.	Exchangeable Ca, Mg and Na	Using neutral normal ammonium acetate and atomic absorption spectrophotometry (Jackson, 1967).
6.	Exchangeable Fe, Cu, Mn and Zn	Using DTPA extracting solution and atomic absorption spectrophotometry (Lindsay and Norvel, 1978).
7.	Exchangeable Al	Using 1 M KCl and atomic absorption spectrophotometry (Jackson, 1967)

The following laboratory procedures were used to determine different forms of potassium.

Water soluble K

Water soluble K was estimated by extraction with distilled water. Ten gram of soil was treated with 50 ml of distilled water, shaken for 1 hour and filtered. Potassium was determined by flame photometry (Jackson, 1967).

Available K

Available K was estimated by extraction with neutral normal ammonium acetate (Hanway and Heidal, 1952). Five g of soil was treated with 25 ml of neutral normal ammonium acetate, shaken for 5 minutes and was filtered. Potassium was determined by flame photometry.

Exchangeable K

This was computed as the difference between available K and water soluble K.

HNO_3 extractable K

Finely ground soil (2.5 g) was taken in an Erlenmeyer flask and 1.0 N HNO_3 (25ml) was added. The contents were boiled for 10 minutes, cooled, filtered and made upto 100 ml in a volumetric flask by subsequent washing with 0.1 N HNO_3. Potassium was determined by flame photometry (Wood and Deturk, 1941).

Non exchangeable K

It was estimated by subtracting available K from HNO_3 - K.

Total K

Finely ground soil (0.1 g), taken in a platinum crucible was digested with 5 ml HF and 0.5 ml $HClO_4$ on a hot plate. The contents were then evaporated to dryness in a sand bath at 200 to 225°C. It was cooled and 5ml of 6N HCl and 5 ml of water were added. Then the solution was gently boiled over a hot plate, and the residue was completely dissolved. It was cooled and transferred to 100 ml volumetric flask and made upto volume. Potassium was determined by flame photometry (Pratt, 1965).

Quantity - Intensity parameters

The following procedure by Beckett (1964 b) was adopted.

Five centrifuge tubes were filled with 5 g each of soil passing through 2mm sieve. Thirty millilitre each of 0.01 M $CaCl_2$ solution containing graded levels of KCl (0, 0.5 , 1.0 2.0 and 3.0 x 10^{-3} M KCl) was added to the tubes. These samples were shaken for 1 hour and then centrifuged. In the supernatant solution, K was determined by flame photometry and Ca and Mg by atomic absorption spectrophotometry.

The activity ratio $AR^K = \dfrac{a^K}{\sqrt{a^{Ca} + a^{Mg}}}$ was calculated from the concentration of K, Ca and Mg. The amount of K gained or lost ($\pm$ ΔK) by soil was calculated by subtracting the concentration of K in the solution before and after equilibration.

The quantity intensity Q/I curve was prepared with AR^K on the X-axis and $\pm \Delta K$ on the Y axis. From the plot of ΔK versus the activity ratio, the Quantity/ Intensity (Q/I) parameters were obtained. The intercept of Q/I curve on the X- axis (AR axis) gave the equilibrium activity ratio (AR_e^K) which measures the immediately available K relative to Ca and Mg.

The ΔK_0 value was obtained by drawing a tangent from the point on Q/I curve where $\Delta K = 0$. The ΔK_L Value was obtained by extrapolation of the Q/I curve till it intercepted the Y - axis. The difference between ΔK_L and ΔK_o gave the value of ΔK_x.

The potential buffering capacity (PBC^K) was determined by dividing ΔK_0 by AR_e^K. The potassium potential was estimated by multiplying ΔK_0 with PBC^K.

The free energy change of the K – (Ca + Mg) exchange was calculated from the relationship (Beckett, 1972), given below.

$$- \Delta G = 2.303 \; RT \log AR_e^K$$

where, ΔG denotes the free energy change of K - (Ca + Mg) exchange, R is the gas constant, T is the absolute temperature and AR_e^K the activity ratio of K at equilibrium when $\Delta K = 0$. This value denotes the work done to extract K from soil and hence they are negative.

Characterisation of Clay minerals

The fine clay for X - ray diffraction analysis was separated as per the procedure outlined by Kunze and Dixon (1986).

The powdered clay was placed on a slide and X-rayed using a Philips X-ray diffractometer with Copper Kα radiation. Identification of clay minerals present in the samples was made by calculating the characteristic 'd' spacings.

Statistical analysis

Analysis of variance technique was used to study the effect of applied treatments on various parameters investigated. Simple correlations were also established between soil chemical properties, fractions of potassium and Q/I parameters. Simple linear and multiple regression equations were developed to relate yield with significant attributes.

Q/I curves were prepared with the mean values of AR^K and $\pm \Delta K$ for two replications. The resultant Q/I parameters, therefore, were not replicated. Thus the tables 10 and 11 were not statistically analysed.

RESULTS

RESULTS

Data generated through soil chemical analysis and the observations on yield of coconut were subjected to statistical analysis to study the effect of applied treatments on various parameters. Results of the analysis of variance, correlations and multiple regression analysis are presented in Tables 1 to 22.

4.1. Soil properties

Mean data on the effect of treatment combination, the main effects of N, P and K and the two-factor interactions on various soil properties are presented in tables 1, 2 and 3. Salient findings are textually depicted.

4.1.1. Soil reaction

The treatments recorded a pH range of 4.03 ($n_2p_1k_1$) to 5.1 ($n_0p_1k_0$), the mean being 4.64. The plots where no nitrogen was applied during the last 25 years ie., from the start of the experiment recorded a significantly high pH value compared to those treated with 340 and 680 g N/palm/year (Table 2). Such differences were not seen in the case of P and K. The interaction effects of N, P and K also did not influence the pH of the soil.

4.1.2. Electrical Conductivity

Electrical conductivity for all the soil samples of different treatments were less than 0.05 ds m^{-1}; indicating low salt concentration in the soil solution. So the data were not subjected to statistical analysis.

4.1.3. Organic Carbon

The soils recorded low organic carbon content 0.32 ($n_0p_2k_0$) to 0.48 per cent ($n_2p_1k_2$) the mean being 0.40 per cent. None of the fertilizer elements, or their interactions significantly affected the soil organic carbon (Table 1,2,3). However the main effect of nitrogen was remarkable, where n_2 treatment recorded 0.42 per cent against 0.38 per cent in n_0 treatment.

4.1.4. Cation Exchange Capacity (CEC)

The CEC of the soil under different fertilizer treatments ranged from 3.10 ($n_0p_0k_0$) to 4.75 ($n_0p_2k_2$) c mol (p^+) kg^{-1}. The CEC of the soil was found to increase with an increase in the level of N from n_0 to n_2. In the case of P no significant difference was seen in CEC at p_1 and p_2 treated plots but CEC was high in these plots compared to p_0 plots. CEC in the k_2 treated plots were significantly high in comparison with k_1 and k_0, but between k_1 and k_0, no significant difference was observed. The effect of two factor interactions NP, NK and PK on CEC were significant (Table 3). In the absence of N, an increasing trend was seen at incremental level of P. But in the presence of n_1 and n_2 a quadratic trend was seen at p_o, p_1 and p_2. As far as NK interaction was considered, K produced an increasing trend in the absence of N, and a quadratic trend at n_1 level, but such a pattern was not seen in the case of k in combination with n_2. However no significant difference in CEC was seen at various levels of K in combination with n_1. Similarly when k was combined with n_2 no significant difference was observed at k_0 and k_1 and also k_0 and k_2.

The effect of NPK interaction on CEC was not significant (Table 1).

4.1.5. Exchangeable calcium

The exchangeable Ca content of the soil was not significantly influenced by the long term fertilizer application of N, P and K either alone or in combination. However, the p_1 and p_2 levels resulted in remarkable improvement of exchangeable Ca (Table 2). This was more so at n_1 level (table 3).

4.1.6. Exchangeable magnesium

The exchangeable Mg content of the soil under different treatments varied from 13.43 ($n_0p_2k_2$) to 21.47 ppm ($n_2p_1k_0$). In the case of Mg the main effects of P and K were not significant, but that of N was significant. The exchangeable Mg content of the soil was found to increase with an increase in level of N from n_0 to n_2 (Table 2). The exchangeable Mg content of n_2 treated plot was significantly higher than n_0 and n_1. In the case of NK interactions K produced a decreasing trend in the absence of N and an increasing trend at n_1 level. Such a pattern was not seen in the case of K in combination with n_2. However no significant difference in the exchangeable Mg content was seen at various levels of K in combination with n_0 and n_2. But when K was combined with n_1, the exchangeable Mg content of the plot treated with k_2 was significantly higher than the plots receiving K at k_1 level. The NPK interaction has not influenced the exchangeable Mg content of soil (Table 1).

4.1.7. Exchangeable Sodium

The exchangeable Na content of the soil was influenced by the long term application of N, but not of P and K. The exchangeable Na content of the soil deteriorated due to the application of N at 340 and 680 g N/palm/year. As far as NP interactions are considered P produced an increasing trend in the presence of n_2, quadratic trend in the presence of n_1 and no such pattern in the absence of N. The NK interaction and the PK interaction did not produce any significant difference in the exchangeable Na content. Similarly the NPK interaction also did not produce any significant change.

4.1.8. Exchangeable Aluminium

Exchangeable Al content of the soil was influenced by the long term application of N but not of P and K. An increasing trend was observed from n_0 to n_2. The exchangeable Al contents of n_1 and n_2 treated plots were significantly higher than the plots which has not received N. The interaction effects of N,P and K have not influenced the exchangeable Al content of the soil.

4.1.9. Exchangeable iron

None of the fertilizer elements N,P,K or their interaction affected the exchangeable Fe content of the soil.

Table 1. Effect of graded nutrition of coconut on soil properties

Sl. No.	Treatment	pH	Organic carbon (%)	CEC cmol kg^{-1}	Exchangeable Cations (ppm)							
					Ca	Mg	Na	Al	Fe	Mn	Cu	Zn
1	$n_0p_0k_0$	4.90	0.37	3.10	38.60	27.20	26.00	72	28.56	28.45	0.85	2.59
2	$n_0p_0k_1$	4.48	0.47	3.10	30.07	24.57	38.00	126	21.42	30.17	0.85	2.67
3	$n_0p_0k_2$	5.09	0.35	3.55	30.07	14.74	26.00	72	32.13	26.72	0.88	2.56
4	$n_0p_1k_0$	5.10	0.38	3.50	39.46	15.89	43.00	72	30.35	32.75	0.77	2.74
5	$n_0p_1k_1$	4.84	0.37	3.60	49.27	15.77	33.00	108	21.42	32.76	0.79	2.30
6	$n_0p_1k_2$	4.86	0.34	3.70	25.60	21.14	42.00	108	24.99	24.99	0.88	2.64
7	$n_0p_2k_0$	4.95	0.32	3.65	35.20	22.06	29.00	72	21.71	31.04	0.79	2.83
8	$n_0p_2k_1$	4.94	0.38	4.15	39.46	15.09	60.00	54	28.56	29.32	0.87	2.62
9	$n_0p_2k_2$	4.87	0.46	4.75	32.42	13.47	28.00	72	28.56	31.03	0.77	2.71
10	$n_1p_0k_0$	4.60	0.33	3.95	27.30	15.43	54.00	126	30.35	27.59	0.80	2.92
11	$n_1p_0k_1$	4.26	0.45	4.05	29.01	19.89	34.00	144	32.13	30.18	0.73	2.70
12	$n_1p_0k_2$	4.45	0.44	4.05	24.53	24.12	38.00	126	25.28	28.44	0.82	2.59
13	$n_1p_1k_0$	4.51	0.38	4.25	30.28	15.43	12.00	90	28.56	40.47	0.86	2.78
14	$n_1p_1k_1$	4.56	0.40	4.20	27.51	24.00	15.00	126	30.35	31.04	0.75	2.64
15	$n_1p_1k_2$	4.46	0.43	4.15	52.04	26.51	24.00	126	28.56	34.48	0.81	2.72
16	$n_1p_2k_0$	4.85	0.33	3.65	47.99	14.74	23.00	90	32.13	26.71	0.80	2.36
17	$n_1p_2k_1$	4.68	0.40	4.15	45.81	14.51	26.00	108	24.99	26.72	0.76	2.60
18	$n_1p_2k_2$	4.63	0.44	3.95	40.31	24.11	15.00	108	27.02	32.77	0.76	2.53
19	$n_2p_0k_0$	4.34	0.42	3.90	44.79	25.36	15.00	126	27.03	25.00	0.85	2.56
20	$n_2p_0k_1$	4.74	0.46	3.90	43.72	23.54	13.00	90	35.70	47.41	0.80	2.88
21	$n_2p_0k_2$	4.08	0.35	4.05	26.66	25.60	19.00	144	32.13	33.63	0.79	2.80
22	$n_2p_1k_0$	4.93	0.47	4.70	24.95	32.21	9.00	126	23.49	27.58	0.80	2.31
23	$n_2p_1k_1$	4.03	0.41	4.25	31.35	21.81	49.00	108	30.35	30.18	0.73	2.43
24	$n_2p_1k_2$	4.56	0.48	4.50	35.19	25.03	10.00	126	26.78	29.32	0.86	2.83
25	$n_2p_2k_0$	4.73	0.35	4.25	37.11	23.42	17.00	90	32.13	32.78	0.79	2.83
26	$n_2p_2k_1$	4.37	0.47	4.30	39.89	29.59	33.00	144	25.28	31.91	0.82	2.76
27	$n_2p_2k_2$	4.57	0.38	4.70	29.01	24.45	49.00	108	35.70	31.91	0.87	2.75
Mean		4.64	0.40	4.00	35.46	21.47	28.89	106	28.36	30.94	0.81	2.65
CD (0.05)							23.31				0.072	

Table 2. Main effects of N,P and K on soil properties.

Sl. No.	Treatment	pH	Organic carbon (%)	CEC cmol kg^{-1}	Exchangeable cations (ppm)							
					Ca	Mg	Na	Al	Fe	Mn	Cu	Zn
1	n_0	4.90	0.38	3.68	35.57	18.88	36.11	84	26.41	29.69	0.82	2.63
2	n_1	4.60	0.40	4.04	36.08	19.86	26.78	116	28.82	30.93	0.79	2.65
3	n_2	4.50	0.42	4.28	34.74	25.67	23.78	118	29.84	32.19	0.81	2.68
CD		0.18		0.11		3.60	7.70	23.24			0.02	
4	p_0	4.60	0.40	3.74	32.75	22.27	29.22	114	29.41	30.84	0.82	2.69
5	p_1	4.70	0.40	4.09	35.07	21.97	26.33	110	27.20	31.51	0.80	2.60
6	p_2	4.73	0.39	4.17	38.57	20.16	31.11	94	28.45	30.46	0.80	2.66
CD				0.11								
7	k_0	4.77	0.37	3.88	36.19	21.30	25.33	96	28.25	30.26	0.81	2.65
8	k_1	4.54	0.42	3.97	37.34	20.97	33.44	112	27.80	32.19	0.79	2.62
9	k_2	4.62	0.40	4.16	32.87	22.13	27.89	110	29.02	30.36	0.82	2.68
CD				0.11							0.02	

Table 3. Effect of two factor interactions of N, P and K on soil properties

Sl. No.	Treatment	pH	Organic carbon (%)	CEC cmol kg^{-1}	Exchangeable Cations (ppm)							
					Ca	Mg	Na	Al	Fe	Mn	Cu	Zn
1	n_0p_0	4.82	0.39	3.25	32.91	22.17	30.00	90	27.37	28.44	0.86	2.60
2	n_0p_1	4.93	0.36	3.60	38.11	17.60	39.33	96	25.59	30.17	0.81	2.56
3	n_0p_2	4.92	0.38	4.18	35.69	16.87	39.00	66	26.28	30.46	0.81	2.72
4	n_1p_0	4.43	0.41	4.02	26.94	19.81	42.00	132	29.25	28.74	0.78	2.74
5	n_1p_1	4.51	0.40	4.20	36.61	21.98	17.00	114	29.16	35.33	0.81	2.71
6	n_1p_2	4.72	0.39	3.92	44.70	17.78	21.33	102	28.05	28.73	0.77	2.49
7	n_2p_0	4.38	0.41	3.95	38.39	24.83	15.67	120	31.62	35.34	0.81	2.75
8	n_2p_1	4.50	0.45	4.83	30.50	26.35	22.67	120	26.87	29.03	0.79	2.52
9	n_2p_2	4.56	0.40	4.42	35.33	25.82	33.00	114	31.04	32.20	0.82	2.77
CD				0.20			13.34			10	0.04	0.20
10	n_0k_0	4.98	0.36	3.42	37.75	21.71	32.66	72	26.87	30.75	0.80	2.72
11	n_0k_1	4.75	0.40	3.62	39.59	18.48	43.66	96	23.80	30.75	0.83	2.53
12	n_0k_2	4.94	0.38	4.00	29.36	16.45	32.00	84	28.56	27.58	0.84	2.63
13	n_1k_0	4.65	0.35	3.95	35.19	15.20	29.67	102	30.35	31.59	0.82	2.68
14	n_1k_1	4.50	0.41	4.13	34.11	19.46	25.00	126	29.16	29.31	0.74	2.64
15	n_1k_2	4.51	0.43	4.05	38.96	24.91	25.67	120	26.95	31.89	0.80	2.61
16	n_2k_0	4.66	0.41	4.28	35.62	27.00	13.67	114	27.55	28.45	0.81	2.56
17	n_2k_1	4.38	0.44	4.15	38.32	25.00	31.67	114	30.44	36.50	0.78	2.69
18	n_2k_2	4.40	0.40	4.42	30.28	25.02	26.00	126	31.54	31.62	0.84	2.79
CD				0.20		6.23					0.04	
19	p_0k_0	4.61	0.37	3.65	36.90	22.66	31.67	108	28.64	27.01	0.83	2.69
20	p_0k_1	4.49	0.46	3.68	34.27	22.66	28.33	120	29.75	35.92	0.79	2.75
21	p_0k_2	4.54	0.38	3.88	27.08	21.48	27.67	114	29.85	29.60	0.83	2.65
22	p_1k_0	4.84	0.41	4.15	31.56	21.17	21.33	96	27.47	33.60	0.81	2.61
23	p_1k_1	4.47	0.39	4.02	36.04	20.52	32.33	114	27.37	31.33	0.75	2.46
24	p_1k_2	4.63	0.41	4.12	37.61	24.22	25.33	120	26.78	29.60	0.85	2.73
25	p_2k_0	4.84	0.33	3.85	40.10	20.07	23.00	84	28.66	30.18	0.79	2.67
26	p_2k_1	4.66	0.42	4.2	41.72	19.73	39.67	102	26.28	29.32	0.81	2.66
27	p_2k_2	4.69	0.42	4.47	33.91	20.68	30.67	96	30.43	31.90	0.80	2.66
CD				0.20							0.04	

4.1.10. Exchangeable Manganese

The main effects of N, P and K did not produce significant difference in the exchangeable Mn content of the soil. So the interactions between N, P and K assumed little importance.

4.1.11. Exchangeable Copper

The exchangeable Cu content of the soil was influenced by the long term application of N and K but not P.

Application of N and K produced a quadratic trend in the exchangeable Cu content of the soil. In the presence of n_1 and n_2 at various levels of P a quadratic trend was observed. But such a pattern was not seen in the absence of N at various levels of P. In the case of NK interaction, K produced an increasing trend in the absence of N and a quadratic trend in the presence n_1 and n_2. In the case of PK interactions at various levels of P in combination with various level of K,a quadratic trend was observed.

The NPK interaction also produced significant changes in the exchangeable Cu content of the soil.

4.1.12. Exchangeable Zinc

The main effects of N, P and K did not produce significant changes in the exchangeable Zn content of the soil. So the interactions between N, P and K assumed little importance.

4.1.13. Clay mineralogy

The X-ray diffractogram of the clay fraction of the soil is presented in figure 1 and the claymineral characterisation is presented below. Kaolinite was found to be the dominant clay mineral in the soil and no other clay minerals were found in appreciable quantities.

Clay mineral characterisation of the experimental site.

'd' spacing	Relative intensity	clay mineral identified
7.104	100	Kaolinite
4.432	51	Kaolinite
4.155	47	Kaolinite
3.850	37	Kaolinite
3.562	95	Kaolinite
2.555	39	Kaolinite
2.491	42	Kaolinite
2.335	43	Kaolinite
2.288	37	Kaolinite

4.2. Potassium status of the soil

The mean values of data on the effect of applied fertilizers in the contents of soil potassium fractions are presented in tables 4, 5 and 6. There were significant differences in the forms of potassium present in the soil after 25 years of continuous application and crop uptake. The contents of water

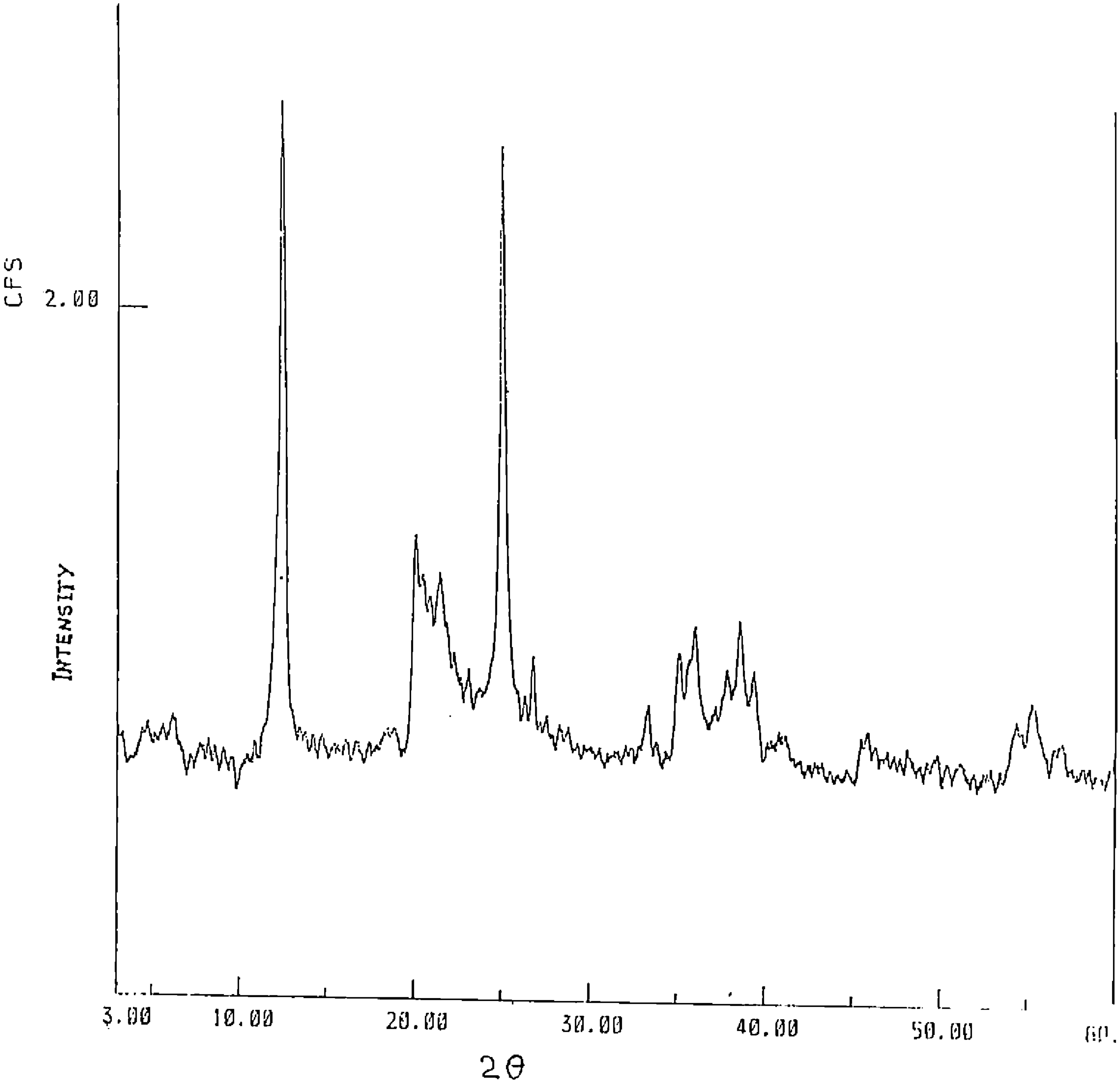

Fig. 1. X-ray diffractogram of the clay fraction of the soil

soluble, available and exchangeable K, increased significantly with higher levels of potash application. The increase was considerable in the case of HNO_3-K also. No definite trend was observed for non exchangeable K. though the plots which did not receive K showed higher non exchangeable K.

4.2.1. Water soluble K

The water soluble potassium in the soils under graded doses of N, P and K varied from 6.00 to 18.50 ppm with a mean content of 10.80 ppm. $n_1p_2k_1$ recorded highest water soluble K and $n_1p_2k_0$ recorded lowest water soluble K. The effect of NPK interaction on water soluble potassium content was significant (Table 4).

The main effects of N and P were not significant on water soluble K while the main effect of K produced significant changes (Table 5). The water soluble K content increased from k_0 to k_2 treatments with k_1 and k_2 treatments recording significantly higher values than k_0 (without K). The effect of two factor interactions on water soluble K contents were not significant. (Table 6).

4.2.2. Available K

Available K contents of the soil under different fertilizer treatments ranged from 12.5 ($n_1p_1k_0$) to 63.00 ppm ($n_0p_1k_2$) with a mean content of 32.69 ppm.

The effect of NPK interactions on available K was not significant (Table 4). Main effects of N and P on available K content were not significant whereas long term application of K has significantly affected the available K in the soil (Table 5). The available K content of the soil increased with higher levels of K application from k_0 to k_2. Both k_1 and k_2 levels were significantly superior to k_0. The effect of two factor interactions NP and NK on available K content were not significant while PK interaction resulted in significant variation in available K content (Table 6). The available K content at p_1k_2 was significantly higher than other PK interactions. There was significant improvement in available K with incremental doses of fertilizer K combined with p_1 level. At p_0 and p_2 levels, the trend was quadratic.

4.2.3. Exchangeable K

The exchangeable K content of the soils under graded doses of N, P and K ranged from 4.00 to 51.00 ppm with a mean content of 21.91 ppm. The exchangeable K was higher in $n_0p_1k_2$ and lowest in $n_0p_0k_2$. The effect of NPK interactions on exchangeable K content was not significant (Table 4). The main effects of N and P on the content of exchangeable K were not significant, whereas the main effect of K was significant (Table 5). The content of exchangeable K increased with higher doses of potassium from k_0 to k_2. The exchangeable K content of the k_1 and k_2 were significantly higher than k_0 (without K). Among the two factor interactions only PK interaction could influence the content of exchangeable K significantly (Table 6). The exchangeable K content of p_1k_2 was significantly higher than other PK interactions. As in the case of available K, the enhancing effect of K fertilization on exchangeable K was more pronounced when K treatments were combined with P at p_1 level. The exchangeable K in this case, ranged from 6.67 at k_0 to 19.67 at k_1 and 44.83 ppm at k_2 level (Table 6).

Table 4. Effect of graded nutrition of coconut on potassium fractions in the soil

Sl. No.	Treatments	Water-soluble K(ppm)	Available K(ppm)	Exchangeable K(ppm)	HNO_3-K (ppm)	Non Exchangeable K(ppm)	Total K (ppm)
1	$n_0p_0k_0$	6.50	19.00	12.50	68	49.00	1750
2	$n_0p_0k_1$	14.50	37.00	22.50	140	103.00	1550
3	$n_0p_0k_2$	15.50	19.50	4.00	124	104.50	1550
4	$n_0p_1k_0$	10.50	18.00	7.50	112	94.00	1700
5	$n_0p_1k_1$	10.00	38.50	28.50	116	77.50	1650
6	$n_0p_1k_2$	12.00	63.00	51.00	132	69.00	3100
7	$n_0p_2k_0$	7.00	17.50	10.50	92	74.50	1600
8	$n_0p_2k_1$	9.00	34.00	25.00	76	42.00	1450
9	$n_0p_2k_2$	8.00	57.50	49.50	80	22.50	2100
10	$n_1p_0k_0$	9.00	14.00	5.00	48	34.00	1750
11	$n_1p_0k_1$	13.00	37.00	24.00	64	40.00	1700
12	$n_1p_0k_2$	10.50	41.00	30.50	96	55.00	1850
13	$n_1p_1k_0$	8.00	12.50	4.50	72	59.50	1850
14	$n_1p_1k_1$	7.50	25.00	17.50	51	26.00	1700
15	$n_1p_1k_2$	14.50	60.00	45.50	88	28.00	1650
16	$n_1p_2k_0$	6.00	14.00	8.00	104	90.00	1900
17	$n_1p_2k_1$	18.50	51.00	32.50	124	73.00	2950
18	$n_1p_2k_2$	8.50	25.00	16.50	56	31.00	2300
19	$n_2p_0k_0$	12.00	41.50	29.50	68	26.50	2200
20	$n_2p_0k_1$	10.00	36.50	26.50	52	15.50	3200
21	$n_2p_0k_2$	16.00	44.00	28.00	68	24.00	1550
22	$n_2p_1k_0$	6.50	14.50	8.00	36	21.50	1200
23	$n_2p_1k_1$	11.50	24.50	13.00	48	23.50	1050
24	$n_2p_1k_2$	17.00	54.50	38.00	92	37.50	1050
25	$n_2p_2k_0$	12.50	45.50	33.00	64	18.50	800
26	$n_2p_2k_1$	9.50	24.00	14.50	60	36.00	1000
27	$n_2p_2k_2$	8.00	14.00	6.00	40	26.00	1100
Mean		10.80	32.69	21.91	80	48.20	1750
CD (0.05)		8.17					

Table 5. Main effects of N,P and K on potassium fractions in the soil

Sl. No.	Treatment	Water soluble K (ppm)	Available K (ppm)	Exchangeable K (ppm)	HNO_3-K (ppm)	Non Exchangable K (ppm)	Total K (ppm)
1	n_0	10.33	33.77	23.44	104.44	70.67	1827.77
2	n_1	10.61	31.06	20.44	78.11	48.50	1961.11
3	n_2	11.44	33.22	21.83	58.66	25.44	1461.11
CD (0.05)					31.86	31.76	
4	p_0	11.89	32.16	20.27	80.88	50.17	1900.00
5	p_1	10.83	34.50	23.72	83.00	48.50	1661.11
6	p_2	9.67	31.38	21.72	77.33	45.94	1688.88
7	k_0	8.67	21.83	13.16	73.77	51.94	1638.88
8	k_1	11.50	34.16	22.67	81.22	48.50	1805.55
9	k_2	12.22	42.06	29.89	86.22	44.17	1805.55
CD (0.05)		2.70	10.76	9.42			

Table 6. Effect of two factor interactions of N,P and K on potassium fraction in the soil

Sl. No.	Treatments	Water soluble K (ppm)	Available K (ppm)	Exchangaeble K (ppm)	HNO_3-K (ppm)	Non Exch-angeable K (ppm)	Total K (ppm)
1	n_0p_0	12.17	25.17	13.00	110.67	85.50	1616.67
2	n_0p_1	10.83	39.83	29.00	120.00	80.17	2150.00
3	n_0p_2	8.00	36.33	28.33	82.67	46.330	1716.66
4	n_1p_0	10.83	30.67	19.83	69.33	43.00	1716.66
5	n_1p_1	10.00	32.50	22.50	70.33	37.88	1733.33
6	n_1p_2	11.00	30.00	19.00	94.67	64.67	2383.33
7	n_2p_0	12.67	40.67	28.00	62.67	22.00	2316.66
8	n_2p_1	11.67	31.17	19.66	58.67	27.50	1100.00
9	n_2p_2	10.00	27.83	17.83	54.16	26.83	966.67
10	n_0k_0	8.00	18.17	10.17	90.67	72.50	1683.33
11	n_0k_1	11.17	36.50	25.33	110.66	74.17	1550.00
12	n_0k_2	11.83	46.67	34.83	112.00	65.33	2250.00
13	n_1k_0	7.67	13.50	5.83	74.67	61.17	1833.33
14	n_1k_1	13.00	37.66	24.67	79.67	46.33	2116.66
15	n_1k_2	11.17	42.00	30.83	80.00	38.00	1933.33
16	n_2k_0	10.33	133.83	23.50	56.00	22.17	1400.00
17	n_2k_1	10.33	28.33	18.00	53.33	25.00	1750.00
18	n_2k_2	13.67	37.50	24.00	66.67	29.17	1233.33
19	p_0k_0	9.17	24.83	15.66	61.33	36.50	1900.00
20	p_0k_1	12.50	36.83	24.33	85.33	52.83	2150.00
21	p_0k_2	14.00	34.83	20.83	96.00	61.17	1650.00
22	p_1k_0	8.33	15.00	6.67	73.33	58.33	1583.33
23	p_1k_1	9.67	29.33	19.67	71.67	42.33	1466.67
24	p_1k_2	14.50	59.17	44.83	104.00	44.83	1933.33
25	p_2k_0	8.50	25.67	17.17	86.67	61.00	1433.33
26	p_2k_1	12.33	36.33	24.00	86.67	50.33	1800.00
27	p_2k_2	8.17	32.17	24.00	58.67	26.50	1833.33
CD (0.05)			18.64	16.32			

4.2.4. HNO_3 — K

The content of HNO_3-K of soils ranged from 36 to 140 ppm with a mean content of 80.41 ppm. HNO_3-K was highest in the treatment $n_2p_0k_1$ and lowest in $n_2p_1k_0$. However, the effect of NPK interaction on HNO_3-K was not significant (Table 4). The main effect of N on HNO_3-K content was significant (Table 5). The HNO_3-K decreased from n_0 to n_2. The HNO_3-K content of the n_0 treatment was significantly higher than the n_2 treatment. n_1 and n_2 treatments were on par. The main effects of P and K on HNO_3-K content were not significant (Table 5). But the data showed an increasing trend with higher levels of K. The effect of two factor interaction NP, NK and PK on HNO_3-K were also not significant (Table 6).

4.2.5. Non exchangeable K

The non-exchangeable K content of the soil varied from 15.5 ($n_2p_0k_1$) to 104.5 ppm ($n_0p_0k_2$) with a mean content of 48.20 ppm. None of the interactions, nor the main effects of K or P could affect this parameter significantly. However, long term application of ammonium sulphate resulted in significant reduction of non exchangeable K in the soil (Table 5). The values decreased from 70.67 ppm at n_0 level to 48.50 and 25.44 ppm at n_1 and n_2 levels respectively.

A decreasing trend in non exchangeable K was observed with increasing levels of P as well as K, though the effects were not significant (Table 5).

4.2.6. Total K

The total K content of the soil under graded doses of N, P and K varied from 800 to 3200 ppm with a mean content of 1750 ppm. The total K content was highest in the treatment $n_2p_0k_1$ and lowest in $n_2p_2k_0$. The effect of NPK interactions on total K was not significant. (Table 4). The main effect of N, P and K and the effect of two factor interactions NP, NK and PK on total K were also not significant (Tables 5 and 6).

4.3. Quantity / Intensity parameters of Potassium

The effect of long term differential nutrition of coconut on the Q/I parameters and the mean values for the experimental area are available in table 7. The treatments resulted in remarkable variation in all the parameters.

There was considerable variation in these potassium availability indices. For example, the PBC^K ranged from 0.21 to 2.33 with a mean of 0.96 meq 100 g^{-1} (mol $litre^{-1})^{1/2}$ whereas the AR_e^K ranged from 0.0006 to 0.006 with a mean of 0.0027(mol $litre^{-1})^{1/2}$ (Table 7).

Higher levels of N resulted in an increase in PBC^K whereas potassium application reduced the PBC^K (Table 8).

AR_e^K decreased from n_0 to n_1 and n_2 levels. At p_0 and p_2 levels AR_e^K was same and AR_e^K at p_1 level was higher than p_0 and p_2 levels. AR_e^K decreased from k_0 to k_1 level, but increased from k_1 to k_2 level. (Tables 7 and 8).

Table 7. Effect of graded nutrition of coconut on Q/I parameters of potassium

Sl. No.	Treat- ment	PBC^K me $100g^{-1}$ (mol $litre^{-1})^{1/2}$	AR_e^K (mol $litre^{-1})^{1/2}$	ΔKo me $100g^{-1}$	ΔKx me $100g^{-1}$	ΔKL me $100g^{-1}$	K Potential me $100g^{-1}$ (mol $litre^{-1})^{1/2}$	ΔG K J/mol
1	$n_0p_0k_0$	2.00	0.0014	0.0028	0.0010	0.0038	0.0056	-16.26
2	$n_0p_0k_1$	0.53	0.0064	0.0034	0.0016	0.0050	0.0018	-12.50
3	$n_0p_0k_2$	0.71	0.0014	0.001	0.0008	0.0018	0.00071	-16.26
4	$n_0p_1k_0$	0.67	0.0054	0.0036	0.0024	0.0060	0.0024	-12.92
5	$n_0p_1k_1$	1.30	0.0020	0.0026	0.0014	0.0040	0.0034	-15.37
6	$n_0p_1k_2$	0.38	0.0064	0.0024	0.0016	0.0040	0.00091	-12.50
7	$n_0p_2k_0$	1.33	0.0048	0.0064	0.0014	0.0078	0.0085	-13.20
8	$n_0p_2k_1$	1.00	0.002	0.002	0.0006	0.0026	0.0020	-15.37
9	$n_0p_2k_2$	0.21	0.0028	0.0006	0.0034	0.0040	0.00013	-14.54
10	$n_1p_0k_0$	0.39	0.0036	0.0014	0.0076	0.0090	0.00055	-13.92
11	$n_1p_0k_1$	0.82	0.0022	0.0018	0.0008	0.0096	0.0015	-15.14
12	$n_1p_0k_2$	0.71	0.0014	0.0010	0.0014	0.0024	0.0071	-16.26
13	$n_1p_1k_0$	3.33	0.0006	0.0020	0.0026	0.0028	0.0067	-18.35
14	$n_1p_1k_1$	0.38	0.0026	0.0010	0.0010	0.0020	0.00038	-14.72
15	$n_1p_1k_2$	0.52	0.0046	0.0024	0.0014	0.0038	0.0014	-13.33
16	$n_1p_2k_0$	0.75	0.0012	0.0009	0.0015	0.0024	0.00068	-16.68
17	$n_1p_2k_1$	0.55	0.0022	0.0012	0.0012	0.0024	0.00067	-15.14
18	$n_1p_2k_2$	0.72	0.0050	0.0036	0.0002	0.0038	0.0026	-13.11
19	$n_2p_0k_0$	2.00	0.002	0.002	0.0002	0.0022	0.0040	-17.09
20	$n_2p_0k_1$	1.18	0.001	0.0026	0.0005	0.0031	0.0031	-15.14
21	$n_2p_0k_2$	0.25	0.0022	0.0008	0.003	0.0038	0.0002	-14.21
22	$n_2p_1k_0$	0.75	0.0032	0.0012	0.0006	0.0018	0.0009	-15.93
23	$n_2p_1k_1$	0.25	0.0016	0.0004	0.0028	0.0032	0.0001	-15.93
24	$n_2p_1k_2$	0.57	0.0042	0.0024	0.004	0.0064	0.0014	-16.26
25	$n_2p_2k_0$	1.71	0.0014	0.0024	0.0006	0.003	0.004	-16.26
26	$n_2p_2k_1$	0.83	0.0012	0.001	0.0004	0.0014	0.00083	-16.64
27	$n_2p_2k_2$	2.00	0.001	0.002	0.0004	0.0024	0.0040	-17.09
Mean		0.96	0.0027	0.0020	0.0016	0.0036	0.0022	-15.19

Table 8. Main effects of N,P and K on Q/I parameters of soil potassium

Sl. No.	Treament	PBC^K me $100g^{-1}$ (mol $litre^{-1})^{1/2}$	AR_e^K (mol $litre^{-1})^{1/2}$	ΔKo me $100g^{-1}$	ΔKx me $100g^{-1}$	ΔKL me $100g^{-1}$	K Potential (me $100g^{-1}$ mol $litre^{-1})^{1/2}$	ΔG K J/mol
1	n_0	0.90	0.0036	0.0028	0.0016	0.0043	0.0028	-14.33
2	n_1	0.91	0.0026	0.0017	0.0020	0.0035	0.0017	-15.18
3	n_2	1.06	0.0019	0.0016	0.0014	0.0030	0.0021	-16.06
4	p_0	0.95	0.0024	0.001	0.0019	0.0037	0.0020	-15.20
5	p_1	0.91	0.0034	0.002	0.002	0.0038	0.0020	-15.03
6	p_2	1.01	0.0024	0.0022	0.0011	0.0033	0.0026	-15.34
7	k_0	1.44	0.0026	0.0025	0.0022	0.0043	0.0037	-15.62
8	k_1	0.76	0.0024	0.0018	0.0030	0.003	0.0014	-15.11
9	k_2	0.67	0.0032	0.0018	0.0016	0.0036	0.0012	-14.84

Δk_0 decreased from n_0 to n_1 and n_2 levels and increased from p_0 to p_1 and p_2 levels. Δk_0 decreased from k_0 to k_1 level. Δk_0 values of the k_1 and k_2 levels were same (Tables 7 and 8).

Δk_x increased from n_0 to n_1 but decreased from n_1 to n_2. Δk_x increased from p_0 to p_1 and p_2 levels. Δk_x increased from k_0 to k_1 level but decreased from k_1 to k_2 level (Tables 7 and 8).

Δk_L decreased from n_0 to n_1 and n_2 levels. Δk_L increased from p_0 to p_1 and k_0 to k_1, level but decreased from p_1 to p_2 level and k_1 to k_2 level (Tables 7 and 8).

K potential decreased from n_0 to n_1, but increased from n_1 to n_2 levels. K potential increased from p_0 and p_1 levels to p_2 levels. It decreased from k_0 to k_1 and k_2 levels (Tables 7 and 8).

Free energy (ΔG) increased from n_0 to n_1 and n_2 plots and it remained almost same for p_0, p_1 and p_2 levels. It decreased from k_0 to k_1 and k_2 levels (Tables 7 and 8).

4.4. Yield of Coconut

The mean values of data on the effect of applied treatments on the yield of coconut are presented in tables 9, 10 and 11.

The main effect of potassium and its interaction with applied nitrogen had effected significant variation in the yield of nuts. The yield increased from k_0 level to k_1 and then to k_2 levels in all the four years under study (Table 10).

Table 9. Effect of graded nutrition of coconut on yield of nuts

Sl. No.	Treatment	Mean number of nuts per treatment 1989	1990	1991	1992	Mean yield per palm for 1990-91
1	$n_0p_0k_0$	231	83	251	208	84
2	$n_0p_0k_1$	300	119	278	189	99
3	$n_0p_0k_2$	493	192	398	363	148
4	$n_0p_1k_0$	84	62	89	114	38
5	$n_0p_1k_1$	457	120	371	286	122
6	$n_0p_1k_2$	283	129	242	221	93
7	$n_0p_2k_0$	145	66	130	119	49
8	$n_0p_2k_1$	310	162	365	251	132
9	$n_0p_2k_2$	416	137	418	278	160
10	$n_1p_0k_0$	181	65	145	167	53
11	$n_1p_0k_1$	347	175	351	301	132
12	$n_1p_0k_2$	282	56	264	270	99
13	$n_1p_1k_0$	35	29	40	42	17
14	$n_1p_1k_1$	499	136	406	264	135
15	$n_1p_1k_2$	514	187	490	304	169
16	$n_1p_2k_0$	12	8	8	15	4
17	$n_1p_2k_1$	382	179	308	242	122
18	$n_1p_2k_2$	475	162	431	309	148
19	$n_2p_0k_0$	76	35	179	44	54
20	$n_2p_0k_1$	476	181	323	293	126
21	$n_2p_0k_2$	486	102	397	285	141
22	$n_2p_1k_0$	20	17	21	62	10
23	$n_2p_1k_1$	320	169	268	245	109
24	$n_2p_1k_2$	575	175	469	268	161
25	$n_2p_2k_0$	25	24	66	27	46
26	$n_2p_2k_1$	336	84	267	174	148
27	$n_2p_2k_2$	498	127	340	271	146
Mean		306	111	271	208	102

Table 10. Main effects of N,P and K on yield of coconut

Sl. No.	Treatment	Mean no. of nuts/treatment (4 palms)				Mean yield per palm for 1990-91
		1989	1990	1991	1992	
1	n_0	302	119	282	225	103
2	n_1	303	110	271	213	98
3	n_2	312	101	259	185	105
4	p_0	319	112	287	235	104
5	p_1	309	113	266	201	95
6	p_2	289	105	259	187	106
CD (0.05)					38	
7	k_0	90	43	103	89	40
8	k_1	381	147	326	249	125
9	k_2	447	140	383	285	141
CD (0.05)		63	24	61	38	21

Table 11. Effect of two factor interactions of N, P and K on yield of coconut

Sl. No.	Treatment	Mean no. of nuts per treatment ie., 4 palms				Mean yei per palm for 1990-
		1989	1990	1991	1992	
1	n_0p_0	341	131	309	253	110
2	n_0p_1	273	103	234	207	84
3	n_0p_2	290	121	304	216	114
4	n_1p_0	270	98	253	246	94
5	n_1p_1	349	117	312	203	107
6	n_1p_2	290	116	249	188	92
7	n_2p_0	346	106	300	207	107
8	n_2p_1	305	120	253	192	93
9	n_2p_2	286	78	224	157	113
10	n_0k_0	153	70	157	147	57
11	n_0k_1	356	133	338	242	118
12	n_0k_2	397	152	352	287	134
13	n_1k_0	76	34	64	75	25
14	n_1k_1	409	163	355	269	130
15	n_1k_2	423	135	395	294	139
16	n_2k_0	40	25	89	44	36
17	n_2k_1	377	144	286	237	128
18	n_2k_2	520	134	402	275	149
CD (0.05)		109				
19	p_0k_0	163	61	191	140	63
20	p_0k_1	374	158	317	261	119
21	p_0k_2	420	166	353	306	129
22	p_1k_0	46	36	50	73	22
23	p_1k_1	425	141	348	265	122
24	p_1k_2	457	163	400	264	141
25	p_2k_0	61	33	68	54	33
26	p_2k_1	342	141	313	222	134
27	p_2k_2	463	142	396	286	152

Continuous application of N without potassium resulted in significant reduction of yield (Table 11). Also at n_1 and n_2 levels, graded doses of potassium produced concomitant improvement in nut yield. Similar trend was observed in the case of PK interaction also though the effect was not statistically significant. No definite pattern was observed in the case of NP interaction. NPK interaction was also not significant in the case of coconut yield. However, the palm receiving no fertilizers over the last quarter of century, yielded better than those receiving N or P without potassium.

An attempt was made to pool the yields for 1990 and 1991 and the mean number of nuts per palm were analysed. The results presented in tables 7, 8 and 9 (last column) also showed that potassium nutrition at k_1 and k_2 levels could enhance coconut production significantly. The yield per palm increased from 40 at no potassium treatment to 125 and 141 nuts at potassium levels of k_1 and k_2 respectively (Table 10). In the case of NK and PK interactions, though not significant, it was seen that potassium nutrition with or without N or P could result in better yields (Table 11).

4.5. Correlation Studies

Correlations were worked out between various parameters under study, to determine the extent of interactions of these observations. The coefficients of correlation are tabulated and the results are presented in different sections.

4.5.1. Correlation between soil properties

Correlation was worked out between soil properties and the

Table 12. Coefficient of correlation between soil properties

Sl. No.	Soil properties	pH	Organic C	CEC	Exch. Ca	Exch. Mg	Exch. Na	Exch. Al	Exch. Fe	Exch. Mn	Exch. Cu	Exch. Zn
1	pH											
2	Organic carbon	-0.3101										
3	CEC	-0.2633	0.3630									
4	Exchangeable Ca	0.1711	0.0141	-0.2122								
5	Exchangeable Mg	0.3622	0.4441*	0.1433	-0.1433							
6	Exchangeable Na	0.0205	-0.2635	-0.1424	-0.1671	-0.3469						
7	Exchangeable Al	-0.7389**	0.4103*	0.2368	-0.2174	0.5292**	-0.1669					
8	Exchangeable Fe	-0.1261	-0.1699	0.2124	-0.055	-0.1433	0.0155	-0.1327				
9	Exchangeable Mn	-0.1062	0.1974	0.1087	0.1842	0.0554	-0.2828	-0.1012	0.341			
10	Exchangeable Cu	0.2579	-0.1215	-0.1565	-0.0786	0.0672	0.0738	-0.1975	-0.0777	-0.1282		
11	Exchangeable Zn	-0.1455	-0.0325	0.1162	-0.1833	0.0229	0.0428	0.0326	0.3204	0.4127*	0.1081	

* Significant at 5% level

** Significant at 1% level

coefficients of correlation are presented in table 12. pH was negatively correlated to organic C, CEC, exchangeable Mg, Al, Fe, Mn and Zn and positively correlated to exchangeable Ca, Na, and Cu. pH was significantly and negatively correlated with exchangeable Al (Table 12). Organic C was significantly and positively correlated to exchangeable Mg and Al. Organic C was positively correlated to CEC, exchangeable Ca, Mg, Al and Mn and negatively correlated to pH, exchangeable Na,Fe, Cu and Zn. CEC was positively correlated to organic C, exchangeable Mg, Al, Fe, Mn and Zn and negatively correlated to pH, exchangeable Ca, Na and Cu.

Exchangeable Ca was positively correlated to exchangeable Mn and negatively correlated to exchangeable Mg, Na, Al, Fe, Cu and Zn.Exchangeable Mg was positively correlated with exchangeable Al, Mn, Cu and Zn and negatively correlated with exchangeable Na and Fe. Exchangeable Na was positively correlated with exchangeable Fe, Cu and Zn and negatively correlated with exchangeable Al and Mn. Exchangeable Al was significantly and negatively correlated to pH and significantly and positively correlated with organic carbon and exchangeable Mg. It was negatively correlated to exchangeable Fe, Mn and Cu and positively correlated to Zn. Exchangeable Fe was positively correlated to exchangeable Mn and Zn and negatively correlated to exchangeable Cu. Exchangeable Mn was negatively correlated with exchangeable Cu and positively correlated with exchangeable Zn. Exchangeable Cu was positively correlated with exchangeable Zn.

4.5.2. Correlation between soil properties and fractions of soil potassium

Coefficients of correlation between soil properties and potassium fractions are presented in table 13.

Table 13. Coefficient of correlation between soil properties and potassium fractions

Sl. No.	Soil Properties	Water soluble K	Available K	Exchangeable K	HNO_3-K	Nonexchangeable K	Total K
1	pH	-0.3246	-0.1777	-0.1211	0.3500	0.4503*	0.1884
2	Organic carbon	0.1397	0.2582	0.2594	-0.1991	-0.3410	-0.0383
3	CEC	-0.0420	0.1485	0.1799	-0.5650**	-0.6861**	-0.2565
4	Exchangeable Ca	0.0666	0.1711	0.1769	0.1962	0.0981	0.2012
5	Exchangeable Mg	-0.0337	0.0280	0.0409	-0.4226*	-0.4730*	-0.2825
6	Exchangeable Na	-0.0723	0.1067	0.1046	0.1353	0.2117	-0.1274
7	Exchangeable Al	0.3322	0.2091	0.1553	-0.2075	-0.3138	-0.1254
8	Exchangeable Fe	-0.0302	-0.1820	0.1988	-0.4413*	-0.3510	-0.0238
9	Exchangeable Mn	0.3410	-0.0584	-0.0385	-0.2897	-0.2794	0.1364
10	Exchangeable Cu	0.0491	0.0146	0.0059	0.2741	0.2525	-0.0323
11	Exchangeable Zn	0.3204	0.1454	0.1154	-0.1467	0.2345	0.0141

* Significant at 5% level

** Significant at 1% level

The pH was negatively correlated to water soluble K, available K and exchangeable K and positively correlated to HNO_3-K, non-exchangeable K and total K. It was positively and significantly correlated to non exchangeable K.

Organic carbon was positively correlated to water soluble K, available K and exchangeable K and was negatively correlated to HNO_3-K, non-exchangeable K and total K.

The CEC was significantly and negatively correlated to HNO_3-K and non exchangeable K. CEC was negatively correlated to water soluble K and total K and was positively correlated to available K and exchangeable K.

Exchangeable Ca was positively correlated to all potassium fractions. Exchangeable Mg was significantly and negatively correlated to HNO_3-K and non exchangeable K. Exchangeable Mg was negatively correlated with water soluble K and total K and was positively correlated to available K and exchangeable K. Exchangeable Na was positively correlated to available K, exchangeable K, HNO_3-K and non exchangeable K and was negatively correlated to water soluble K and total K. Exchangeable Al was negatively correlated to HNO_3-K, non exchangeable K and total K and was positively related to water soluble K, available K and exchangeable K. Exchangeable Fe was significantly and negatively correlated to HNO_3-K and was negatively correlated to water soluble K, available K, non exchangeable K and total K. Exchangeable Fe was positively correlated to exchangeable K. Exchangeable Mn was positively correlated to water soluble K and total K and was negatively correlated to available K, exchangeable K, HNO_3-K, and non exchangeable K. Exchangeable Cu was positively correlated to water soluble K, available K, exchangeable K, HNO_3-K and non-exchangeable K and was negatively correlated to total K. Exchangeable Zn was positively correlated to watersoluble K, available K, exchangeable K, non exchangeable K and total K and was negatively correlated to HNO_3-K.

4.5.3. Correlation between soil properties and Q/I parameters of potassium

Correlation was worked out between soil properties and Q/I parameters of K and the results are available in table 14.

The pH was positively correlated to PBC^K, AR_e^K, Δk_0, Δk_L, K potential and ΔG and was negatively correlated to Δk_x. Organic carbon was positively correlated to AR_e^K and negatively correlated to PBC^K, Δk_0, Δk_x, Δk_L, K potential and ΔG. The CEC was significantly and negatively correlated to Δk_0. It was positively correlated to Δk_x and was negatively correlated to PBC^K, AR_e^K, Δk_L, K potential and ΔG.

Exchangeable Ca was positively correlated to PBC^K, Δk_0, and K potential and was negatively correlated to AR_e^K, Δk_x, Δk_L and ΔG. Exchangeable Mg was positively correlated with PBC^K, AR_e^K, Δk_0, and K potential and negatively correlated with Δk_x, Δk_L and ΔG. Exchangeable Na was positively correlated with AR_e^K, Δk_x, Δk_L and ΔG and was negatively correlated to PBC^K, Δk_0 and K potential. Exchangeable Al was significantly and negatively correlated to K potential. Exchangeable Al was positively correlated to AR_e^K, Δk_x and ΔG and was negatively correlated to PBC^K, Δk_0 and Δk_L. Exchangeable Fe was positively correlated to PBC^K and Δk_x and was negatively correlated to AR_e^K, Δk_0, Δk_L, K potential and ΔG. Exchangeable

Table 14. Coefficients of correlation between soil properties and Q/I parameters of potassium

Sl. No.	Treatment	PBC^K	AR_e^K	ΔKo	ΔKx	ΔKL	K Potential	ΔG
1	pH	0.079	0.1336	0.3565	-0.1259	0.1547	0.2390	0.1536
2	Organic carbon	-0.1695	0.0081	-0.1712	-0.1925	-0.2668	-0.2856	-0.0673
3	CEC	-0.0376	-0.3441	-0.4521*	0.0755	-0.2673	-0.2528	-0.3597
4	Exchangeable Ca	0.1377	-0.0612	0.2197	-0.2828	-0.0654	0.1862	-0.0293
5	Exchangeable Mg	0.0202	0.0287	0.0942	-0.3424	-0.1826	0.0562	-0.0323
6	Exchangeable Na	-0.2203	0.1432	-0.0253	0.2523	0.2417	-0.1671	0.2370
7	Exchangeable Al	-0.2745	0.059	-0.3132	0.1062	-0.1009	-0.4096**	0.0233
8	Exchangeable Fe	0.089	-0.3507	-0.3474	0.0393	-0.2065	-0.1325	-0.2770
9	Exchangeable Mn	0.3190	-0.0546	0.1947	-0.0771	-0.0092	0.3175	-0.0396
10	Exchangeable Cu	0.3980*	-0.0374	0.0811	-0.0865	-0.0627	0.2331	-0.2671
11	Exchangeable Zn	0.0920	0.2629	0.2567	0.3715	0.4625*	0.2126	0.1796

* Significant at 5% level

** Significant at 1% level

Mn was positively correlated to PBC^K, Δk_0 and K potential and was negatively correlated to AR$_e^K$, Δk_x, Δk_L and ΔG. Exchangeable Cu was significantly and positively correlated to PBC^K. It was positively correlated to Δk_0 and negatively correlated to AR$_e^K$, Δk_x, Δk_L, and ΔG. Exchangeable Zn was significantly and positively correlated to Δk_L and was positively correlated to rest of the Q/I parameters (Table 14).

4.5.4. Correlation between soil properties and yield of coconut

Correlation coefficient worked out between soil properties and yield of coconut are presented in table 15.

pH was negatively correlated to coconut yield during the years 1989, 1990, 1991 and 1992.

Organic carbon, CEC, exchangeable Na, Al, Fe, Mn and Zn were positively correlated with yield during the years 1989, 1990, 1991 and 1992.

Exchangeable Ca was positively correlated with yield during the years 1989, 1990 and 1991 and was negatively correlated with yield during the year 1992. Exchangeable Mg was positively correlated with yield during 1989 and 1991 and was negatively correlated to yield during 1990 and 1992. Exchangeable Cu was negatively correlated to yield during the years 1989, 1990, 1991 and 1992 (Table 15).

4.5.5. Correlation between fractions of soil potassium

Water soluble K was significantly and positively correlated with available K, exchangeable K and HNO_3-K and was positively correlated to non

Table 15. Coefficient of correlation between soil properties and yield of coconut

Sl. No.	Soil Properties	Yield of coconut 1989	1990	1991	1992
1	pH	-.2208	-0.118	-0.2345	-0.1382
2	Organic carbon	0.2882	0.275	0.3343	0.2252
3	CEC	0.1646	0.0664	0.1387	0.0435
4	Exchangeable Ca	0.0314	0.109	0.0859	-0.08
5	Exchangeable Mg	0.0711	-0.1234	0.0568	-0.0451
6	Exchangeable Na	0.00098	0.1471	0.0293	0.1888
7	Exchangeable Al	0.2249	0.0147	0.1888	0.1125
8	Exchanageable Fe	0.1453	0.1567	0.0748	0.1425
9	Exchangeable Mn	0.1906	0.1418	0.0904	0.1122
10	Exchangeable Cu	-0.0148	-0.0918	-0.0121	-0.064
11	Exchangeable Zn	0.1394	0.0963	0.1034	0.0567

Table 16. Coefficients of correlation between soil potassium fractions

Sl. No.	Potassium fractions	Water soluble K	Available K	Exch. K	HNO_3 - K	Non Exchan. K	Total K
1	Water soluble K						
2	Available K	0.6124**					
3	Exchangeable K	0.4477*	0.9811**				
4	HNO_3-K	0.4541*	0.3673	0.3035			
5	Non exch. K	0.1487	-0.1709	-0.2305	0.8499**		
6	Total K	0.0712	0.3184	0.3407	0.3005	0.1387	

* Significant at 5% level

** Significant at 1% level

exchangeable K and total K. Available K was significantly and positively correlated with exchangeable K. It was positively correlated with HNO_3-K and total K and negatively correlated to non exchangeable K. Exchangeable K was positively correlated with HNO_3-K and total K and negatively correlated with non exchangeable K (Table 16).

The HNO_3-K was significantly and positively correlated to non exchangeable K and positively correlated with total K. Non exchangeable K was positively correlated with total K (Table 16).

4.5.6. Correlation between fractions of soil K and Q/I parameters

The correlation coefficients worked out between soil potassium fractions and Q/I parameters are available in table 17.

Water soluble K was positively correlated to AR_e^K, Δk_x, Δk_L and ΔG and was negatively correlated to PBC^K, Δk_0 and K potential. Available K and exchangeable K were positively correlated with AR_e^K and ΔG and was negatively correlated with PBC^K, Δk_0, Δk_x, Δk_L and K potential. HNO_3-K was significantly and positively correlated with AR_e^K. It was positively correlated with Δk_0, Δk_L and ΔG and was negatively correlated with PBC^K, Δk_x and K potential. Non exchangeable K was positively correlated to AR_e^K, Δk_0, Δk_L, K potential and ΔG and was negatively correlated to PBC^K and Δk_x. Total K was positively correlated to AR_e^K, Δk_0 and ΔG and was negatively correlated with PBC^K, Δk_x, Δk_L and K potential. All the fractions of K were negatively correlated with PBC^K and were positively correlated with AR_e^K and ΔG (Table 17).

Table 17. Coefficient of correlation between soil potassium fractions and Q/I parameters

Sl. No.	K fractions	PBC^k	AR_e^k	ΔK_0	ΔK_x	ΔK_L	K potential	ΔG
1	Water soluble K	-0.3226	0.2468	-0.133	0.0897	0.0155	-0.3474	0.1616
2	Available K	-0.3502	0.3318	-0.0929	-0.001	-0.0164	-0.3144	0.2973
3	Exchangeable K	-0.3170	0.3153	-0.0718	-0.0213	-0.0203	-0.2701	0.2952
4	HNO_3-K	-0.2033	0.4453*	0.2238	-0.0135	0.1524	-0.0701	0.3494
5	Non exchangeable K	-0.0216	0.2818	0.2886	-0.0236	0.1623	0.0979	0.2051
6	Total K	-0.0743	0.2417	0.0812	-0.0752	-0.0144	-0.0308	0.3108

* Significant at 5% level

4.5.7. Correlation between fractions of soil K and yield

Soil K fractions were correlated with yield for four years and results are presented in table 18.

Water soluble K was significantly and positively correlated with yield of coconut during the years 1989, 1990 and 1991 and positively correlated with yield during 1992. Available K was significantly and positively correlated with yield during 1989, 1990 and 1991 and positively correlated with yield during 1992.

Exchangeable K was significantly and positively correlated with yield during the year 1991 and was positively correlated with the yield during 1989, 1990 and 1992. HNO_3-K was positively correlated with yield during 1989, 1990, 1991 and 1992, while non-exchangeable K was negatively correlated to yield. Total K was positively correlated with yield during 1989, 1990, 1991 and 1992.

4.5.8. Correlation between Q/I parameters of potassium

Results of correlation between different Q/I parameters of potassium are as follows (Table 19).

PBC^K was significantly and positively correlated with K potential and significantly and negatively correlated with AR_e^K and ΔG. PBC^K was positively correlated with Δk_0 and negatively correlated with Δk_x and Δk_L. AR_e^K was significantly and positively correlated with Δk_0, Δk_L and ΔG.

Table 18. Coefficients of correlation between soil potassium fraction and yield

Sl. No.	K fractions	Yield of coconut			
		1989	1990	1991	1992
1	Water soluble K	0.4114*	0.4943*	0.4292*	0.3647*
2	Available K	0.3942*	0.4110*	0.5034*	0.3444
3	Exchangeable K	0.3461	0.3440	0.4649*	0.3000
4	HNO_3 K	0.0342	0.1348	0.0584	0.0817
5	Non Exchangeable K	-0.1834	-0.070	-0.2134	-0.0916
6	Total K	0.0906	0.2207	0.0794	0.1621

* - Significant at 5% level

Table 19. Coefficients of correlation between Q/I parameters of potassium

Sl. No.	Q/I parameters	PBC^k	AR_e^k	ΔK_o	ΔK_x	ΔK_L	K potential	ΔG
1	PBC^k							
2	AR_e^k	-0.4790*						
3	ΔK_o	0.2736	0.5445**					
4	ΔK_x	-0.2826	0.2505	-0.1602				
5	ΔK_L	-0.1768	0.6317**	0.5498**	0.7155**			
6	K potential	0.8117**	-0.0754	0.7369**	-0.2371	0.2240		
7	ΔG	-0.6018**	0.9116**	0.4525*	0.1880	0.5456**	-0.1698	

* - Significant at 5% level

** - significant at 1% level

AR_e^K was positively correlated with Δk_x and negatively correlated with K potential. Δk_0 was positively and significantly correlated with Δk_L, K potential and ΔG. Δk_0 was negatively correlated with Δk_x. Δk_x was significantly and positively correlated with Δk_L. Δk_x was positively correlated with ΔG and negatively correlated with K potential. Δk_L was significantly and positively correlated with ΔG and negatively correlated with K potential. K potential was negatively correlated with ΔG (Table 19).

4.5.9. Correlation between Q/I parameters of potassium and yield

Correlation was worked out between Q/I parameters and the yield for four years and the results are presented in table 20.

PBC^K was significantly and negatively correlated with yield during 1989, 1990, 1991 and 1992 (Table 20). AR_e^K was positively correlated with yield. The labile K parameters Δk_0, Δk_x and Δk_L were negatively correlated with yield during 1989, 1990, 1991 and 1992. K potential was also negatively correlated with yield. Free energy (ΔG) was positively correlated with yield (Table 20).

4.6. Regression Analysis

Simple linear and multiple regression equations relating yield with significant attributes are presented in Tables 21 and 22.

Ten different soil attributes, which have shown direct or indirect influence on the yield, were selected to fit linear regression equations. None of

Table 20. Coefficients of correlation between Q/I parameters of potassium and yield

Sl. No.	Q/I parameters	Yield of coconut			
		1989	1990	1991	1992
1	PBC^k	-0.3958*	-0.4153*	-0.3951*	-0.4442*
2	AR_e^k	0.1799	0.2509	0.2017	0.1752
3	ΔK_o	-0.1405	-0.0623	-0.1250	-0.1516
4	ΔK_x	-0.0247	-0.0684	-0.0601	-0.0192
5	ΔK_L	-0.0601	-0.0489	-0.0754	-0.0578
6	K potential	-0.3458	-0.3264	-0.3395	-0.3756
7	ΔG	0.1991	0.2915	0.2328	0.2696

* - Significant at 5% level

Table 21. Linear regression equations relating the yield with soil chemical environment

Sl.No.	X	Y = yield 1989	r^2	Y = yield 1990	r^2	Y = yield 1991	r^2	Y = yield 1992	r^2	Y = yield 90-91	r^2
1	Organic carbon	$y= -100.70+1021.23x$	.083	$y= -18.21+323.26x$	.08	$y= -103.89+941.74x$	.11	$y= 29.88+447.77x$	.0051	$y= -45.71+370.01x$	.14
2	CEC	$y= 31.72+68.56x$	.027	$y= 73.85+9.17x$	.004	$y= 87.4+45.9x$	.02	$y= 167.56+10.16x$	.002	$y= -5.27+26.72x$	.05
3	Water soluble K	$y= 76.1+21.31x$	.17	$y= 18.89+8.49x$	.24	$y= 80.51+17.67x$	.18	$y= 93.82+10.6x$	.13	$y= 34.49+6.22x$	.18
4	Exchangeable K	$y= 209.09+4.43x$	.12	$y= 78.57+1.46x$	.12	$y= 167.66+2.15x$	0.22	$y= 161.06+2.15x$	0.09	$y= 66.89+1.59x$	.19
5	Available K	$y= 160.26+4.46x$	.16	$y= 60.12+1.54x$	.17	$y= 123.23+4.53x$	.25	$y= 136.76+2.19x$	.12	$y= 51.50+1.54x$	.23
6	Non Exchangeable K	$y= 362.94-1.18x$	.034	$y= 117.75-0.15x$	.005	$y= 323.84-1.09x$	.05	$y= 224.17-0.33x$	.008	$y= 123.6-0.45x$	.06
7	PBC^k	$y= 400.37-98.51x$	.16	$y= 143.36-34.28x$	.17	$y= 346.04-78.15x$	.16	$y= 267.6-62.03x$	.20	$y= 127.99-27.49x$	.15
8	ARe^k	$y= 255.32+18677.46x$	.18	$y= 87.06+8641.29x$	.063	$y= 225.99+16646.56x$	.041	$y= 180.5+10204.51x$	.03	$y= 91.09+3895.24x$	.02
9	K Potential	$y= 369.42-28896.7x$	.032	$y= 130.38-9047.1x$	.11	$y= 320.67-22554.5x$	.12	$y= 246.84-17611.13$	.14	$y= 120.67-8666.62x$	.14
10	AG	$y= 652.37+22.80x$	.04	$y= 278.68+11.07x$	.085	$y= 593.06+21.19x$	.054	$y= 471.32+17.32x$	.072	$y= 186.20+5.56x$	.03

Table 22. Multiple regression equations relating yield and soil potassium status

y = yield of nuts in 1989

y = 253.71 + 335.82 water soluble K − 324.33 available K + 326.28 exchangeable K − 105.08 PBC^k + 15127 ARe^k + 9730.31 K potential ($r^2 = 0.30$)

y = yield of nuts in 1990

y = 63.08 + 30.09 water soluble K − 23.57 available k + 24.022 exchangeable K − 39.16 PBC^k − 3184.96 ARe^k + 5924.13 K Potential ($r^2 = 0.34$)

y = yield of nuts in 1991

y = 198.97 + 197.88 water soluble K − 189.51 available k + 192.60 exchangeable K − 79.80 PBC^k − 2220.01 ARe^k + 9159.02 K potential ($r^2 = 0.35$)

y = yield of nuts 1992

y = 197.84 − 4.442 water soluble K + 11.40 available k − 10.5 exchangeable K − 78.52 PBC^k − 10260.63 ARe^k + 8580.77 K potential ($r^2 = 0.27$).

y = Mean yield of nuts during 1990 and 1991

y = 753.54 + 254.57 water soluble k − 251.39 available K + 252.22 exchangeable K + 13.59 PBC^k − 33616.69 ARe^k − 5330.66 K potential ($r^2 = 0.38$)

the equations resulted in significant r^2 values for all the four year's yield estimates (Table 21) and also for the yield estimate for 1990-1991.

Nevertheless, the linear equations developed to estimate yield in relation to watersoluble K, exchangeable K, available K, PBC^K, AR_e^K and K potential were relatively better in r^2 values. These parameters were used to develop the multiple regression equations presented in table 22. It was observed that coconut yield could be explained by variations in these parameters, but only with moderate accuracy (r^2 ranged from 0.27 to 0.38).

DISCUSSION

DISCUSSION

Nutrient management at different levels over a long period of time would result in significant soil spatial variability in the coconut garden. The changes in soil chemical environment due to applied treatments and the resultant differences in the response of coconut have been measured and presented in the foregoing chapter. The results can now be discussed in the light of published information and fundamental theoretical considerations.

5.1 Soil chemical environment in the coconut garden

Several of the soil chemical constituents under observation have changed in magnitude as is evident from the data on tables 1 to 3. This excludes the potassium dynamics which forms the major thrust of the present investigation.

The soil properties affecting K availability are pH, organic carbon, cation exchange capacity, interacting cations and mineralogical characteristics. (Chatterjee and Maji, 1984).

The pH of soil was significantly reduced as a result of application of $(NH_4)_2SO_4$ @ 340 g and 680 g N/tree/ year for 25 years whereas the plot which has not received $(NH_4)_2SO_4$ for 25 years recorded a significantly higher pH compared to others (Fig.2). Acidifying effect of NH_4^+ ions as a result of continuous addition of $(NH4)_2SO_4$ in the basins of coconut palms has been

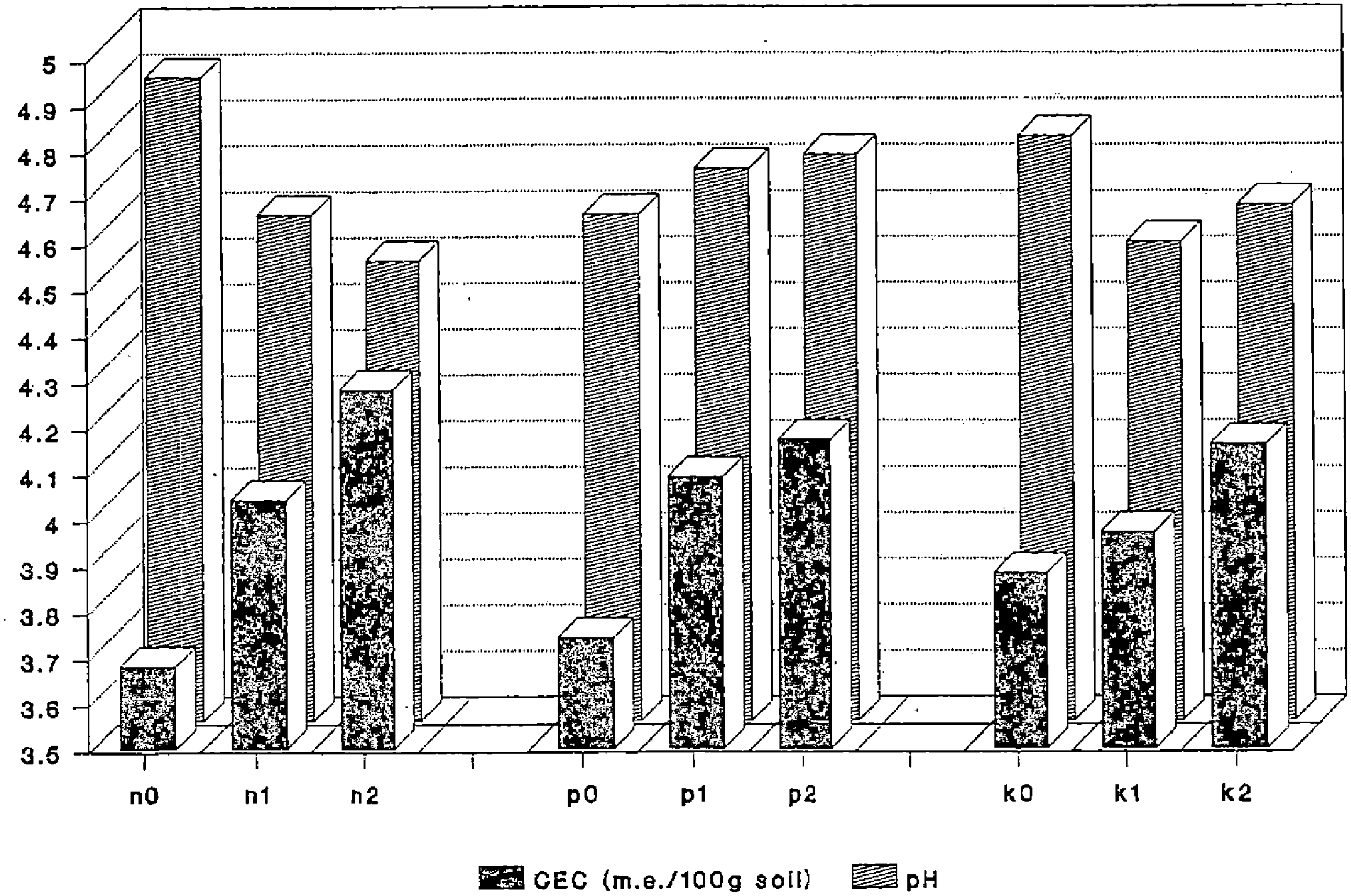

Fig. 2. Main effects of N, P and K on pH and CEC

reported by Kamaladevi *et al.* (1975), Pushpangadan (1985), Anil Kumar and Wahid (1989) and Prabhakumari (1992).

The soils recorded a low organic carbon content (0.32 to 0.48%). The lowest organic carbon value considered ideal for the growth of coconut was 1.0 (Manciot *et al.*, 1979). The organic carbon content of the soil under investigation was much below the ideal value. There was no significant difference in the organic carbon content in the soil under different treatments. This corroborates the finding of Pushpangadan (1985) and Prabha Kumari (1992). In soils which are inherently low in organic carbon content, chemical fertilization for long periods will not produce drastic changes in organic carbon content.

Owing to the predominance of low activity clay minerals, the experimental soils recorded very low CEC. However the imposition of fertilizer treatments created significant differences in CEC. CEC of the fertilized plots was significantly higher than unfertlized plots. CEC was found to increase with higher levels of N, P and K (Fig.2). Pushpangadan (1985) reported that application of N and K continuously resulted in a significant increase in CEC from unfertilized to fertilized plots.

The exchangeable Ca content of the soil was not influenced significantly by the long term application of fertilizers. Exchangeable Ca content of the soil increased with increasing rate of superphosphate due to the influence of Ca present in the fertilizer material (Fig.3). Anil Kumar and Wahid (1989) also reported the increase in Ca content of the soil as a result of

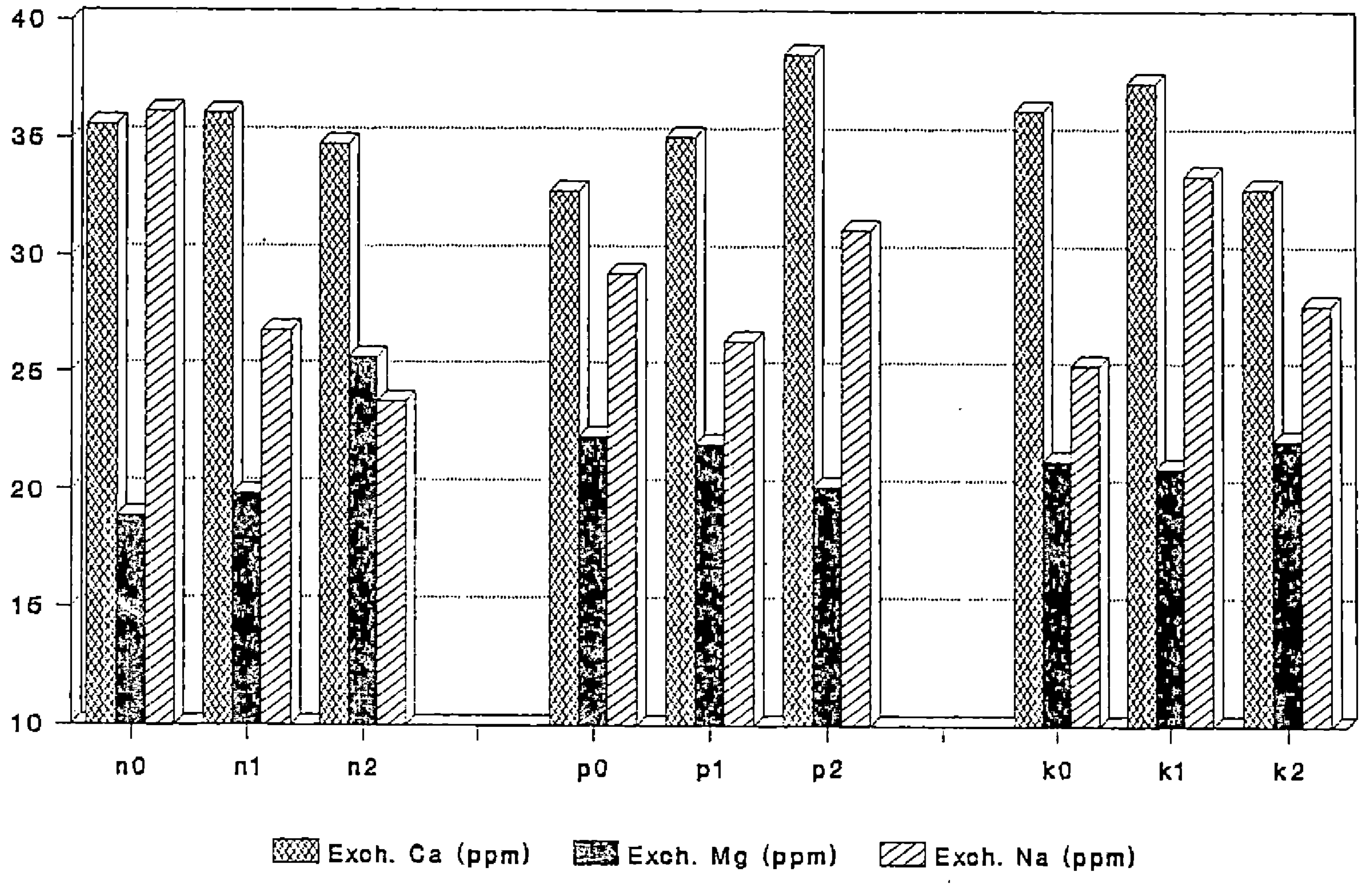

Fig. 3. Main effects of N, P and K on Exchangeable Ca, Exchangeable Mg and Exchangeable Na

continuous application of super phosphate. The exchangeable Ca content of the soil decreased as a result of application of N and K at highest levels (Fig.3). Pushpangadan (1985) and Prabha Kumari (1992) reported that the continuous application of N resulted in a decrease in Ca status of soil due to leaching of Ca under the influence of residual acidity brought from the application of $(NH_4)_2SO_4$.

The continuous application of fertilizers did not significantly affect the exchangeable Mg content of the soil. However continuous application of N significantly increased exchangeable Mg content from n_0 to n_2 levels, while P and K did not influence the Mg content of soil which might be due to the K x Mg antagonism in the absence of applied Mg (Fig.3). Similar reports were made by Pushpangadan (1985) and Prabha Kumari (1992).

The long term application of N reduced the exchangeable Na content of the soil, while the continuous application of P and K did not affect the exchangeable Na status (Fig.3).

The exchangeable Al content of the soil increased with increasing doses of N (Fig.4). This may be due to the reduction in pH as a result of continuous application of $(NH_4)_2 SO_4$. The long term application of P and K did not significantly affect the exchangeable Al content of the soil.

The exchangeable Fe, Mn and Zn contents of the soil were not significantly affected by the long term application of N,P or K fertilizers. Similar reports were made by Anil Kumar and Wahid (1989) in the case of Fe

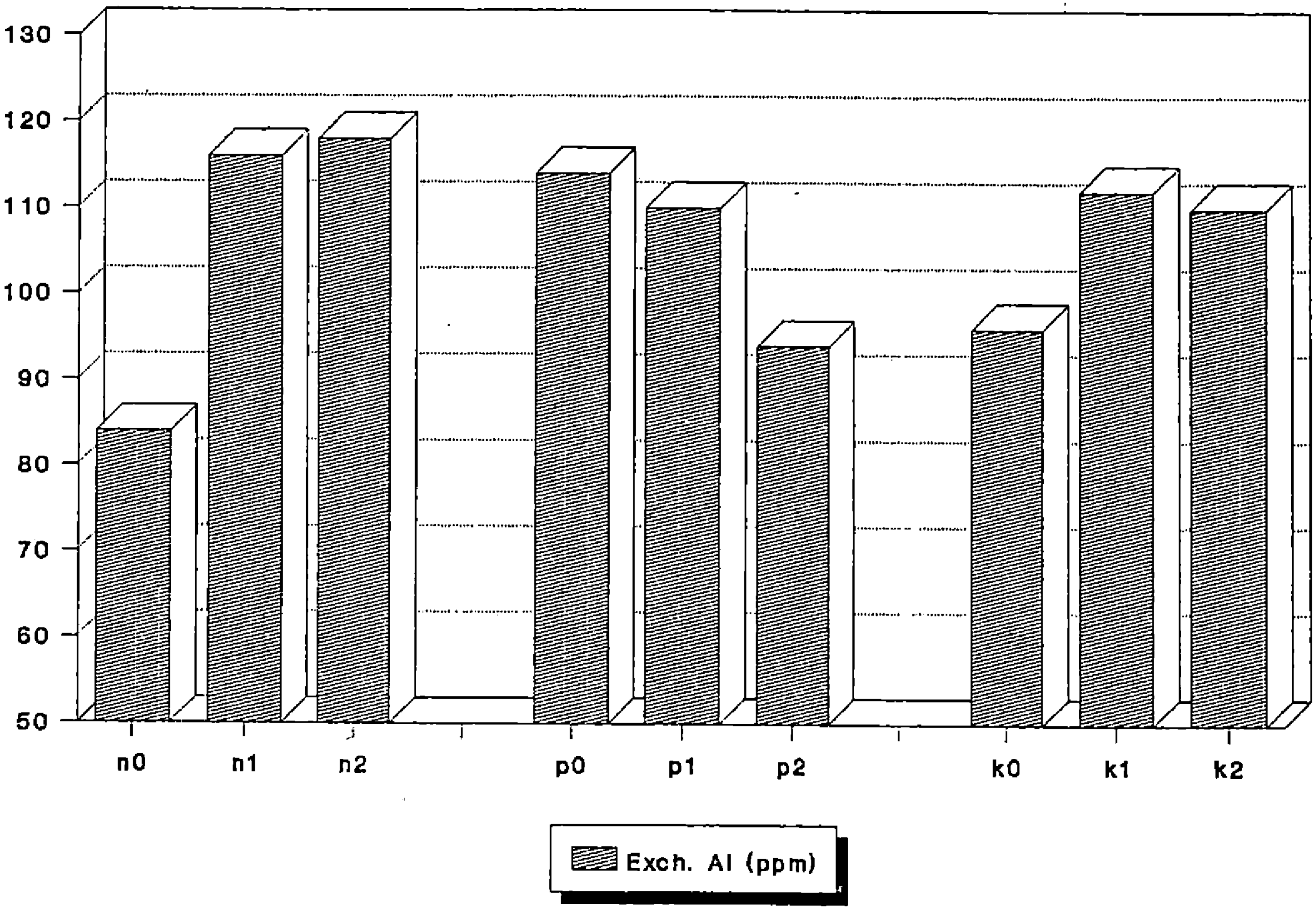

Fig. 4. Main effects of N, P and K on Exchangeable Al

and Zn. However, they reported erosion of soil Mn fertility along the root zone profile due to drop in pH. The long term application of N and K significantly affected the exchangeable Cu content of the soil, where as the effect of P was not pronounced.

Among the soil characteristics studied under the present project, Zn and Mn were found to be correlated positively (Table 12). Another notable observation was the significant negative correlation between exchangeable Al and pH. The influence of exchangeable Al in determining the soil reaction of acid soils has been reported by several workers. Exchangeable Al was positively and significantly correlated with exchangeable Mg. In turn, exchangeable Mg was positively correlated with organic carbon. The influence of exchangeable Al on the dynamics of major as well as minor nutrients deserves further attention, even though Al is not rated as essential plant nutrient.

5.2 Potassium availability indices in the coconut garden

Availability of soil potassium is a function of its chemical forms in the soil as well as other soil properties. Several methods have been suggested for reasonable soil tests to represent potassium availability for crop uptake. One of the most popular methods involve extraction of potassium with Normal Neutral Ammonium acetate and designating it as available K (Hanway and Heidal, 1952). However, several scientists have suggested inclusion of other forms of potassium as availability indices (Sachdev and Khera, 1980; Bajaj and Goswami, 1987 and Beegle and Baker, 1987). Lal *et al.* (1990) reported that on long term fertilization exchangeable and non exchangeable forms of K play an important role in K uptake by maize and wheat. In the present study estimations were carried out on different fractions of soil as well as the quantitiy-intensity parameters of soil K. The effect of graded nutrition of coconut was reflected in the contents and interactions of these parameters.

There were significant differences in the forms of potassium present in the soil after 25 years of continuous addition and crop uptake. The contents of water soluble, available and exchangeable k increased significantly with higher levels of potash application whereas HNO_3-K, non exchangeable K and total K remained unchanged (Fig.5). HNO_3-K also increased with increasing doses of K, though it was not significant whereas non- exchangeable K decreased with increasing doses of K. This corroborates the finding of Premakumar (1989). Anil Kumar and Wahid (1989) reported an increase in available K as a result of continuous application of muriate of potash to coconut. A slight increase in total potassium content of the soil was observed due to continuous potash addition, though it was not significant. But the contribution towards total potassium was mainly from available and exchangeable forms as evident by the low non- exchangeable potassium content of fertilized plots. Large reserves of potassium cannot be built up in such a soil with predominantly non expanding clay minerals. Chatterjee *et al.* (1983) reported that in non-fixing type soils (eg. Kaolinite dominant) non exchangeable K was considered as an inferior source of potassium for plant. Since kaolinitic clay minerals have no inter layer binding site for K and have low CEC, they do not hold non exchangeable K. Therefore as far as potassium dynamics is concerned, kaolinite has behaved similar to sand particles. Thus it

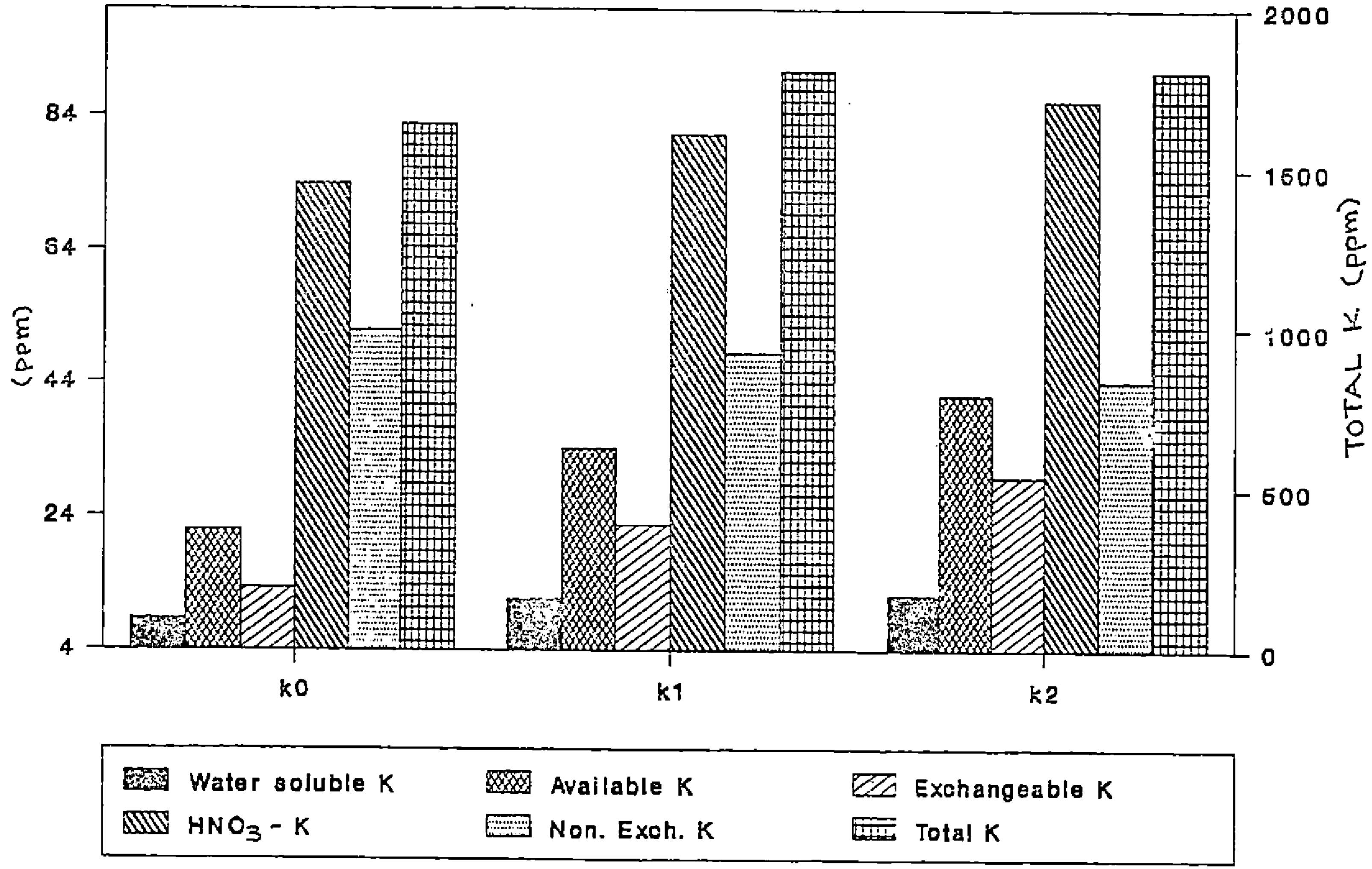

Fig. 5. Main effects of K on water soluble, available, exch., HNO_3- K Non. exch. and total K

is evident that the reserves of soils dominant in kaolinite cannot be made sufficient for sustained crop production and hence continuous K fertilization may be recommended for coconut in such soils.

Long term application of N and P did not significantly affect the potassium content of the soil though there was a decreasing trend in easily extractable forms with an increase in N and P (Fig.5). The reduction in exchangeable K content as a result of long term application of P due to the influence of Ca in the fertilizer material in replacing the K from exchange sites was reported by Anil Kumar and Wahid (1989).

The quantity-intensity relations of labile soil K relate its availability or intensity (I) to the amount (Q) present in the soil. The power of a given soil to supply any particular nutrient is characterised by both the total amount of nutrient present and intensity at which it is supplied. The relationship between these two parameters may be determined by the Quantity - Intensity (Q/I) technique proposed by Beckett (1964 b). The Q/I relation gives a measure of both the current K potential in the labile pool (degree of availability or intensity factor, I) measured as the activity ratio and the way in which this potential depends on the quantity (Q) of the labile K in the soils.

The PBC^K value ranged from 0.25 to 3.33 $me.100g^{-1}$ $(mol\ litre^{-1})^{1/2}$. Valsaji (1989) reported a PBC^K value of 0.86 to 9.6 $me.100g^{-1}$ $(mol\ litre^{-1})^{1/2}$ in Neyyattinkara sandy loam soil. The treatment $n_1p_1k_0$ recorded the highest PBC^K of 3.33 $me.100g^{-1}$ $(mol\ litre^{-1})^{1/2}$. A high soil PBC^K value is indicative of greater capacity of the soil to maintain K concentration for longer periods although it often leads to low K intensity. The lowest PBC^K value of 0.25 $me.100g^{-1}$ $(mol\ litre^{-1})^{1/2}$ was recorded in the treatments $n_2p_0k_2$ and $n_2p_1k_1$.

Application of N increased the PBC^K values from n_0 to n_2, where as the effect of P was quadratic. PBC^K decreased from k_0 to k_2 treated plots(Fig.6). The lowering of PBC^K value indicate a high potassium intensity due to increase in the fertilizer dose in k_1 and k_2 treated plots. A low PBC^K value in this soil necessitates frequent fertilization because such soils fail to maintain a given K supply for a considerable period (Sparks and Liebhardt, 1981).

The equilibrium activity ratio (AR_e^K) ranged from 0.0006 to 0.0064 $(mol\ litre^{-1})^{1/2}$. Valsaji (1989) reported a range of 0.011 to 0.026 $(mol\ litre^{-1})^{1/2}$ in Neyyattinkara sandy loam soils. The lowest AR_e^K value was observed in $n_1p_1k_0$ treatment and highest in $n_0p_0k_1$ and $n_0p_1k_2$ treatments. This indicates that a reduction in AR_e^K value was noticed when N and P were applied without K. This corroborates the findings of Patra and Khera (1983). An increase in AR_e^K value was found when K was applied alone and in combination with lowest level of P. But Biswas *et al.* (1989) observed that absence of any one of the major nutrients in the fertilizer schedule resulted in a decrease in AR_e^K value.

Application of N resulted in a decrease in AR_e^K value from n_0 to n_2 treated plots where as application of P had a quadratic effect. AR_e^K value was higher in p_1 treated plot than p_0 and p_2 treated plots.

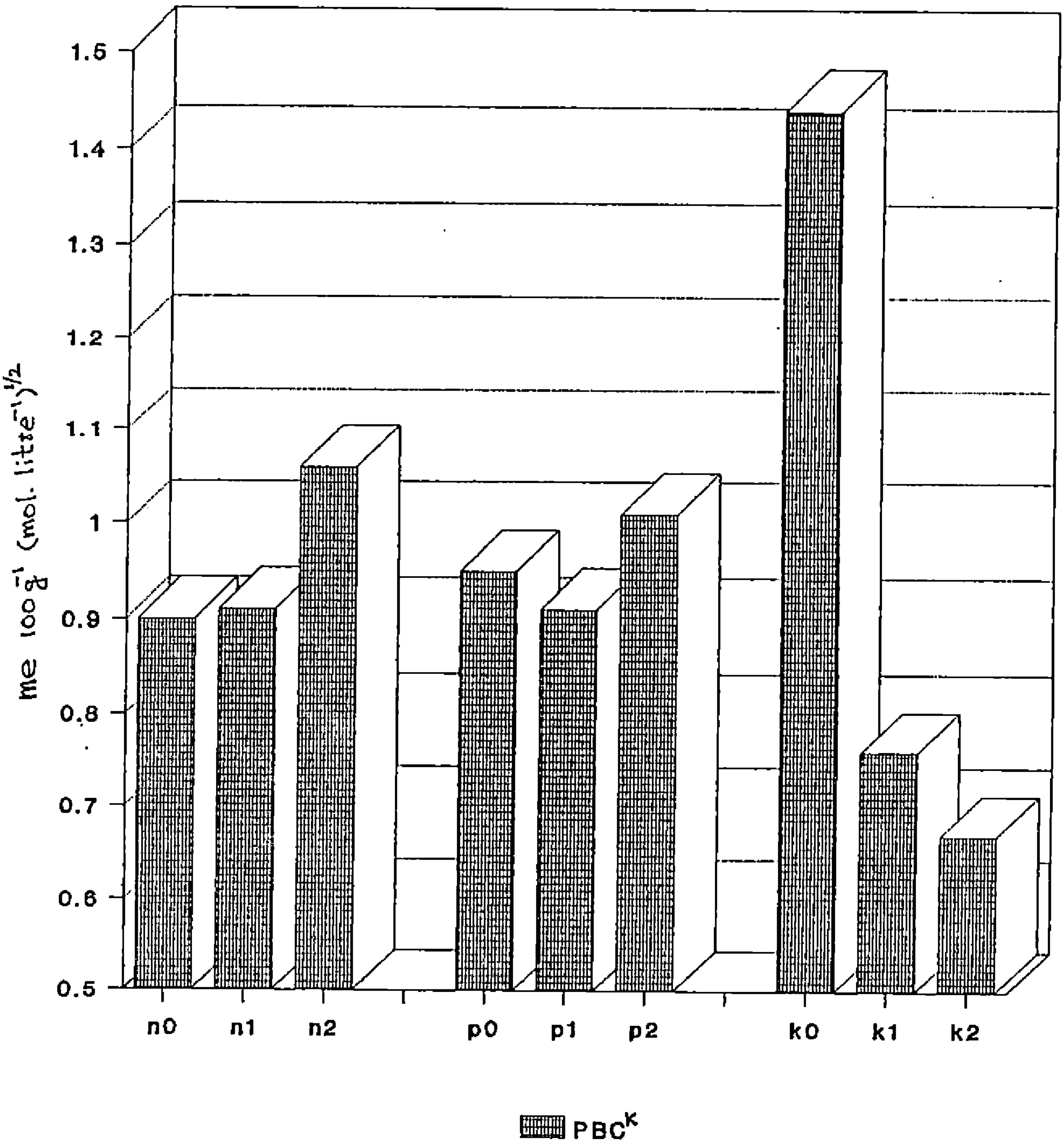

Fig. 6. Main effects of N, P and K on PBC^K

Increased levels of K fertilization increased AR_e^K, which conformed with findings of Beckett (1964 b), Le Roux and Sumner (1968 b) and Sparks and Liebhardt (1981). The values of AR_e^K in the present study were well above the minimum AR_e^K ($5x10^{-4}$ mol L^{-1}) at which the crop may respond to K application (Beckett,1972).

The K held on non specific planar sites (ΔK_0) ranged from 0.0004 to 0.0064 me 100 g^{-1}. Valsaji (1989) reported that ΔK_0 ranged from 0.013 to 0.120 me $100g^{-1}$. The mean value for ΔK_0 was 0.002 me. $100g^{-1}$ which was much lower than the mean value of exchangeable K. (0.011 meq.$100g^{-1}$). Sparks and Liebhardt (1981) and Dutta and Joshi (1992) reported a lower ΔK_0 value than exchangeable K. These observations find support from the report of Beckett and Nafady (1968) who reported that a part of exchangeable K did not contribute to the ΔK_0 pool. Mean value of ΔK_0 was also lower than mean value of NH_4OAC-K. Sparks and Liebhardt (1981) reported that NH_4OAC-K tended to over predict exchangeable K in some soils. Higher exchangeable or labile K with NH_4OAC-K was attributed to displacement of K with a crystalline radius of $1.33A^0$ by NH_4^+ with crystalline radius of $1.43A^0$ from wedge zones or specific sites of K bearing minerals (Rich, 1964).

The content of K associated with specific sites (ΔK_x) ranged from 0.002 to 0.0076 me.$100g^{-1}$, which was lower than the range (0.35 to 0.42 meq.$100g^{-1}$) reported by Valsaji (1989). ΔK_x values were higher in the n_1, p_1 and k_1 treated plots compared to other plots. ΔK_x value increased when K was applied @450 g K_20/palm/year, but decreased when 900 g K_2O/ palm/ year was applied. Sparks and Liebhardt (1981) reported that K fertilization increased the value of ΔK_x in soils containing $14A^0$- intergrade minerals (Chloratized vermiculite).

Labile K (ΔK_L) obtained from Q/I relationship is the loosely held K being exchanged by the Ca ions from colloidal surface (Beckett *et al.,* 1966). The labile K includes both the K held at specific sites (ΔK_x) and non specific sites (ΔKo). The ΔK_L of the soils ranged from .0014 to .009 me $100g^{-1}$. Valsaji (1989) reported a range of .048 to .54 me $100g^{-1}$ in Neyyattinkara sandy loam soils.

Application of N decreased the ΔK_L values from n_0 to n_2. The effect of P was quadratic. The plots not receiving K fertilizers recorded a higher ΔK_L compared to those receiving K fertilizer.

The K potential of the different treatments ranged from .0001 to 0.0085 me $100g^{-1}$ $(\text{mol litre}^{-1})^{1/2}$. The K potential decreased with K fertilization application.

The free energy of exchange (ΔG) ranged from -12.50 to -18.35 $KJmol^{-1}$. Woodruff (1955) suggested a critical value of -16.8 $kJmol^{-1}$ for response. Except the treatments $n_1p_1k_0$, $n_2p_0k_0$ and $n_2p_2k_2$, the ΔG values of all other treatments were lower than the critical value. According to his classification a value of -16.8 to -14.7 KJ mol^{-1} are deficient in available K, values between - 14.7 and -10.5 KJ mol^{-1} are adequate and those having less than - 8.4 KJ mol^{-1} cause K toxicity. As per this classification the majority of soils under investigation came under the deficient range and the rest under the adequate range. Maida (1980) reported ΔG values of -12 to -16 KJ mol^{-1} in soils growing tea plants and field observations showed that tea plants growing on soils having ΔG values less than -15 KJ mol^{-1} responded to k fertilizers.

5.3. Potassium dynamics in the coconut garden

The state of equilibrium that exists in the soil with chemical identities of potassium as well as its attribute variables, is dynamic, and therefore subject to spatial and temporal variations. Hence prediction of the behaviour of soil potassium in a specific soil situation is often difficult. The type and extent of interaction of each form of potassium with other soil components would fluctuate often beyond the limits of empirical expressions. Nevertheless the ensuing text explores the intricacies in these relationships so as to develop viable models to predict potassium dynamics in a coconut growing soil under rainfed situation.

Following is a perusal of the correlations obtained between various properties under study.

The pH was significantly and positively correlated to non exchangeable K, negatively correlated to water soluble K, available K, exchangeable K and positively correlated to HNO_3-K and total K. Subba Rao and Sekhon (1991) reported that the effect of pH on water soluble and exchangeable K content and their relationship were not conspicuous in soils with appreciable amount of organic carbon and pH greater than 5.5.

Organic carbon was positively correlated to readily available forms of K viz., water soluble K, available K, exchangeable K and was negatively correlated to HNO_3-K, non exchangeable K and total K. An increase in water soluble and exchangeable K contents with increase in organic carbon content in acid tropical soils has been reported by Subba Rao and Sekhon (1991).

CEC was significantly and negatively correlated to difficulty exchangeable forms of K, viz., HNO_3-K and non-exchangeable K. CEC was negatively correlated to water soluble K, total K and was positively correlated to available K and exchangeable K. A positive correlation of CEC with water soluble, exchangeable and difficulty exchangeable forms was reported by Shanmughanathan and Loganathan (1976) in some coconut growing soils of Srilanka.

The exchangeable Ca was found to correlate positively with all the potassium fractions. This corroborates the finding of Shanmughanathan and Loganathan (1976).

The exchangeable Mg was significantly and negatively correlated to difficultly exchangeable forms of K namely HNO_3-K and non exchangeable K. It was negatively correlated to water soluble K, total K and was positively correlated to available K and exchangeable K.

The exchangeable Na content of the soil was positively correlated to available K, exchangeable K, HNO_3-K, non exchangeable K and was negatively correlated to water soluble K and total K.

The exchangeable Al was negatively correlated to total K, non exchangeable K, HNO_3-K and was positively correlated to water soluble, available K and exchangeable K. Competition of Al for exchange sites may increase K availability of the soil containing high amounts of exchangeable Al.

The exchangeable Fe was significantly and negatively correlated with HNO_3-K. Exchangeable Fe, cu, Mn and Zn were positively correlated to water soluble K, available K and non exchangeable K. Exchangeable Cu, Mn and Zn were positively correlated with exchangeable K, whereas exchangeable Fe was negatively correlated with exchangeable K. The correlation of Cu and Mn with HNO_3-K were positive and that of exchangeable Zn was negative. Exchangeable Mn and Zn were correlated positively with total K, while exchangeable Cu was correlated negatively with total K.

The watersoluble K was significantly and positively correlated to available K, exchangeable K and HNO_3-K. Positive non significant correlations were observed between water soluble K, non exchangeable K and total K. Similar reports have been made by Devi *et al.* (1990) in Vellayani and Neyyattinkara soil series. Available K was positively and significantly correlated with exchangeable K and water soluble K. Mishra and Srivastava (1991) reported similar results in soils of Garhwal Himalayas. The exchangeable K was positively correlated to HNO_3-K and was negatively correlated to nonexchangeable K where as HNO_3-K was significantly and positively correlated with non exchangeable K. These relationships suggest the dynamic equilibrium existing between different forms of soil potassium.

Among the soil properties organic carbon, CEC, exchangeable Na and Al were negatively correlated with PBC^K. Other soil properties were positively correlated to PBC^K. Only exchangeable Cu was significantly and positively correlated with PBC^K. None of the K fractions were significantly correlated to PBC^K. The K fractions were negatively correlated to PBC^K indicating that an increase in K fractions results in a low buffering capacity of the soil. Dutta and Joshi (1992) reported that the PBC^K values were related neither with soil characteristics nor with available forms of K and the variability in PBC^K values could be explained better due to combined effect of soil characteristics than that of available forms of K.

None of the soil properties were significantly correlated to AR_e^K. Similar results were reported by Dutta and Joshi (1992). Among the K fractions HNO_3-K was significantly correlated to AR_e^K. Dutta and Joshi (1992) reported that none of the available forms of K significantly correlated with AR_e^K.

The Δk_0 was found to be significantly and negatively correlated to CEC. None of other soil properties significantly correlated with Δk_0. Also none of the potassium fractions significantly correlated with Δk_0. This corroborates the findings of Dutta and Joshi (1990, 1992) who reported that neither the soil properties nor the K fractions did significantly affect Δk_0.

None of the soil properties and K fractions correlated significantly with ΔK_x. Similar results were observed by Chandi and Sindhu (1983) and Dutta and Joshi (1992).

Among the soil properties ΔK_L was significantly correlated with exchangeable Zn. None of the other soil properties and K fractions significantly affected ΔK_L. Dutta and Joshi (1990, 1992) reported that none of the soil properties and K fractions were significantly correlated to ΔK_L.

The K potential was significantly and negatively correlated to exchangeable Al. Other soil properties were not significantly correlated to K potential. Dutta and Joshi (1990, 1992) reported that K potential was significantly correlated with CEC, significantly and negatively correlated with pH (Dutta and Joshi, 1990).

None of the K fractions significantly correlated with K potential. This is in agreement with the findings of Dutta and Joshi (1990, 1992).

ΔG was found to be positively correlated with all potassium fractions.

The potential buffering capacity of K was significantly and negatively correlated to AR_e^K and ΔG and positively correlated to K potential and Δk_0. Among the quantity factors, PBC_k was correlated negatively with ΔK_x and Δk_L whereas Δk_L was significantly correlated with ΔK_o and ΔK_x. Chandi and Sindhu (1983) reported a positive correlation of PBC^K with labile K parameters and a negative correlation with AR_e^K. A positive significant correlationsof AR_e^K with ΔK_o, ΔK_L and ΔG were observed. These relationships indicate that higher amount of K and higher amount of free energy of exchange were associated with higher AR_e^K. The free energy of exchange (ΔG) was significantly and positively correlated with AR_e^K, ΔK_o and ΔK_L and negatively related to PBC^K. The quantity factors ΔK_o and ΔK_L were significantly and positively correlated to AR_e^K indicating the close relationship of labile K parameters (quantity factors) with the intensity factor. The inter relationships among the quantity intensity parameters point out that any change in one entity will be accompanied by changes in other parameters.

5.4 Yield response of coconut

5.4.1. Response to graded nutrition

The field experiment represents a variety of fertilizer management levels under rainfed coconut cultivation. However the 27 combinations did not differ significantly with respect to yield of nuts. The results (tables 7,8 and 9) highlight the importance of extraneous factors other than fertilizers, especially available moisture, in determining the yield of coconut under rainfed situations. Reports by Nair *et al.* (1988) suggest that upto 50% increase in yield in coconut could be achieved by the effect of irrigation.

Even under rainfed situations, the levels of potassium significantly influenced nut yield. More than 200% increase in yield was observed during all the years (Table 10) at k_1 and k_2 levels than k_0 level. However the percentage increase in yield from k_1 to $k_2$was not as high as that from k_0 to k_1 though the differences were significant (Fig. 7). Potassium levels were found to interact significantly with N status of the soil especially during 1989. Nitrogen application without potassium resulted in a decrease in yield whereas N along

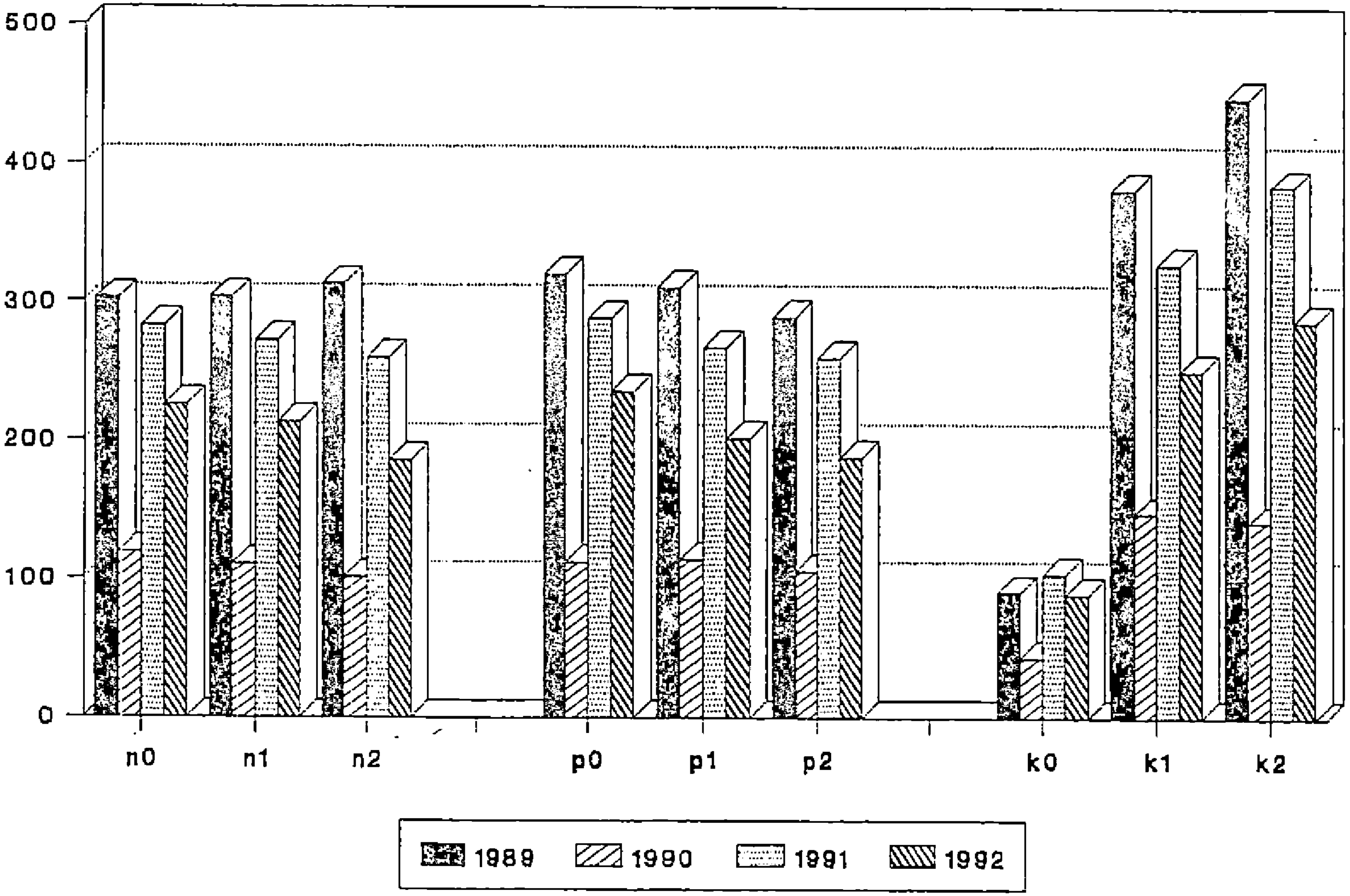

Fig. 7. Main effects of N, P and K on yield (Mean number of nuts per treatment ie., 4 palms)

with K significantly increased the yields. The importance of potash nutrition to coconut palms has been reported on several occassions (Fremond and Ouvrier, 1971, Magat *et al.* 1975, Margate *et al.*, 1979 and Singh and Mishra, 1991). There were also earlier reports that the limiting effect of N will be more pronounced when K is applied without N.

5.4.2 Response to soil chemical environment

The effect of soil chemical environment on the availability of nutrients especially K is discussed elsewhere (Section 5.1). Simple correlations were worked out between various soil parameters and the yield (Table 15). Those factors which were found to influence yield were included in the construction of linear regression equations (Table 21). Organic carbon and cation exchange capacity were found to be the two main factors influencing the yield of coconut. Reports by Manciot *et al.* (1979) support the present findings.

5.4.3 Response to potassium dynamics

Yield of coconut was significantly correlated with water soluble, available and exchangeable K. The relationship was positive in the case of above fractions as well as HNO_3-K and total K. Non exchangeable K showed a negative relationship with yield. Same was the case with PBC^K. Valsaji (1989) reported that water soluble K, exchangeable K, available K, HNO_3-K and PBC^K were significantly and positively related to yield whereas non exchangeable K had a positive non significant relationship.

Judging from the findings it can be suggested that coconut yield estimates could be better accomplished if the level of K extracted with NH_4-OAC is considered along with other fractions of K as well as the PBC^K. Consequently simple linear regressions were worked out to define coconut yield. (Table 21). The equations were significant in the case of watersoluble K, available K, exchangeable K and PBC^K. According to Valsaji (1989) these factors can influence coconut yield in an appreciable level.

Attempts were made to quantify the effect of potassium dynamics on coconut yield. The parameters selected for this exercise was based on the findings discussed earlier. The regression equations obtained thus are available in Table 22. It was seen that the influence of the parameters under study on the yield of coconut under rainfed conditions is only about 30 to 35 percent. Similar attempts on yield estimates are reported earlier also.

Foregoing discussion on the results obtained points to the relative significance of potassium dynamics under rainfed coconut cultivation.

SUMMARY

SUMMARY

Chemical fertilization of coconut plantations without organic matter supplement over a long period will affect the inherent soil chemical environment. Therefore, the response of coconut palms to added fertilizer may also change with time. Coconut plantations are always managed by supplying large quantities of potassium fertilizers compared to other nutrients. Continuous addition of potassium with and without other nutrients will affect the different fractionsof soil potassium and therefore, potassium fertility of the soil. Potassium fertility, is, inturn, affected by various soil properties. An attempt has been made to document the soil chemical environment as well as the dynamics of soil potassium after 25 years of differential fertilizer doses in a coconut plantation.

Soil samples from the root zone (0-60cm) of the 25 year old coconut palms from a 3^3 confounded factorial experiment on NPK were analysed for various soil chemical constituents including fractions of potassium and the Q/I parameters of soil potassium. Treatment effects on the yield at 25th to 28th years (1989 to 1992) as well as the above parameters were analysed statistically.

Several of the soil chemical constituents under observation have changed in magnitude in response to long term fertilization and removal of nutrients by the growing palms.

Acidifying effect of NH_4^+ ions as a result of continuous addition of $(NH_4)_2SO_4$ in the basins of coconut palms was pronounced. The pH readings for n_2, n_1 and n_0 plots were 4.48, 4.55 and 4.89 respectively. There was no significant variation in organic carbon content of the soil. It was observed that the soils were inherently low in organic carbon content (0.32 to 0.48%). Owing to the predominance of low activity clay minerals, the experimental soils recorded very low CEC. Fertilized plots recorded significantly higher CEC than unfertilized plots.

Exchangeable Ca content of the soil increased with increasing rate of superphosphate (mono calcium phosphate) addition. Exchangeable Mg content of the soil was not affected by the treatments. Long term application of N reduced the exchangeable Na content of the soil and increased the Al content.

Exchangeable Fe, Mn and Zn were not affected by the long term application of N, P or K fertilizers whereas the Cu contents were influenced by addition of N and K.

Correlation studies revealed the influence of exchangeable Al on Zn, Mn and Mg as well as soil reaction. The influence of exchangeable Al on the dynamics of major as well as minor nutrients deserves further attention, even though Al is not rated as essential plant nutrient.

The water soluble K, available K and exchangeable K increased significantly with application of K. A slight increase in the total K and HNO_3-K content was observed due to continuous K addition, though it was not significant. Non-exchangeable K decreased with increasing doses of K. Large reserves of K cannot be built up in soil with predominantly non expanding clay minerals. Thus it is evident that the reserves of soils dominant in kaolinite cannot be made sufficient for crop production and hence continuous K fertilization may be recommended for coconut in such soils. Long term application of N and P did not significantly affect the potassium content though there was a decreasing trend in easily extractable forms with increase in N and P.

There was considerable variation in the Q/I parameters of soil potassium as a result of continuous fertilization. The PBC^K value ranged from 0.21 to 2.33 me $100g^{-1}$. Higher levels of N resulted in an increase in PBC^K whereas potassium application reduced PBC^K indicating high potassium intensity in k_1 and k_2 treated plots. A reduction in the AR_e^K value was noticed when N and P were applied without K. An increase in AR_e^K value was observed with increasing doses of K. The AR_e^K values were found to be well above the minimum AR_e^K value at which the crop may respond to K application. The K held on non specific planar sites (Δk_0) decreased with K application. The content of K associated with specific sites (Δk_x) was higher in k_1 treated plots than k_0 and k_2 treated plots. Labile K (ΔK_L) decreased with N application. The plots not receiving K fertilizers recorded a higher ΔK_L compared to those receiving K fertilizer. The K potential of the soil decreased with K application whereas the free energy of exchange (ΔG) increased with K application. Most of the soils recorded a ΔG value lower than the critical value for response.

Correlation studies have shown that HNO_3 – K was significantly and negatively correlated to CEC, exchangeable Mg and Fe. Non exchangeable K was significantly and positively correlated to pH and negatively correlated to

CEC and exchangeable Mg. None of the other soil properties were significantly correlated with potassium fraction. Among the Q/I parameters significant negative correlations were observed between CEC and Δk_0 and also between K potential and exchangeable Al. Significant positive correlations were observed between PBC^K and exchangeable Cu and also between ΔK_L and exchangeable Zn. The water soluble K was significantly and positively correlated to available K, exchangeable K and HNO_3-K. In turn, HNO_3-K was significantly and positively correlated with non exchangeable K. The HNO_3-K was found to be significantly and positively correlated with AR_e^K. The PBC^K was significantly and positively correlated with K potential and negatively correlated with AR_e^K and ΔG. Positive significant correlation of AR_e^K with Δk_0, Δk_L and ΔG indicate that higher amount of K and higher amount of free energy of exchange were associated with higher AR_e^K. Significant positive correlation were observed between ΔK_L, Δk_x and Δk_0. The free energy of exchange (ΔG) was significantly and positively correlated with AR_e^K, Δk_0, and Δk_L. The quantity factors Δk_0, and Δk_L were significantly and positively correlated with AR_e^K.

Even under rainfed conditions the levels of potassium significantly influenced the coconut yield. More than 200% increase in yield was observed during the years 1989, 1990, 1991 and 1992 at k_1 and k_2 levels than k_0 level. However, the percentage increase in yield form k_1 to k_2 was not as high as that from k_0 to k_1 though the differences were not significant. Nitrogen application without potassium resulted in a decrease in yield where as N along with K significantly increased the yields.

Yield of [illegible] coconut was significantly and positively correlated with water soluble, available and exchangeable K. Judging from the findings it can be suggested that coconut yield estimates could be better accomplished if the level of K extracted with NH_4-OAC is considered along with other fractions of K as well as PBC^K. The regression equations worked out based on the above parameters suggest[illegible] that the influence of the parameters under study on the yield of coconut under rainfed conditions is only about 30 to 35 percent. This highlights the importance of extraneous factors other than fertilizers, especially the available moisture in determining the yield of coconut under rainfed conditions.

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* Originals not seen

POTASSIUM DYNAMICS IN NEYYATTINKARA SOIL SERIES UNDER COCONUT CULTIVATION

By

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ABSTRACT OF THESIS
SUMBITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE
MASTER OF SCIENCE IN AGRICULTURE
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI THIRUVANANTHAPURAM
1993

ABSTRACT

Soil fertility in relation to the dynamics of soil potassium in a coconut garden was assessed to study variations due to differential nutrition of coconut. Soil samples from the root zone (0-60cm) of the 25 year old coconut palms from a 3^3 confounded factorial experiment on NPK were analyzed for various soil chemical constituents including fractions of potassium and Q/I parameters of soil potassium. Treatment effects on the yield at 25th to 28th years (1989 to 1992) as well as above parameters were analyzed statistically.

Acidifying effects of NH_4^+ ion was revealed in the plots which received continuous addition of $(NH_4)_2$ SO_4 as the source of N for coconut. The soils recorded low organic carbon content and cation exchange capacity, indicating predominance of low activity clays. Kaolinite was the dominant clay mineral observed in X-ray diffraction studies.

Exchangeable calcium increased with increasing rates of super phosphate addition. Exchangeable Mg, Fe, Mn and Zn were not affected by the treatments while sodium contents were influenced by nitrogen doses and the Cu contents by N and K. Correlation studies revealed the influence of exchangeable Al on Zn, Mn and Mg as well as soil reaction.

Potassium application resulted in higher concentrations of water soluble K, available K, exchangeable K, HNO_3-K and total K, while non exchangeable K was reduced.

Potassium application increased the AR_e^K values and decreased the PBC^K. The ΔG values, indicating the energy required by the crop to extract soil potassium, was found to be within the range of potassium deficiency, suggesting the need for potassium nutrition. Significant correlations were obtained between the difficultly extractable forms of potassium and two principal soil characteristics-CEC and soil reaction. Otherwise under low potassium status, potash nutrition and the resultant available forms of potassium were not influenced by inherent soil properties.

The potassium availability indices suggested for the coconut growing environment, based on correlation and regression analysis are NH_4-OAC K as well as the Q/I parameters namely AR_e^K, PBC^K and ΔG.

Levels of potassium significantly influenced the coconut yield. More than 200% increase in nut yield was observed with potash addition, over the no potassium treatment. Nitrogen application without potassium decreased the yields.

Yield of coconut was significantly and positively correlated with available K, exchangeable K and water soluble K. Yield estimates are prepared through simple linear and multiple regression equations, considering the treatment effects and the correlation between various parameters.