SOIL NUTRIENT DYNAMICS IN COCOA
(*Theobroma cacao*)

By

SMITHA, B.

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara, Thrissur

1995

DECLARATION

I hereby declare that this thesis entitled "**Soil nutrient dynamics in cocoa (*Theobroma cacao*)**" is a bonafied 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.

Vellanikkara
5-6-'95

SMITHA, B.

Dr.P.A. WAHID
Professor (Radiotracer)
Kerala Agricultural University

College of Horticulture
Vellanikkara

CERTIFICATE

Certified that this thesis entitled **"Soil nutrient dynamics in cocoa (*Theobroma cacao*)"** is a record of research work done independently by **Miss.Smitha, B.** 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.

DR.P.A. WAHID
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Miss.Smitha, B.**, a candidate for the degree of **Master of Science in Agriculture** with Major in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled "**Soil nutrient dynamics in cocoa (*Theobroma cacao*)**" may be submitted by Miss.Smitha, B., in partial fulfilment of the requirement for the degree.

Dr.P.A. WAHID
Professor (Radiotracer)
Radiotracer Laboratory, Vellanikkara
(Chairman)

Dr.A.I. Jose
Professor & Head
Dept. of Soil Science &
Agricultural Chemistry
College of Horticulture
Vellanikkara
(Member)

Dr.R. Vikraman Nair
Professor & Head
Dept. of Agronomy
College of Horticulture
Vellanikkara
(Member)

Dr.V.K. Venugopal
Associate Professor
Dept. of Soil Science &
Agricultural Chemistry
College of Agriculture
Vellayani
(Member)

ACKNOWLEDGEMENT

I express my deep sense of gratitude and sincere thanks to **Dr.P.A.Wahid**, Professor, Radiotracer Laboratory, College of Horticulture, Vellanikkara and Chairman of my Advisory Committee for his personal attention, constant inspiration and valuable guidance during the course of this research work and preparation of the thesis. But for his unfailing patience, understanding and encouragement this venture would not have been completed successfully. My sincere and heartfelt gratitude ever remains with him.

I acknowledge gratefully **Dr.A.I.Jose**, Professor and Head, Department of Soil Science and Agricultural Chemistry for his valuable suggestions and good help during the course of the research work.

It is my pleasant previlage to place on record my sincere thanks to **Dr.R.Vikraman Nair**, Professor and Head, Department of Agronomy and member of the Advisory Committee for the valuable help rendered to me during the course of investigation.

My sincere thanks are due to **Dr.V.K.Venugopal**, Associate Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani and member of the Advisory Committee for all his support, suggestions and timely help.

With all regards I acknowledge the sincere help provided whole-heartedly by **Dr.P.V.Balachandran**, Associate Professor, Radiotracer Laboratory, Vellanikkara during the course of the research work.

The help rendered by Smt.N.V.Kamalam, Associate Professor (Safty Officer), Radiotracer Laboratory, Vellanikkara is gratefully acknowledged.

I express my heartfelt gratitude to Sri.M.Nandakumaran, Associate Professor, Department of Animal Nutrition, College of Veterinary and Animal Sciences, Mannuthy, for the kind and generous help rendered during the estimation of micronutrients in the AAS.

I also place on record my sincere gratitude to Dr.A.V.R.Kesava Rao, Assistant Professor, Department of Agricultural Meteorology, College of Horticulture, for his help in preparing the graphs.

I am thankful to Sri.V.K.G.Unnithan, Associate Professor, Department of Agricultural Statistics, College of Horticulture, Vellanikkara for the help received in statistically analysing the data.

The good help received from all the staff members of the Department of Soil Science and Agricultural Chemistry, is gratefully acknowledged.

The assistance and co-operation extended to me by the labourers of College of Horticulture are very much appreciated. I thank them sincerely.

My heartfelt gratitude and moral obligation remain with Mrs.Betty Bastin, Assistant Professor, College of Horticulture, Vellanikkara for her many acts of kindness and help.

I wish to thank all my friends who have contributed much towards the completion of my research work.

At this moment, I cannot, but recall with love and gratitude the constant encouragement and inspiration given to me by my beloved parents, brother and my grandmother, which had always been a source of inspiration for me, and this small venture is not an exception.

My sincere thanks are due to Sri.Joy and M/s.Blaise Computer Consultancy for the neat typing and prompt service.

The award of Junior Research Fellowship by Kerala Agricultural University is gratefully acknowledged.

SMITHA, B.

To My Parents

CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix No.	Title
I	Analysis of variance for testing significance of soil chemical characteristics (available nutrients) of NPK field trial
II	Analysis of variance for testing significance of soil chemical characteristics (nutrient reserves) of NPK field trial

Introduction

INTRODUCTION

Cocoa (*Theobroma cacao*) is one of the most important beverage crops in the world. It originated in the upper Amazon region of Latin America. Commercial cultivation of cocoa was started in India in the early 1960s. Kerala is the principal cocoa growing state in India accounting for 80 per cent of the area under cocoa. Cocoa is mainly recommended as a component crop in many plantations, especially under coconut and arecanut.

Annual application of fertilizers over a long period in a perennial crop garden leads to considerable changes in the rootzone soil. Not only the direct effect of fertilizers, but also the interaction effects between nutrient elements contained in fertilizer materials and between nutrients and soil components also assume significance. The impact can be assessed through long-term fertility experiments by determining the residual as well as cumulative effects of fertilizers on various soil fertility parameters.

Cocoa has naturally adapted to shade and is grown as a second tier under natural tree crops. The shade response of cocoa is closely linked to soil moisture content as the inhibitory effect due to excessive exposure can be counteracted by more frequent irrigations. In addition, irrigation alters the nutrient status of the soil significantly as most of the nutrient elements are subjected to leaching. Nutrient absorption by the plant also varies considerably between shaded and open and between irrigated and unirrigated conditions. Thus soil chemical characteristics of the rootzone as well as mineral nutrition of the plant are altered either favourably or adversely by the shade and irrigation levels. It is in this context, studies on the long-term effects of inorganic fertilization, irrigation and shade assumes importance.

The studies reported in this thesis have the following objectives.

- * To evaluate the extent of depletion or enrichment of nutrients in various soil strata of cocoa rootzone as influenced by regular application of NPK fertilizers.
- * To examine the role of irrigation and shade in changing the fertility status of the rootzone.
- * To assess the build-up or depletion of soil nutrients in different soil layers as a function of time.
- * To study the nutritional aspects of cocoa as influenced by continuous fertilization, irrigation and shade.

Review of Literature

2. REVIEW OF LITERATURE

The literature relevant to the present study is reviewed in this section.

2.1 General habit and mineral nutrition of cocoa

The natural home of cocoa tree is the lower tree storey of evergreen tropical rainforest. In this environment the tree is subjected to high mean and annual temperatures, high rainfall and relative humidity and low light intensity.

Hardy (1958) stated that for cocoa the depth of root penetrable soil should be at least 1.5 m. According to Smyth and Montogomery (1962), a minimum of 25 per cent clay plus silt was required in fine earth fractions in 25-50 cm soil layer to support healthy cocoa. Experiments conducted by Alvim (1959) and Lemee (1955) had shown that compared to many other tropical tree crops cocoa is exceptionally sensitive to shortages in soil moisture. Optimum pH for growth of cocoa is 6.5 (Purseglove, 1969).

Zevallos (1970) observed that 85 per cent of cocoa root systems is distributed in the top 45 cm depth of soil. Wahid *et al.* (1989) studied the root activity pattern of cocoa and they found that more than 85 per cent of the feeder roots were located within a radius of 150 cm around the tree. They also found that root activity of cocoa decreased sharply beyond 60 cm depth. Bhat and Bavappa (1972) reported that most of the cocoa roots were confined to the area within 100 cm from the trunk. Occurrence of N-fixing bacteria *Azospirillum* in the rootzone of cocoa was reported by Govindan and Nair (1984). They observed fairly high population of *Azospirillum* in the root environment of cocoa.

According to Herrera *et al.* (1978) cocoa tree absorbs most of the nutrients in ionic forms. The most important elements in cocoa nutrition are N, P, K and B (Opeke, 1982). Nelliat (1978) concluded that cocoa was a heavy feeder of K. A good crop of cocoa removes as much as 170 kg K ha^{-1} (Uexkull,1978). Potassium is also the principal element present in the fruit of cocoa (Fassbender *et al.*, 1985).

Based on results of fertilizer trials with shaded cocoa, Ahenkorah and Akrofi (1971) reported major response of cocoa to P with an optimum dose between 45 and 90 kg P_2O_5 ha^{-1}. A study conducted by Morais (1988) indicated that cocoa could be grown for five years without fertilizer. He found that application of P increased cocoa yield considerably while application of K or micronutrients did not have significant effect on yield. Experiments conducted by Murray (1975) revealed that heavy application of ammonium sulphate depressed the yield of cocoa. Wessel (1966) reported 30 per cent yield increase from the combined application of N and P fertilizers. Interaction effect of K with P for greater productivity of cocoa was also reported (Usherwood, 1982). Other workers have also reported similar response to N and P fertilizers (Wessel, 1970; KAU, 1993). Ahenkorah *et al.* (1987) opined that the rate of decline in yield of unfertilized trees during senescent phase was greater than that of fertilized trees. Wessel (1970) from the results of a fertilizer trial in cocoa at Nigeria observed no response of cocoa to K fertilizer, but both N and P fertilizers gave increased yields.

2.2 Nutrient cycling in cocoa ecosystem

Litter fall is the major pathway for return of N, P, Ca and usually Mg to the soil (Adams and Attiwill, 1985). According to them nutrient turnover is related to the rate of organic matter turnover. Leite and Valle (1990) opined that both through fall and leaf fall were important in nutrient recycling in cocoa ecosystem. From an examination of nutrient contents of newly fallen plant residues and that of ground litter in different cocoa agro-ecosystems with and without shade trees Santana *et al.* (1990) observed that concentrations of N and P were higher in the leaves of shade trees than in cocoa leaves, while the reverse was true for Ca, Mg, Zn and Mn.

Eaton *et al.* (1973) found that recycling of nutrients from cocoa canopy occurs generally in the order of K > Ca > Mg > P. Tukey (1969) observed heavy leaching of K from the foliage of cocoa tree. In a study on nitrogen cycling in shaded cocoa plantation (Aranguren *et al.*,(1982) observed that 61 per cent of the total N in the litter fallen was contributed by shade tree leaves. Leite and Valle (1990) concluded that most of the K cycled from the canopy was directly absorbed by cocoa and/or by shade tree. Yoo and Jung (1991) studied the cycling of Fe, Cu and Zn in a mature cocoa plantation in South-West Nigeria. They noticed that these nutrients were immobilized in the woody components of tree than in the decidous parts. Manikandan *et al.* (1987) reported that cocoa leaf fall significantly improved the Zn status of cocoa basin.

2.3 Impact of long-term inorganic fertilization on soil chemical characteristics

2.3.1 Nitrogen fertilizers

The build-up of soil organic carbon due to continuous application of N was reported by Patiram and Singh (1993). A study on the effect of forty years of regular fertilizer application on soil organic N and carbon contents revealed that during this period, 18 per cent of applied N was incorporated into soil organic fraction (Rasmussen and Rhode, 1988).

Application of ammonium sulphate or ammonium chloride decreased the pH in the fertilized band significantly (Petric and Jackson, 1984). Lower pH in cocoa soil basins receiving continous application of inorganic N fertilizers was also noticed by Manikandan *et al.* (1987). According to Oluobi (1989) urea application does not make a consistent difference in soil pH for a short period but continued use of urea acidified the soil to such an extent as to impair its productivity. Continued use of ammonia-based fertilizers lowered soil pH levels affecting crop growth. The depth and intensity of acidification was influenced by rate and type of N fertilizer (Rasmussen and Rhode, 1989). Sherbakov *et al.* (1989) also observed an increased soil acidity due to continued application of inorganic N fertilizers. Darusman *et al.* (1991) studied the changes in soil chemical properties after twenty years of fertilization with different N sources and compared with a no nitrogen control. They noticed a significant reduction in soil pH from 6.2 to 5.2.

Eighteen years of regular application of N fertilizers resulted in only a minimal increase in mineralisable N content of the soil (Khan *et al.* 1978). From the results of a long-term fertility trial Rao *et al.* (1982) concluded that application of N alone, accelerated N loss from the soil whereas such losses were minimised when applied along with P or K fertilizers. Bergstrom and Brink (1986) opined that a build-up of inorganic N in soil occurs only when nitrogenous fertilizers were applied in excess amounts.

Continuous application of N fertilizers was found to depress the availability of K in soil (Muthuswamy *et al.*, 1990). The experiments conducted by Krishnakumari and Khora (1983) revealed that application of N along with P fertilizers caused greater depletion of K from the soil. In terms of fertilizer equivalents they calculated that for effecting unit increase in available K, it required 5.89 units of fertilizer K in plots intensively fertilized with N and P.

2.3.2 Phosphorus fertilizers

Build-up of available soil P due to continuous application of P fertilizers was reported by many workers (Wahid *et al.*, 1975; Rao *et al.* 1982; Khan *et al.* 1986; De Datta *et al.* 1988; Anilkumar and Wahid, 1989; Muthuswamy *et al.* 1990 and Mekenzie *et al.* 1992). Schwab *et al.* (1990) studying the effect of 40 years of phosphorus fertilization on soil P availability indices observed a downward movement of P up to 60 cm depth. They concluded that movement of P in soil is governed by the P fixing capacity of soil. Hartnez (1992) studied the influence of long-term fertilizer rate on P status of a sandy soil. He noticed that total P and equilibrium P concentration in soil solution increased with increasing rate of fertilization whereas P sorption capacity decreased with increasing P enrichment of the soil.

Highest accumulation of Bray-1 extractable P concentration was found in the surface 10 cm layer of P fertilized plots (Schwab *et al.*, 1990). Bates and Baker (1960) also observed a greater accumulation of P in the surface soils. According to Coelho *et al.* (1993), continous application of P fertilizers to sugarcane for ten years resulted in the accumulation of P in soil up to 200 cm depth. Perrott and Munsell (1989) observed heavy build-up of P reserves in soil due to continuous application of P fertilizers. He quantified the formation of total soil P at the rate of 280 μgP g^{-1} of superphosphate in 0-25 mm depth of soil. Peterson and Krueger (1980) quantified the rate of build-up of available soil P as 1 kg ha^{-1} for every 2.3 kg ha^{-1} of applied P over a period of eight years.

Franklin and Reisenauer (1960) recognised that non-equilibrium P compounds of relatively high availability are formed in soil from added phosphatic fertilizers and such compounds exist for several years in soils of high P sorption capacities. According to Olesen *et al.* (1983) as phosphatic fertilization exceeds plant P removal, P concentration in soil solution increases and if this go above saturation level crystalline solid forms of P get precipitated mainly as octacalcium phosphate in calcareous soils. Shuman (1988) found an increase in soil pH following long-term P fertilization and he attributed it to the reaction of P with Fe and Al oxides producing OH ions.

De Datta *et al.* (1988) opined that exchangeable K values decreased with successive applications of P. Similar results were obtained by Negi *et al.* (1981) also. Addition of P had no significant effect on soil N dynamics according to Javed and Fischer (1990).

2.3.3 Potassium fertilizers

As in the case of P soil K also increases following continuous addition of inorganic K fertilizers (Bakheistad and Burhan, 1973; Singh *et al.* 1980 and Anilkumar and Wahid, 1989; Malenga and Grice, 1991; Joseph, 1993). According to Malenga and Grice (1991) subsoil K content was influenced only by higher rates of application. The results from a long-term fertilizer experiment indicated that exchangeable K status of surface and sub-surface soil increased by 10 and 26 ppm respectively over the initial values due to continuous application of inorganic fertilizers (Sharma and Tripati, 1983). Application of higher levels of K increased the concentration of K in soil solution in laterite soil as compared to alluvial and black soils (Bandyopadhyay and Goswami, 1988). Hudcova (1990) studying the influence of 21 years of inorganic fertilization on soil K dynamics revealed that K application increased K mobility, its migration to subsoil horizons and mobilization from soil reserves.

At lower rates of K, application, applied K was completely fixed, whereas at higher rate of application part of it was lost (Patiram and Prasad, 1983). Omission of N or P from the fertilizer schedule for mango ochards resulted in considerable decrease in K intensity (Biswas *et al.*, 1989).

Cassman *et al.* (1989) studied the cumulative effects of annual application of K on soil K balance. They reported that without K input, NH_4 extractable K^+ in surface soil decreased by 20 per cent within two years and this decrease greatly exceeded the K removal by cotton. Sharply (1990) observed that crop removal and leaching of K was more than the rate of replenishment from non-exchangeable sources. Fotyma *et al.* (1993) from a study on the interaction between soil K and fertilizer K in long-term field experiments observed that residual effect of K applied annually for six years was evident at least for further six years.

Dalal and Mayer (1986) obtained significant correlation between total K and organic carbon content of a virgin soil. Improvement of organic carbon status of soil following long-term muriate of potash application was also reported by Anilkumar (1987) and Srilatha and Saifuddin (1994).

2.3.4 Secondary nutrients (Ca, Mg and S) in soil

Exchangeable Ca and Mg showed a declining trend with increasing doses of N fertilizers in acid soils (Prasad *et al.*, 1983). Schwab *et al.* (1989) noted a decline in the exchangeable Ca and Mg in the upper 20 cm of the soils in the continuously fertilized plots. Similar results were also obtained by Raju (1978) and Patiram and Singh (1993). Sureshlal and Mathur (1992) concluded that 36 years of continuous addition of N fertilizers depleted the status of exchangeable Ca and Mg in soil. Malhi *et al.* (1991) noticed that addition of N fertilizers led to decline in Ca up to 10 cm and in Mg up to 15 cm depth. Anilkumar (1987) observed a two-fold increase in available S status of soil following 22 years of annual application of ammonium sulphate at the rate of 0.35 kg N $year^{-1}$. Owuor *et al.* (1986) revealed that continued application of urea increased the acetate extractable S status of the soil under tea although urea does not add any S to soil directly.

Nemath *et al.* (1987) reported highest accumulation of S between 60 and 200 cm depth in intensively fertilized plots with NPK over a period of 12 years. They also noticed an annual downward movement of S at the rate of 20-30 cm. Nguyen and Goh (1992) noticed a substantial accumulation of organic S in soil as a result of long-term annual application of S containing fertilizers. Continued application of ammonium sulphate and/or superphosphate helped in the build-up of S reserves in soil (Joseph, 1993). Long-term application of superphosphate was reported to cause an increase in total Ca reserves of the soil as reported by Shinde and Ghosh (1964).

2.3.5 Micronutrients in soil

Sureshlal and Mathur (1989) studied the effect of continuous manuring and fertilization on the status of available micronutrients in soil. They noticed that addition of lime along with NPK increased the availability of micronutrients in the soil. Darusman *et al.* (1991) opined that N fertilization increased the availability of micronutrients especially that of Fe, Mn and Cu.

According to Iyengar *et al.* (1981) continued addition of superphosphate brings about deficiency of Zn due to precipitation as $ZnPO_4$. Rao and Ghosh (1983) observed that addition of P fertilizer resulted in significant depletion in exchangeable Zn in comparison with control and N alone treatments. According to Ghanem and Mikkelsen (1988), Zn sorption increases significantly as the P/Fe ratio is increased, and, at all P/Fe ratios, Zn sorption increased as pH value increased and consequently reduced the availability of Zn to plants. Mandal and Mandal (1990) opined that application of P encouraged the transformation of both native and applied Zn to sesquioxide bound form. Addition of P fertilizers had little effect on the plant available fractions of Mn (Shuman, 1988).

Tripati *et al.* (1994) noticed no specific trend in the distribution of available Mn with depth. They attributed the increased quantity of micronutrients in the surface layer of soil to the regular turnover of plant nutrients.

Manikandan *et al.* (1987) reported significantly higher content of Zn in cocoa basin as a result of cocoa leaf fall.

2.4 Impact of irrigation, shade and age of the crop on soil chemical characteristics

Reddy and Shastry (1983) reported that P moved up to 30 cm under high moisture levels, whereas K moved to soil under all irrigation levels with greater movement under higher levels of irrigation. Messiek (1982) after studying the effect of irrigation on different soil types concluded that the rate of movement of Ca and

Mg is a function of clay content. He argued that as clay content increased, movement of Ca and Mg decreased. Rechaigel *et al.* (1985) noticed a lower pH in irrigated soils. They also reported that movement of P and K to lower horizons in soil was greatly influenced by fertilizer application than irrigation. Irrigation with mineral water over a prolonged period resulted in re-distribution of exchangeable cations, particularly Ca (Khrustova and Chernaya, 1988). According to Swarup *et al.* (1994) most of the heavy metals (Zn, Pb and Cd) remained in the top 10 cm layer of soil and their movement through leaching water is negligible.

Shade trees add to the surface soil the nutrients they take up from lower horizons through leaf sheddings and thus maintain a high fertility status and favourable pH (Potti *et al.*, 1978). Adams and Mc Kelvie (1955) observed that on a typical shaded cocoa farm in West Africa, forest tree shade contributed some five tonnes of leaf litter ha^{-1} $year^{-1}$ containing 79 kg N and 4.5 kg P. The average biomass of the litter layer for unshaded and shaded cocoa canopy were 9 and 11 t ha^{-1} $year^{-1}$ respectively (Leite, 1987). Murray (1975) reported that shade trees with a deeper root system exploited minerals from deeper layers of soil and these will enter surface layer through leaf fall. Purseglove (1969) revealed that when cocoa grown under favourable conditions without shade, spectacular response to N was obtained. Ahenkorah *et al.* (1974) observed that when cocoa grown under open conditions loss of mineralized N through volatilisation was more rapid.

Ca and Mg in soil were not influenced by changing shade levels according to Ahenkorah *et al.* (1987).

Ahenkorah *et al.* (1974) opined that for the first seven years of cultivation of cocoa, organic carbon fell from 2.08 to 1.46 per cent but C/N ratio remained fairly constant. Mathew (1977) observed that comparative loss of K from a virgin soil where coffee was grown for 22 years without manuring came to 93 per cent.

2.5 Impact of mineral fertilization, irrigation and shade on foliar nutrient levels

Khan *et al.* (1978) reported that 18 years of regular annual application of N fertilizers significantly raised foliar N levels in coconut. Witholding fertilizer application to coconut for one year lowered foliar N and K levels significantly but not P levels (Wahid *et al.*, 1975). Salam and Sahu (1990) reported an increased uptake of N following long-term N fertilization. Leaf K content decreased with increased N application in tea (Owuor *et al.*, 1987). Mohapatra and Bhat (1983) observed that P content of arecanut leaf was not affected by different P carriers. Thakur *et al.* (1983) observed an increased K level in mango leaves following long-term K application. Khan *et al.* (1986) opined that continuous K fertilization raised the K content of leaves to sufficiency levels in coconut. Anilkumar (1987) reported significant positive correlation between available K in the 0-25, 50-75 and 75-100 cm depths and levels of K in the 6th and 14th fronds of coconut. A study on K nutrition of cotton indicated that with high level of K input, apparent K uptake efficiency from applied K was increased to 50 per cent within two years (Cassman *et al.*, 1989). Witholding K application reduced foliar K content to 0.9 per cent from 1.3 per cent in bearing apple trees (Issac, 1992). From a study on K nutrition of oil palm, Ollagnier *et al.* (1987) reported that critical level of K in oil palm would continue to rise if tree water supply is increased.

Cocoa plants showed higher levels of nutrients in their leaves under heavy shade as compared with trees growing under less or no shade condition (Murray, 1967). Guers (1971) observed that cocoa leaves exposed to direct sunlight showed less N than shaded leaves.

Materials and Methods

3. MATERIALS AND METHODS

Three studies were conducted making use of on-going field experiments with cocoa. These were aimed at examining the changes in soil chemical characteristics due to long-term inorganic fertilization and due to irrigation and shade. Further, an attempt was made to evaluate the dynamics of soil fertility under cocoa as a function of time and also to assess the nutrition of cocoa as influenced by fertilization, irrigation and shade.

3.1 Experiment 1: Soil chemical characteristics and nutrition of cocoa in relation to NPK fertilization

The effect of long-term NPK fertilization on chemical characteristics of cocoa rootzone as well as on foliar nutrient levels were studied making use of an on-going fertilizer trial at the Cadbury-KAU-Co-operative Cocoa Research Project, College of Horticulture, Vellanikkara. This field trial was an NPK factorial experiment testing three levels each of the nutrients. The details of the experiment are as follows.

Design	: 3^3
Total number of treatments	: 27 (N, P and K each at three levels)
Number of replications	: 3
Spacing	: 3 m x 3 m
Plot size	: 27 m x 27 m
Variety	: Forastero
Date of start of the experiment	: 5-7-1983

Levels of nitrogen (g N $palm^{-1}$ $year^{-1}$)

N_0 : 0
N_1 : 100
N_2 : 200

Levels of phosphorus (g P_2O_5 $tree^{-1}$ $year^{-1}$)

P_0 : 0
P_1 : 40
P_2 : 80

Levels of potassium (g K_2O $tree^{-1}$ $year^{-1}$)

K_0 : 0
K_1 : 140
K_2 : 280

Nitrogen, P and K were applied through urea (46% N), superphosphate (18% P_2O_5) and muriate of potash (60% K_2O) respectively. Right from the start of the experiment, no organic matter source was included in the manurial schedule. The soil at the experimental site was laterite (Oxisol). The cocoa trees were nine years old when they were made use for the present study.

For the present study, only two levels of each nutrient namely, zero level and second level were considered. The treatment combinations were:

$N_0 P_0 K_0$
$N_0 P_0 K_2$

$N_0 P_2 K_0$
$N_0 P_2 K_2$
$N_2 P_0 K_0$
$N_2 P_0 K_2$
$N_2 P_2 K_0$
$N_2 P_2 K_2$

3.2 Experiment 2: Soil chemical characteristics of cocoa rootzone in relation to irrigation and shade

The trees under an on-going experiment on the effect of irrigation and shade were used in this study. The area was initially under rubber. Cocoa was planted in 1979 after removing the rubber trees. Rubber trees were removed in such a way so as to give 75 per cent or 0 per cent (complete removal) shade level to cocoa plants. Cocoa was planted at a spacing of 3 m x 3 m. The plants were receiving 100 g N, 40 g P_2O_5 and 140 g K_2O plant^{-1} year^{-1} (KAU, 1993) from the third year of planting onwards. One-third of the above dose was given in the first year of planting, ie. in 1979 and two-thirds in the second year of planting. The plants received sprinkler irrigation from 1988 onwards. Irrigation was given at weekly intervals. The trial was a 2^2 factorial experiment with three replications. The treatments were factorial combinations of two levels of irrigation (irrigated, I_1 and unirrigated, I_0) and shade (shaded, S_1 and open, S_0), namely,

$I_0 S_0$
$I_1 S_0$
$I_0 S_1$
$I_1 S_1$

The shade intensity was 75 per cent. Cocoa trees under this trial were 13 years old when they were made use of for the present study. The irrigated plants were receiving irrigation for the last five years.

3.3 Experiment 3: Soil chemical characteristics of cocoa rhizosphere in relation to age of the stand

The changes in chemical characteristics of soil under cocoa was also studied as a function of time. For this purpose, trees coming under seven age groups namely, 1, 3, 4, 5, 6, 9 and 12 years were selected. There were three replications (individual trees) for each age group. These plants were receiving uniform agronomic management since planting. The fertilizer schedule (KAU, 1993) followed was as follows.

1st year 33.33 g N, 13.33 g P_2O_5 and 46.66 g K_2O plant^{-1} year^{-1}; 2nd year: 66.66 g N, 26.66 g P_2O_5 and 93.32 g K_2O plant^{-1} year^{-1} and from 3rd year onwards 100 g N, 40 g P_2O_5 and 140 g K_2O plant^{-1} year^{-1}.

3.4 Collection and processing of soil samples

Soil samples in the first and second experiments were collected from three depths, 0-25, 25-50 and 50-75 cm at a lateral distance of 50 cm from the tree. Samples from each depth were collected from four points around a tree and pooled to give a sample for each depth for that tree.

In Experiment 1, 72 soil samples were collected from 24 experimental trees in three replications.

In Experiment 2 on irrigation and shade, altogether 36 soil samples were collected from 12 experimental trees in three replications.

In Experiment 3 the method of sampling adopted was also similar to that used in experiments 1 and 2 with the difference of depth of sampling. From the 21 experimental trees in three replications (coming under 7 age groups, namely 1, 3, 4, 5, 6, 9 and 12 years), soil samples were taken from 0-75 cm depth. These samples were used to examine the changes in chemical characteristics of the rootzone with time. Soil samples from adjacent bare land (uncropped and unfertilized) were also collected from 0-75 cm depth. In this case also, three replications were maintained. Soil samples were air-dried and sieved through 2 mm mesh prior to analysis.

3.5 Collection and processing of leaf samples

Leaf samples were collected from all the trees under the fertilizer trial and irrigation and shade trial. Recently matured leaf, (generally second from the tip) from branches on all sides of the upper canopy were collected. There were 81 leaf samples collected from 27 treatment combinations in three replications. In the irrigation and shade trial, leaf samples were collected from the same plants from which soil samples were taken. There were 12 leaf samples collected from four treatments in three replications.

Leaf samples were dried at 75°C and stored in polythene bottles awaiting chemical analysis.

Table 1. Details of the analytical methods used in the study

Soil characteristic	Extractant used	Method of estimation	Reference
pH (H_2O)	H_2O	Direct reading (pH meter)	Jackson (1958)
Organic carbon		Walkley - Black (Titrimetric)	Jackson (1958)
Available P	Bray-1	Ascorbic acid blue colour (Spectrophotometer)	Watanabe and Olsen (1965)
Available K	$\underline{N}.NH_4OA_c$ (pH 7)	Direct reading after dilution (Flamephotometer)	Jackson (1958)
Available Ca	,,	Direct reading after dilution using $SrCl_2$ as releasing agent (Atomic absorption Spectrophoto meter)	Jackson (1958) and Page (1982)
Available Mg	,,	,,	Jackson (1958) and Page (1982)
Available S	N_aOA_c HOA_c (pH 4.5)	Turbidimetric (Spectrophoto meter)	Hesse (1971)
Available Fe	Double acid HCl 0.05 $\underline{N}$ + H_2SO_4 0.025 $\underline{N}$	KSCN red colour (Spectrophotometer)	Perkins (1970)
Available Zn, Mn and Cu	,,	Direct reading (Atomic absorption Spectrophotometer)	Page (1982)
Total P	Nitric-per chloric (2:1) digestion	HNO_3 - Vanadomolybdate yellow colour method (Spectrophoto meter)	Jackson (1958)
Total K	,,	Direct reading after dilution (Flamephotometer)	Jackson (1958)
Total Ca	,,	Direct reading after dilution using $SrCl_2$ as releasing agent (Atomic absorption Spectrophotometer)	Jackson (1958) and Page (1982)
Total Mg	,,	,,	,,
Total Zn, Mn and Cu	,,	Direct reading after dilution (Atomic absorption spectrophotometer)	,,
Total Fe	,,	KSCN red colour (Spectrophotometer)	Jackson (1958)
Total S	Nitric-per chloric digestion with $K_2Cr_2O_7$	Turbidimetry	FAO (1988) and Jones *et al.*, (1972)

plots as different depths. Similarly ANOVA was done taking combinations of irrigation and shade as main plot and various depths as sub plots. The changes in soil fertility with time (age) was evaluated by fitting the data using least squares method to suitable equations (Panse and Sukhatme, 1985).

Results

4. RESULTS

The results of studies conducted in relation to changes in soil chemical characteristics of the rootzone of cocoa consequent to long-term application of inorganic fertilizers, irrigation and shade and age of the stand are presented here.

4.1 Effects of long-term fertilization on soil available nutrients

General chemical characteristics of the soil of the experimental site are given in Table 2.

The data correspond to the unfertilized and uncropped area lying adjacent to the experimental field. The soil was, in general, acidic, low in organic carbon, available P and K, exchangeable bases. The soil contained fairly good amounts of available S and micronutrients. The total contents of these elements were also high.

The data pertaining to the effects of long-term inorganic fertilization on soil characteristics are presented in Table 3.

4.1.1 Effects of urea application

Regular application of urea for a period of nine years resulted in a drop in soil pH from 5.16 (N_0 plots) to 4.67 (N_2 plots). Urea application significantly reduced available K, available Ca and available Mg in the soil. The effect was more pronounced in the case of available Ca which decreased from 547.0 to 342.4 ppm. Among the micronutrients the depressing effect of urea application was evident in the case of available Zn. Application of urea resulted in depletion of soil organic carbon also.

Table 2. Chemical characteristics of the original soil (0-75 cm depth)

Characteristics	
pH	5.10
Organic carbon	0.34
Available P	1.66
Available K	72.3
Available Ca	190.3
Available Mg	134.1
Available S	22.9
Available Fe	10.68
Available Zn	1.87
Available Mn	56.97
Available Cu	2.93
Total P	457.7
Total K	1786
Total Ca	731
Total Mg	555
Total S	154.3
Total Zn	58
Total Mn	455.7
Total Cu	32.88
Total Fe	3.80

Note: Organic carbon and total Fe are expressed as percentages, the others as ppm

Table 3. Effect of NPK fertilizers on chemical characteristics of cocoa rootzone

Treatment	pH	Organic carbon (%)	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)	Available Cu (ppm)
-UR	5.16	0.56	21.74	264.8	547.0	287.7	68.58	13.81	36.38	52.08	4.26
+UR	4.67	0.49	28.48	226.5	342.4	242.0	73.64	15.15	13.27	65.31	4.45
-SP	4.85	0.51	9.58	251.4	366.5	278.3	21.83	14.56	40.67	59.29	5.07
+SP	4.98	0.56	40.64	240.0	522.9	251.5	120.40	14.40	9.57	58.09	3.63
-MOP	4.85	0.51	28.29	152.4	473.5	263.3	86.36	14.48	23.88	63.14	4.82
+MOP	4.97	0.53	21.93	339.0	415.9	266.4	55.86	14.89	25.76	54.24	3.88
CD(0.05)	0.06	0.03	1.57	10.10	18.77	13.92	3.75	0.61	2.05	1.38	0.27
SEm±	0.02	0.01	0.52	3.33	6.12	4.59	1.24	0.02	0.67	0.46	0.09

UR - Urea; SP - Superphosphate; MOP - Muriate of potash

On the other hand urea application significantly improved the soil concentrations of available P, S, available Fe and available Mn. Available Mn content of soil increased from 52.08 to 65.31 ppm.

4.1.2 Effects of superphosphate application

Application of superphosphate helped to build-up the organic matter status of the soil. Substantial build- up of available P was noticed in superphosphate receiving plots. Available P increased from 9.58 ppm in P_0 plots to 40.64 ppm in P_2 plots. Available Ca and available S status of the soil were also improved following super- phosphate application. Available Ca increased from 366.5 to 522.9 ppm and available S increased from 21.83 to 120.40 ppm in the soil. Soil pH increased from 4.85 to 4.98 in these plots. On the contrary, available K, Mg, Zn and Cu were found to decrease in plots receiving superphosphate.

4.1.3 Effects of muriate of potash application

Application of muriate of potash led to considerable build-up of available K in the soil. It increased from 152.4 ppm in K_0 plots to 339.0 ppm in K_2 plots.

Muriate of potash had a negative impact on the status of available P, Ca, S, Mn and Cu. Available Ca decreased from 473.5 to 415.9 ppm and available S from 86.36 to 55.86 ppm as the level of application was raised from K_0 to K_2.

4.1.4 Fertilizer interactions in soil

The effects of application of urea in combination with superphosphate were significant in the case of soil pH (Table 4), available P (Table 5), available Ca

(Table 6), available S (Table 7) and available Mn (Table 8). Soil pH increased from 4.52 in plots receiving only urea to 4.81 in plots receiving both urea and superphosphate. Available P content increased from 11.33 ppm in plots treated with urea to 45.62 ppm in plots treated with both urea and superphosphate. Similarly available S content increased from 19.61 ppm in plots receiving only urea to 127.66 ppm in plots receiving both urea and superphosphate. On the other hand, available Mn content decreased from 75.56 ppm in plots receiving only urea to 55.06 ppm in plots receiving a combined application of urea and superphosphate. Available Ca content of plots receiving only superphosphate reduced from 657.7 to 388.1 ppm in plots receiving both superphosphate and urea.

The combined application of urea and muriate of potash influenced the available K (Table 9), Ca (Table 10) and Mn (Table 11) contents of the soil. Available K content decreased from 373.9 ppm in plots receiving only muriate of potash to 304.0 ppm in plots receiving both muriate of potash and urea. Available Ca content decreased from 356.4 ppm in plots receiving only urea to 328.4 ppm in plots receiving both urea and muriate of potash. Available Mn content decreased from 70.78 ppm in plots receiving urea to 59.85 ppm in plots receiving both urea and muriate of potash.

Application of superphosphate along with muriate of potash influenced available K (Table 12) and S (Table 13) contents of soil. Available K content increased from 165.4 ppm in plots receiving only superphosphate to 314.7 ppm in plots receiving both superphosphate and muriate of potash. On the other hand, available S content decreased from 149.66 ppm in plots receiving only superphosphate to 91.11 ppm in plots receiving both superphosphate and muriate of potash.

Table 4. Effect of urea x superphosphate interaction on soil pH

Urea (UR)	Superphosphate (SP)	
	-SP	+SP
-UR	5.18	5.14
+UR	4.52	4.81
CD (0.05)	0.09	
SEm±	0.03	

Table 5. Effect of urea x superphosphate interaction on soil available P (ppm)

Urea (UR)	Superphosphate (SP)	
	-SP	+SP
-UR	7.82	35.65
+UR	11.33	45.62
CD (0.05)	2.21	
SEm±	0.73	

Table 6. Effect of urea x superphosphate interaction on soil available Ca (ppm)

Urea (UR)	Superphosphate (SP)	
	-SP	+SP
-UR	436.4	657.7
+UR	296.7	388.1
CD (0.05)	26.53	
SEm±	8.75	

Table 7. Effect of urea x superphosphate interaction on soil available S (ppm)

Urea (UR)	Superphosphate (SP)	
	-SP	+SP
-UR	24.05	113.11
+UR	19.61	127.66
CD (0.05)	5.30	
SEm±	1.75	

Table 8. Effect of urea x superphosphate interaction on soil available Mn (ppm)

Urea (UR)	Superphosphate (SP)	
	-SP	+SP
-UR	43.02	61.00
+UR	75.56	55.06
CD (0.05)	1.95	
SEm±	0.64	

Table 9. Effect of urea x muriate of potash interaction on soil available K (ppm)

Urea (UR)	Muriate of potash (MOP)	
	-MOP	+MOP
-UR	155.7	373.9
+UR	149.1	304.0
CD (0.05)	14.30	
SEm±	4.72	

Table 10. Effect of urea x muriate of potash interaction on soil available Ca (ppm)

Urea (UR)	Muriate of potash (MOP)	
	-MOP	+MOP
-UR	590.7	503.4
+UR	356.4	328.4
CD (0.05)	26.53	
SEm±	8.75	

Table 11. Effect of urea x muriate of potash interaction on soil available Mn (ppm)

Urea (UR)	Muriate of potash (MOP)	
	-MOP	+MOP
-UR	55.51	48.64
+UR	70.78	59.85
CD (0.05)	1.95	
SEm±	0.64	

4.2 Effects of long-term fertilization on soil nutrient reserves

Data pertaining to the effects of long-term inorganic fertilization on soil nutrient reserves are presented in Table 14.

Application of urea helped in the build-up of P reserves in soil.

Long-term superphosphate application resulted in build-up of P reserves in soil. Calcium, Mg and S reserves of the soil also showed significant improvement following long-term superphosphate application, while, potassium reserve of the soil suffered depletion from 2220 ppm in P_0 plots to 2021 ppm in P_2 plots.

Muriate of potash application led to substantial build-up of K reserves in the soil, the increase being from 1896 ppm in K_0 plots to 2346 ppm in K_2 plots. It also increased soil S reserves. But it depleted the soil reserves of Ca and Mg. Total Ca content decreased from 1557 to 1428 ppm, Mg from 1060 to 1006 ppm, when the level of application was increased from K_0 to K_2. NPK fertilization also influenced the micronutrient reserves of the soil. Long-term urea application reduced Mn reserves in the soil. Long-term superphosphate application had a depressing effect on Mn and Cu reserves of the soil, total Mn decreased from 646.3 ppm in P_0 plots to 615.8 ppm in P_2 plots. Similarly total Cu decreased from 44.58 to 39.81 ppm as the level of application was increased from P_0 to P_2. Application of either urea or superphosphate caused a perceptible decline in total Zn content of the soil. Urea, superphosphate and muriate of potash increased the total Fe content of the soil. Long-term Muriate of potash application helped to build Mn reserves in soil.

Table 12. Effect of superphosphate x muriate of potash interaction on soil available K (ppm)

Superphosphate (SP)	Muriate of potash (MOP)	
	-MOP	+MOP
-SP	139.5	363.2
+SP	165.4	314.7
CD (0.05)	14.30	
SEm±	4.72	

Table 13. Effect of superphosphate x muriate of potash interaction on soil available S (ppm)

Superphosphate (SP)	Muriate of potash (MOP)	
	-MOP	+MOP
-SP	23.06	20.61
+SP	149.66	91.11
CD (0.05)	5.30	
SEm±	1.75	

Table 14. Effect of NPK fertilizers on nutrient reserves of cocoa rootzone

Treatment	Total P (ppm)	Total K (ppm)	Total Ca (ppm)	Total Mg (ppm)	Total S (ppm)	Total Fe (%)	Total Zn (ppm)	Total Mn (ppm)	Total Cu (ppm)
-UR	671.5	2099	1508	1023	277.7	3.77	183.1	643.8	41.28
+UR	745.6	2143	1476	1044	274.8	4.00	140.5	618.2	43.11
-SP	680.3	2220	1267	833	209.6	3.70	180.3	646.3	44.58
+SP	736.8	2021	1718	1233	342.9	4.07	143.2	615.8	39.81
-MOP	724.9	1896	1557	1060	272.8	3.64	163.4	616.5	40.78
+MOP	692.1	2346	1428	1006	279.7	4.13	160.2	645.5	43.61
CD (0.05)	27.73	85.39	40.01	28.33	4.09	0.06	8.49	5.96	2.84
SEm±	9.14	18.16	13.19	9.35	1.35	0.02	2.79	1.96	0.76

UR - Urea; SP - Superphosphate; MOP - Muriate of potash

Superphosphate x muriate of potash interaction was significant in the case of soil reserves of P (Table 15), K (Table 16) and S (Table 17). Phosphorus reserves decreased from 776.7 ppm in plots receiving only superphosphate to 697.0 ppm in plots receiving both superphosphate and muriate of potash.

Total K increased from 1925 ppm in plots receiving superphosphate to 2118 ppm in plots receiving both superphosphate and muriate of potash.

Sulphur reserves of the soil increased from 332.9 ppm in superphosphate treated plots to 353.5 ppm in plots receiving both superphosphate and muriate of potash.

4.3 Urea x depth interaction

Urea x depth interaction was significant in respect of pH, available S, Fe, Mn and Cu and total S and Fe (Table 18).

Urea application reduced soil pH. The effect was more pronounced in the 50-75 cm layer of soil. Urea application increased available S status of soil in the lower soil layers. (25-50 and 50-75 cm layers of soil). Following long-term urea application available Mn and available Fe contents of soil increased up to 50 cm soil depth, whereas in the case of total Fe the effect was significant up to the lowest depth sampled (ie. 75 cm). The increase in the case of available Cu and total S were significant in the 0-25 cm soil layer only.

4.3.1 Superphosphate x depth interactions

The data pertaining to these effects are presented in Table 19.

Table 15. Effect of superphosphate x muriate of potash interaction on total P (ppm)

Superphosphate (SP)	Muriate of potash (MOP)	
	- MOP	+MOP
-SP	673.2	687.3
+SP	776.7	697.0
CD (0.05)	45.60	
SEm±	15.83	

Table 16. Effect of superphosphate x muriate of potash interaction on total K (ppm)

Superphosphate (SP)	Muriate of potash (MOP)	
	-MOP	+MOP
-SP	1868	2573
+SP	1925	2118
CD (0.05)	120.79	
SEm±	39.82	

Table 17. Effect of superphosphate x muriate of potash interaction on total S (ppm)

Superphosphate (SP)	Muriate of potash (ppm)	
	-MOP	+MOP
-SP	213.3	205.9
+SP	332.9	353.5
CD (0.05)	5.76	
SEm±	1.90	

Table 18. Chemical characteristics of different soil layers as influenced by long-term urea application

Depth (cm)	pH		Available S (ppm)		Available Fe (ppm)		Available Cu (ppm)		Available Mn (ppm)		Total S (ppm)		Total Fe (%)	
	-UR	+UR	-UR	+UR	-UR	+UR	-UR	+UR	-UR	+UR	-UR	+UR	-UR	+UR
0-25	5.28	4.88	54.75	50.08	9.03	11.51	5.73	6.58	64.10	89.51	190.6	213.9	3.22	3.36
25-50	5.14	4.68	63.83	73.83	13.81	15.62	3.98	4.26	52.86	71.34	264.7	271.3	3.68	4.06
50-75	5.05	4.44	87.16	97.00	18.59	18.32	3.06	2.50	39.25	35.09	377.9	339.2	4.41	4.57
CD (0.05)	0.09		6.17		1.00		0.46		2.28		6.71		0.12	
SEm±	0.03		2.14		0.35		0.16		0.79		2.33		0.04	

UR - Urea

Table 19. Chemical characteristics of different soil layers as influenced by long-term superphosphate application

Depth (cm)	pH		Available P (ppm)		Available K (ppm)		Available S (ppm)		Available Cu (ppm)		Total P (ppm)		Total Ca (ppm)		Total S (ppm)		Total Zn (ppm)	
	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP	-SP	+SP
0-25	5.00	5.16	7.44	81.52	316.7	274.5	13.50	91.33	7.05	5.26	594.1	885.0	1451	2091	150.2	254.3	149.7	128.1
25-50	4.82	5.00	10.27	29.40	241.5	235.3	20.16	117.50	4.95	3.29	749.8	725.7	1260	1662	190.0	345.9	183.1	147.0
50-75	4.74	4.76	11.02	11.00	195.9	210.2	31.83	152.33	3.22	2.35	696.9	599.8	1089	1400	288.5	428.6	208.3	154.6
CD (0.05)	0.09		2.48		16.63		6.17		0.46		65.79		46.64		6.71		13.97	
SEm±	0.03		0.90		5.77		2.14		0.16		22.84		16.19		2.33		4.85	

SP - Superphosphate

Effect of superphosphate in reducing soil acidity was significant up to 50 cm depth. Available K and Cu contents also decreased with depth as a result of long-term superphosphate application.

Superphosphate application considerably improved available P as well as P reserves of soil. In the case of total P the increase was significant in the 0-25 cm layer whereas available P increased up to 50 cm depth. Available S and S reserves of the soil increased up to 75 cm depth. Calcium reserves of the soil also showed conspicuous enrichment due to long-term superphosphate application. A reverse trend was noticed in the case of Zn reserves of the soil. The reduction in total Zn content was evident up to the lowest depth sampled ie. up to 75 cm.

4.3.2 Muriate of potash x depth interactions

Long-term application of muriate of potash reduced available P, S, Cu and total Ca contents of soil with depth (Table 20).

4.4 Effect of irrigation and shade on soil chemical characteristics

4.4.1 Effects of irrigation

Effects of irrigation on soil chemical characteristics and nutrient reserves are presented in Tables 21 and 22 respectively.

Irrigation significantly reduced the amounts of available P from 11.25 ppm in unirrigated plots to 8.89 ppm in irrigated plots; available Ca from 234.0 to 156.1 ppm; available Mn from 118.64 to 76.98 ppm and available Cu from 4.76 to 3.91 ppm. On the other hand, available K, Zn and S contents of the soil were higher under irrigated condition.

Table 20. Chemical characteristics of different soil layers as influenced by long-term muriate of potash application

Depth (cm)	Available P (ppm)		Available S (ppm)		Available Cu (ppm)		Total Ca (ppm)	
	-MOP	+MOP	-MOP	+MOP	-MOP	+MOP	-MOP	+MOP
0-25	47.61	41.35	68.16	36.66	6.73	5.58	1892	1650
25-50	25.63	14.03	89.25	48.42	4.78	3.46	1471	1450
50-75	11.62	10.39	101.66	82.50	2.96	2.60	1307	1183
CD (0.05)	2.59		6.17		0.46		65.79	
SEm±	0.90		2.14		0.16		22.84	

MOP - Muriate of potash

Table 21. Effect of irrigation and shade on chemical characteristics of cocoa rootzone

Treatment	pH	Organic carbon (%)	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)	Available Cu (ppm)
-I	4.60	0.674	11.25	281.5	234.0	140.2	81.56	11.20	6.47	118.64	4.76
+I	4.59	0.654	8.89	310.2	156.1	114.0	100.83	12.25	7.42	76.98	3.91
-S	4.60	0.607	8.67	329.9	201.8	127.2	95.78	10.90	7.62	96.96	4.35
+S	4.57	0.721	11.47	261.8	188.3	127.2	86.61	12.54	6.27	98.67	4.32
CD (0.05)	NS	0.10	1.59	15.78	44.66	NS	6.56	1.44	0.68	9.59	0.69
SEm±	0.07	0.03	0.46	4.56	12.91	7.89	1.89	0.42	0.23	2.77	0.20

I - Irrigation, S - Shade, NS- Not significant

Table 22. Effect of irrigation and shade on nutrient reserves of cocoa rootzone

Treatment	Total P (ppm)	Total K (ppm)	Total Ca (ppm)	Total Mg (ppm)	Total S (ppm)	Total Zn (ppm)	Total Mn (ppm)	Total Cu (ppm)	Total Fe (%)
-I	462.6	2645	1320	837.9	273.5	74.67	686.2	41.78	4.09
+I	404.2	2618	1439	844.0	291.2	71.61	633.2	45.44	4.08
-S	400.2	2776	959	883.7	274.1	69.17	568.1	43.50	3.75
+S	466.5	2487	1800	798.1	290.6	77.11	751.4	43.72	4.42
CD(0.05)	14.57	263.94	59.45	23.91	2.66	3.65	11.68	NS	0.17
SEm±	4.21	76.27	17.18	6.91	0.77	1.05	3.38	1.39	0.05

I - Irrigation, S - Shade, NS - Not significant

Soil reserves of P and Mn showed considerable reduction under irrigated condition. Total P decreased from 462.6 to 404.2 ppm and total Mn, from 686.2 to 633.2 ppm when the plots were irrigated. On the other hand soil reserves of Ca and S tended to increase with irrigation.

4.4.2 Irrigation x depth interactions

Irrigation x depth interactions were significant in respect of available P, K, Ca, S and Mn, Total P, S and Mn. The data are presented in Tables 23 and 24. Available P content of the 0-25 cm layer of soil decreased from 21.47 ppm in plots receiving no irrigation to 15.28 ppm in irrigated plots. Available Ca and Mn contents of all the three soil layers (0-25, 25-50 and 50-75 cm) showed significant reduction due to irrigation. On the other hand the available K content of the 0-25 and 25-50 cm soil layers and available S content of 25-50 cm and 50-75 cm soil layers showed conspicuous enrichment with irrigation. Soil reserves of P and Mn showed reduction under irrigation. In the case of total P, the effect was evident throughout the rootzone profile (ie. up to 75 cm). The depletion in total Mn was pronounced in the lower soil layers (25-50 and 50-75 cm). Total S content of 25-50 and 50-75 cm soil layers showed conspicuous enrichment with irrigation.

4.4.3 Effect of shade

The data relating to the effects of shade on available nutrients and total nutrient contents are given in Tables 21 and 22 respectively.

Table 23. Chemical characteristics of different soil layers as influenced by irrigation (I)

Depth (cm)	Available P (ppm)		Available K (ppm)		Available Ca (ppm)		Available S (ppm)		Available Mn (ppm)	
	-I	+I	-I	+I	-I	+I	-I	+I	-I	+I
0-25	21.47	15.28	308.1	353.3	275.9	160.0	51.00	59.33	108.9	87.86
25-50	7.51	6.96	275.4	319.8	187.8	146.7	87.00	115.67	119.0	79.06
50-75	4.78	4.44	261.1	257.4	238.3	161.7	106.67	127.50	128.0	64.02
CD(0.05)	2.82		28.12		32.04		8.41		5.24	
SEm±	0.94		9.38		10.69		2.87		1.75	

Table 24. Irrigation x depth interaction on total nutrient content (ppm)

Depth (cm)	Total P (ppm)		Total S (ppm)		Total Mn (ppm)	
	-I	+I	-I	+I	-I	+I
0-25	561.9	497.8	205.9	201.5	712.3	728.0
25-50	437.6	389.8	288.0	308.7	704.0	632.0
50-75	388.9	325.0	326.7	363.5	642.0	538.0
CD (0.05)	20.62		9.41		14.93	
SEm±	6.88		3.14		4.98	

Organic carbon, available P, K, S, Fe and Zn contents of soil were significantly influenced by shade. While organic carbon, available P and Fe recorded higher values under shaded condition, available K, S and Zn were higher under open condition.

Total P, Ca, S, Fe, Zn and Mn were found to increase under shaded condition. On the contrary, total K, recorded higher values under open condition. Mg reserves of the soil also showed higher values under open condition.

4.4.4 Shade x depth interactions

Shade x depth interactions were significant in respect of available P, Fe, Total P and Total Fe (Table 25).

Available P content of the surface 0-25 cm soil layer was significantly affected by shade. Available P content of shaded plot was 21.66 ppm, while in the open plots available P recorded a value of 15.09 ppm. But the effect was not significant in the lower layers. On the other hand total P content of the 0-75 cm soil layer was significantly influenced by shade. In all the three depths (ie. 0-25, 25-50 and 50-75 cm) total P recorded higher values under shaded conditions.

Available Fe and total Fe also recorded higher values under shaded conditions. Available Fe content of the 25-50 cm soil layer decreased from 14.59 to 10.66 ppm, from shaded to open plots. But this effect was not significant in the 0-25 and 50-75 cm soil layers. But total Fe, increased throughout the depth (ie. 0-75 cm) under shaded conditions compared to open conditions.

Table 25. Chemical characteristics of different soil layers as influenced by shade (S)

Depth (cm)	Available P (ppm)		Available Fe (ppm)		Total P (ppm)		Total Fe (%)	
	-S	+S	-S	+S	-S	+S	-S	+S
0-25	15.09	21.66	7.48	7.38	470.1	589.6	3.04	4.04
25-50	6.99	7.47	10.66	14.59	388.7	438.7	3.95	4.41
50.75	3.93	5.29	14.55	15.65	341.9	371.3	4.23	4.81
CD (0.05)	2.82		1.56		20.62		0.15	
SEm±	0.94		0.52		6.88		0.05	

4.4.5 Irrigation x shade interaction

Irrigation x shade interaction was significant in the case of available P (Table 26). Highest concentration of available P (13.90 ppm) was noticed in shaded plots receiving no irrigation.

4.5 Effect of NPK fertilizer application on foliar nutrient levels of cocoa

The data pertaining to these effects are presented in Table 27.

Application of urea increased foliar nitrogen content. Highest concentration (2.22%) was observed at N_1 level of application. Nitrogen application raised the leaf concentrations of Fe, Mn and Cu. For Fe and Cu highest concentrations (343.6 ppm and 19.40 ppm respectively) were observed at N_1 level of application. Foliar Mn concentration was highest (92.44 ppm) at N_2 level of application. At higher levels of urea application foliar K content decreased (From 1.97% at N_0 to 1.75% at N_2 level).

Long-term application of superphosphate did not increase foliar P concentration significantly. But superphosphate application showed a depressing effect on foliar Zn content. Zinc content of leaf was reduced from 121.2 ppm at P_0 level to 98.6 ppm at P_2 level.

Application of muriate of potash increased foliar K content. Highest concentration (2.20%) was noticed at K_1 level of application. Long-term application of muriate of potash reduced foliar Mg content.

Table 26. Effect of irrigation x shade interaction on soil available P (ppm)

Irrigation (I)	Shade (S)	
	-S	+S
-I	8.60	13.90
+I	8.73	9.05
CD (0.05)	2.28	
SEm±	0.66	

Table 27. Effect of NPK fertilizer application on foliar nutrient levels of cocoa

Treat-ment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
N_0	1.76	0.145	1.97	0.82	0.63	0.256	240.1	112.5	73.92	15.59
N_1	2.22	0.130	1.87	0.78	0.61	0.299	343.6	121.4	84.26	19.40
N_2	1.99	0.126	1.75	0.83	0.62	0.195	288.8	88.8	92.44	19.07
P_0	2.09	0.126	1.78	0.82	0.60	0.255	292.0	121.2	77.92	18.88
P_1	1.89	0.132	1.99	0.79	0.64	0.241	294.1	102.9	82.03	18.59
P_2	1.99	0.144	1.82	0.83	0.60	0.254	285.9	98.6	90.66	16.59
K_0	1.88	0.137	1.46	0.81	0.64	0.251	276.4	110.2	86.59	18.00
K_1	2.31	0.128	2.20	0.80	0.58	0.264	321.4	113.1	72.55	18.77
K_2	1.78	0.136	1.93	0.79	0.63	0.234	274.2	99.5	91.48	17.29
CD(0.05)	0.08	NS	0.13	NS	0.03	NS	43.86	5.30	5.04	1.59
SEm±	0.03	0.007	0.05	0.02	0.01	0.019	16.49	1.99	1.89	0.59

NS - Not significant

Higher level of N or K depressed leaf Zn content of cocoa. Zinc concentration decreased from 121.4 ppm at N_1 level to 88.8 ppm at N_2 level. Similarly when the rate of application of K was raised from K_1 to K_2, Zn content of leaf declined from 113.1 to 99.5 ppm. Similarly superphosphate at higher levels of application reduced the foliar Cu content significantly.

Leaf N content was found to be significantly affected by N x K interaction. Highest concentration of N (2.78%) was noticed at N_1K_1 level of application (Table 28). N x K interaction significantly influenced foliar K content also. N_1K_1 combination recorded highest K content (2.62%) in the leaf (Table 29).

N x P interaction influenced the foliar Zn content significantly (Table 30). Highest concentration (142.11 ppm) was noticed at N_0P_0 level and the lowest (80.11 ppm) at N_2P_2 level.

4.6 Effect of irrigation and shade on foliar nutrition of cocoa

The data pertaining to these effects are given in Table 31.

Irrigated conditions resulted in increased foliar concentrations of N, P, K, S, Fe, Zn, Mn and Cu. Foliar nitrogen content increased from 1.74 to 2.03 per cent, P from 0.173 to 0.232 per cent, K from 2.20 to 2.81 per cent, S from 0.100 to 0.162 per cent, Fe from 166.0 to 205.3 ppm, Zn from 74.50 to 84.25 ppm Mn from 50.08 to 60.42 ppm and Cu from 17.33 to 31.42 ppm, when the plots were irrigated. The only nutrient whose foliar concentration reduced with irrigation was Ca while Mg level remained unaffected.

Table 28. Effect of N x K fertilizer interaction on N content of cocoa leaf (%)

	K_0	K_1	K_2
N_0	1.67	1.84	1.78
N_1	2.12	2.78	1.75
N_2	1.86	2.31	1.82
CD (0.05)		0.06	
SEm±		0.02	

Table 29. Effect of N x K fertilizer interaction on K content of cocoa leaf (%)

	K_0	K_1	K_2
N_0	1.54	2.32	2.06
N_1	1.46	2.62	1.54
N_2	1.40	1.64	2.21
CD (0.05)		0.08	
SEm±		0.03	

Table 30. Effect of N x P fertilizer interaction on Zn content of cocoa leaf (ppm)

	P_0	P_1	P_2
N_0	142.11	96.78	98.78
N_1	126.00	121.44	117.00
N_2	95.66	90.66	80.11
CD (0.05)		3.46	
SEm±		1.30	

Table 31. Effect of irrigation and shade on foliar nutrient levels of cocoa

Treat-ment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
-I	1.74	0.173	2.20	0.775	0.458	0.100	166.0	74.50	50.08	17.33
+I	2.03	0.232	2.81	0.685	0.452	0.162	205.3	84.25	60.42	31.42
-S	1.70	0.193	2.60	0.758	0.425	0.125	170.0	80.50	34.75	23.50
+S	2.07	0.212	2.40	0.702	0.485	0.137	201.3	78.25	75.75	25.25
CD(0.05)	0.10	0.012	0.18	0.073	0.039	0.027	29.62	3.01	1.22	1.18
SEm±	0.03	0.004	0.06	0.025	0.013	0.009	9.83	1.00	0.41	0.39

I - Irrigation; S - Shade

Effect of shade was significant in the case of N, P, K, Mg, Fe, Mn and Cu, of these, foliar K recorded higher values under open condition. Concentrations of the other nutrients were higher under shaded condition.

Significant irrigation x shade interaction was observed in the case of foliar N (Table 32). Highest concentration of N was recorded under irrigated and shaded conditions (2.29%) and the lowest under unirrigated, open conditions (1.64%).

4.7 Effect of age on soil chemical characteristics

Barring soil pH and available Mn, all the soil parameters showed some definite trends over the years. Soil fertility parameters like organic carbon, available and total P, available and total Ca, available Zn, total S and total Cu showed an increase during the initial years which levelled off or decreased later. The dynamics of these soil parameters (y) could be described by a quadratic model of the form $y = a_0 \pm b_1x \pm b_2x^2$ where x is the age of the trees in years. The quadratic model explained 64.6 to 99.8 per cent variability (Figs. 7 to 14). The lowest predictability was observed for organic carbon while the highest predictability for available Zn. In the case of available Zn the predictability was close to 100 per cent when the 1st year available Zn content was treated as an outlier to the fitted curve (Fig. 12).

A linear equation of the form $y = a + bx$ where y is the soil parameter and x is the age of the tree in years is found to fit best for the plots of available and total K, available and total Mg, available Cu and total Zn against time. The R^2 values for these linear models ranged from 0.789 (for total Mg) to 0.942 (for total K).

Table 32. Effect of irrigation x shade interaction on N content of cocoa leaf (%)

Irrigation (I)	Shade (S)	
	-S	+S
-I	1.64	1.84
+I	1.76	2.29
CD (0.05)	0.15	
SEm±	0.05	

The dynamics of soil available Mn with time showed a totally different pattern compared to that of others already mentioned. In this case there was a steady increase for about nine years followed by a sharp decline. The overall pattern could be described by a fourth degree equation with a predictability of 99.8 per cent (Fig. 15).

The changes in soil pH with time did not follow any particular pattern. Soil pH decreased initially followed by a marginal increase and a sharp decrease by 12th year of planting the cocoa trees (Fig. 16).

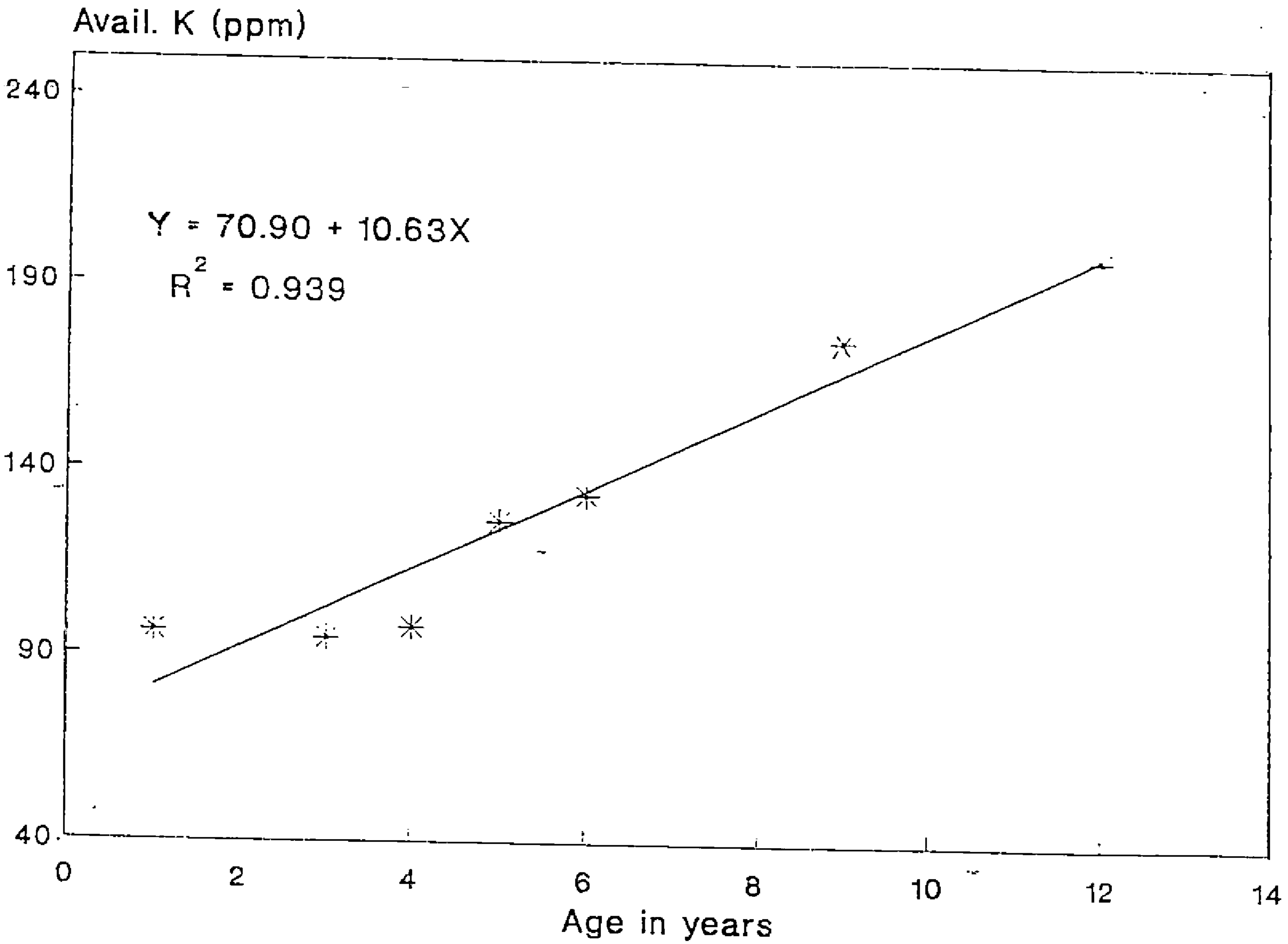

Fig.1. Dynamics of K availability in the rootzone of cocoa in relation to age

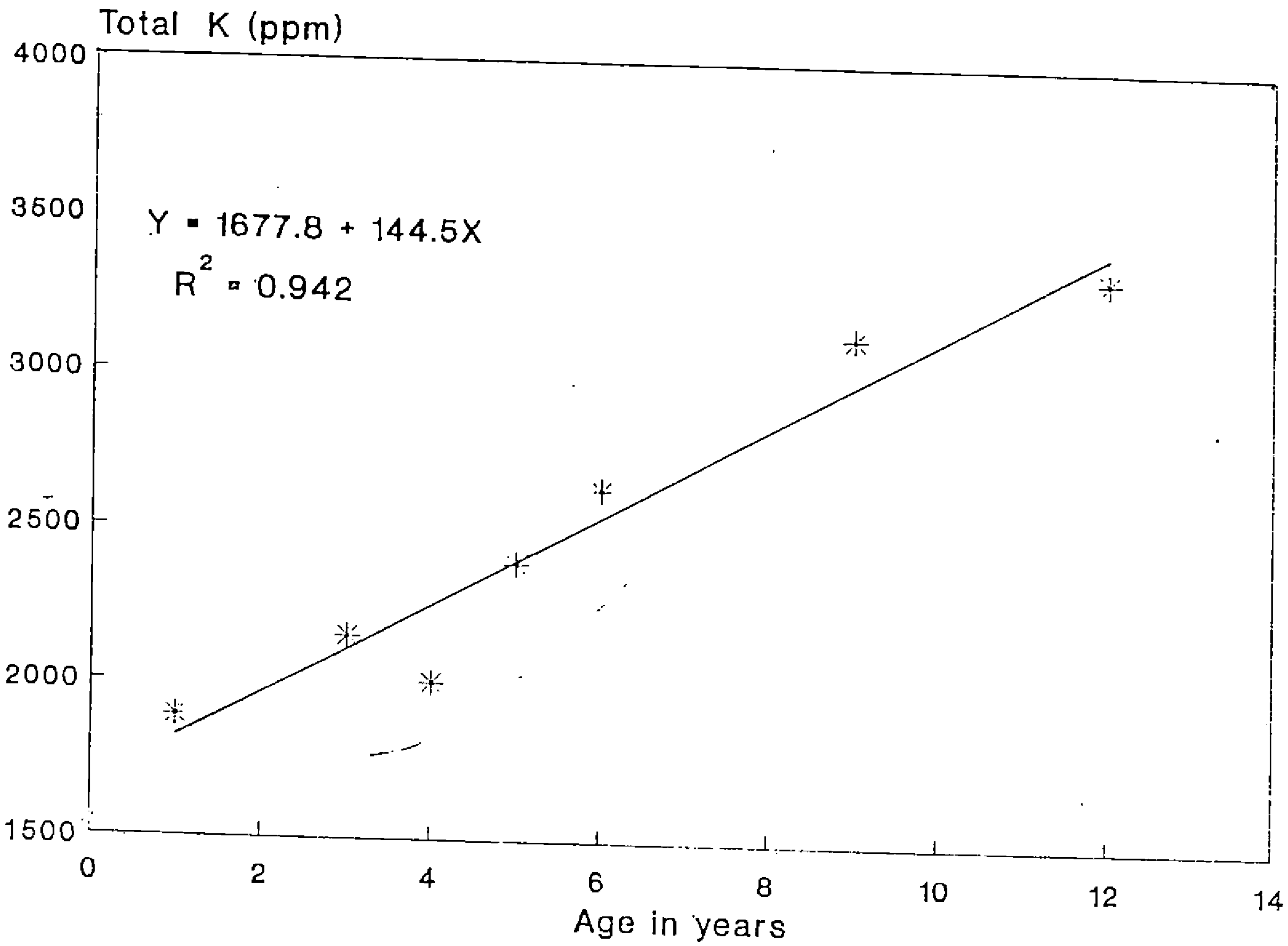

Fig. 2. Changes in K reserves of cocoa rootzone in relation to age

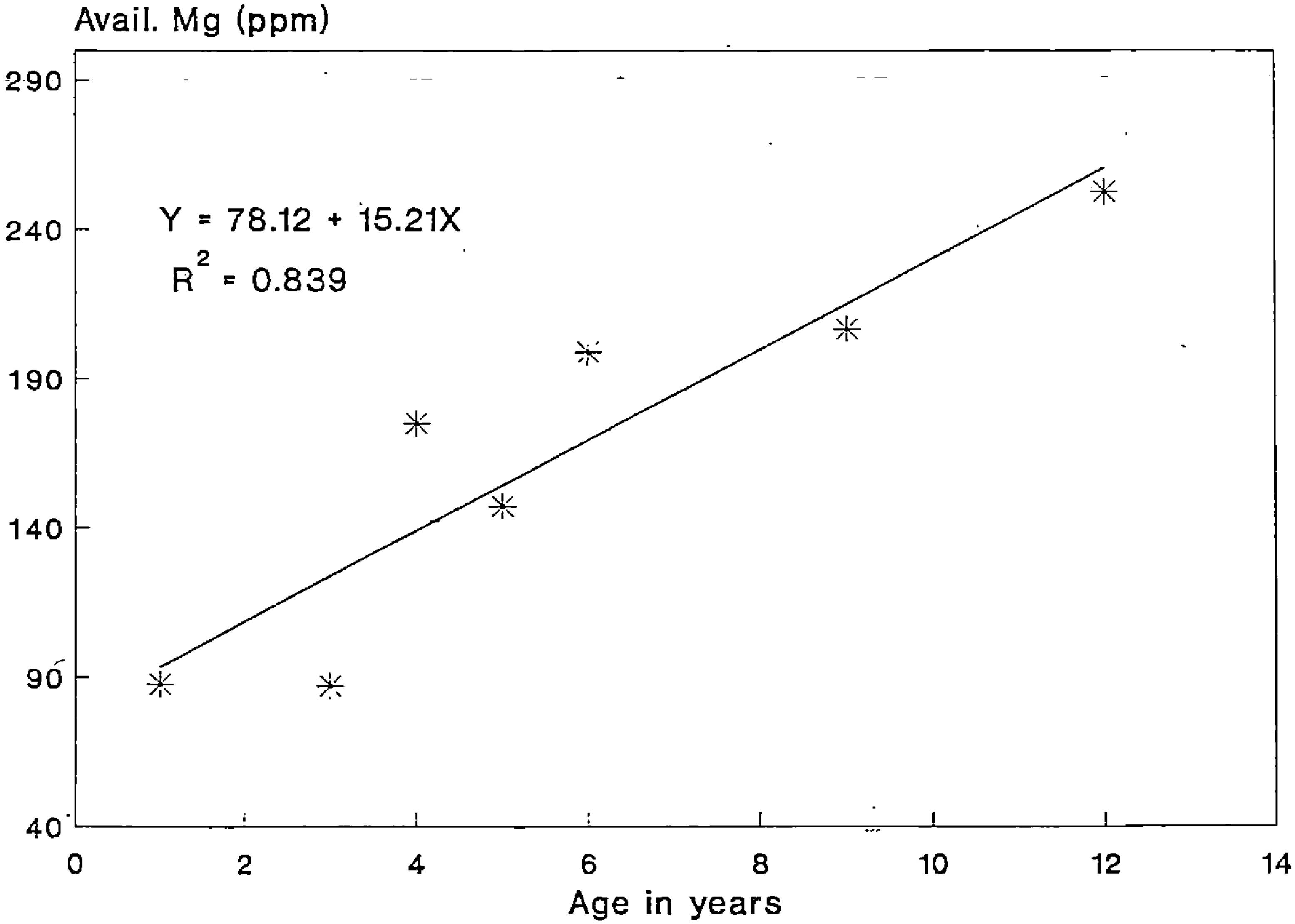

Fig. 3. Dynamics of Mg availability in the rootzone of cocoa in relation to age

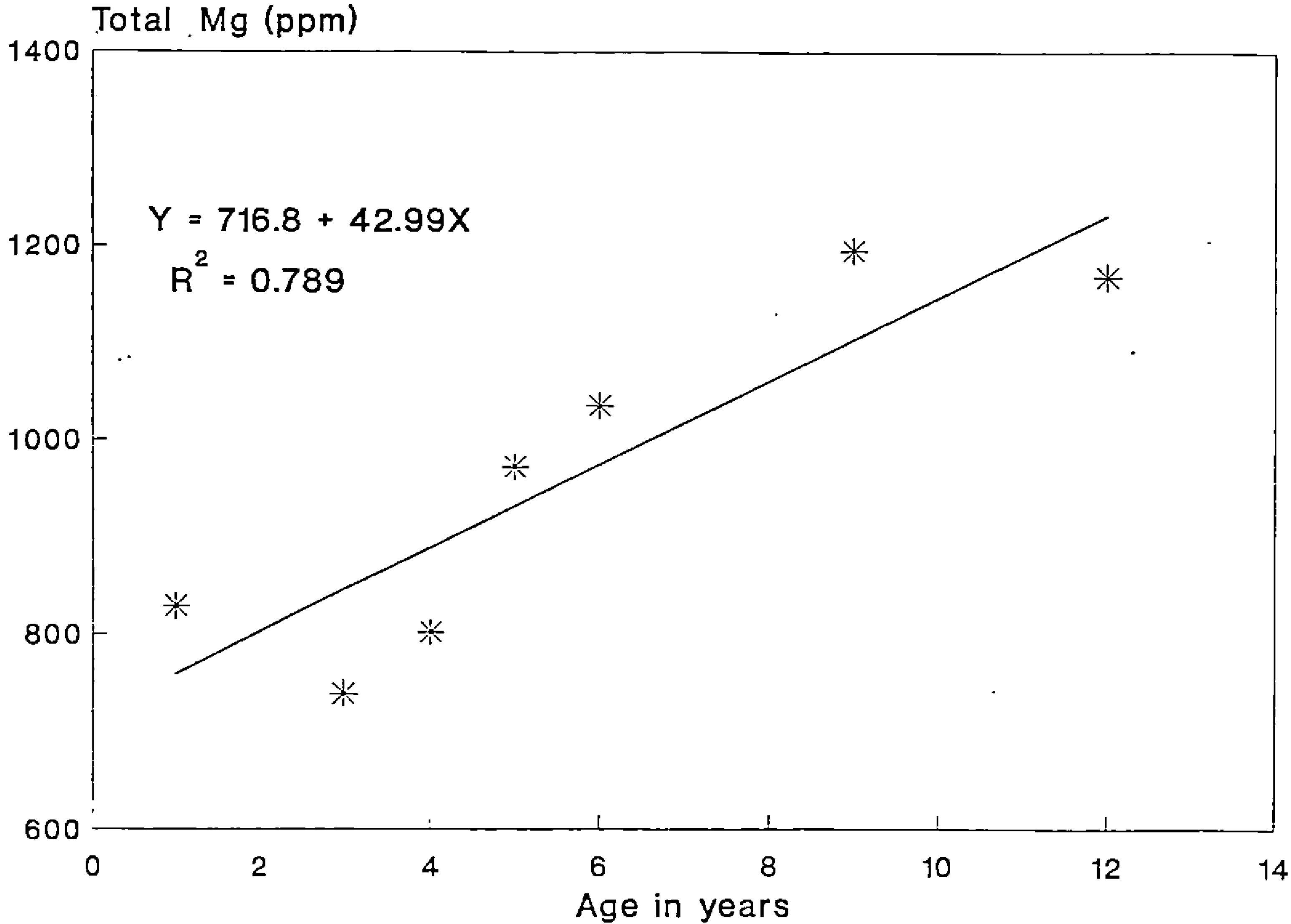

Fig. 4. Changes in Mg reserves of cocoa rootzone in relation to age

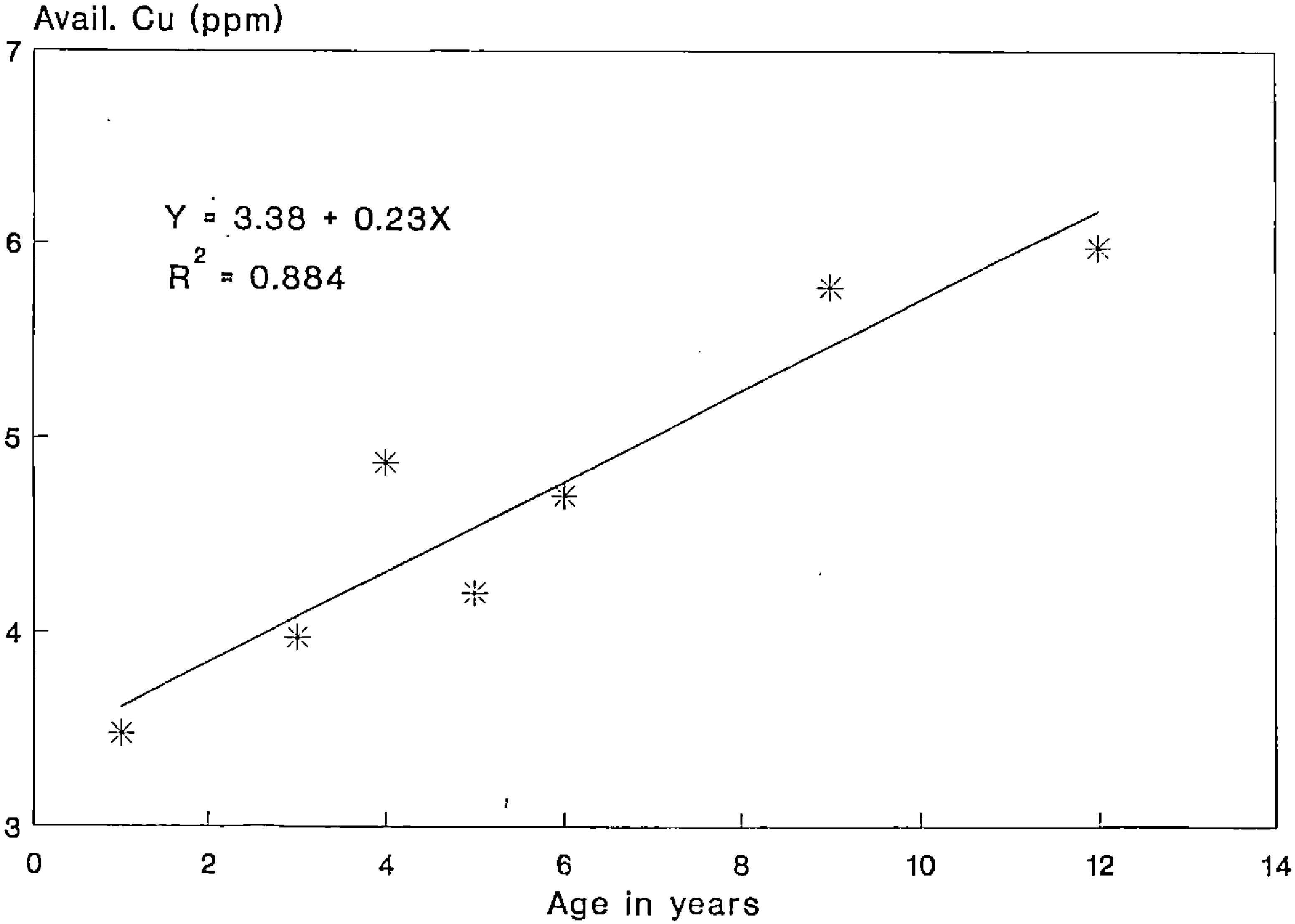

Fig.5. Dynamics of Cu availability in the rootzone of cocoa in relation to age

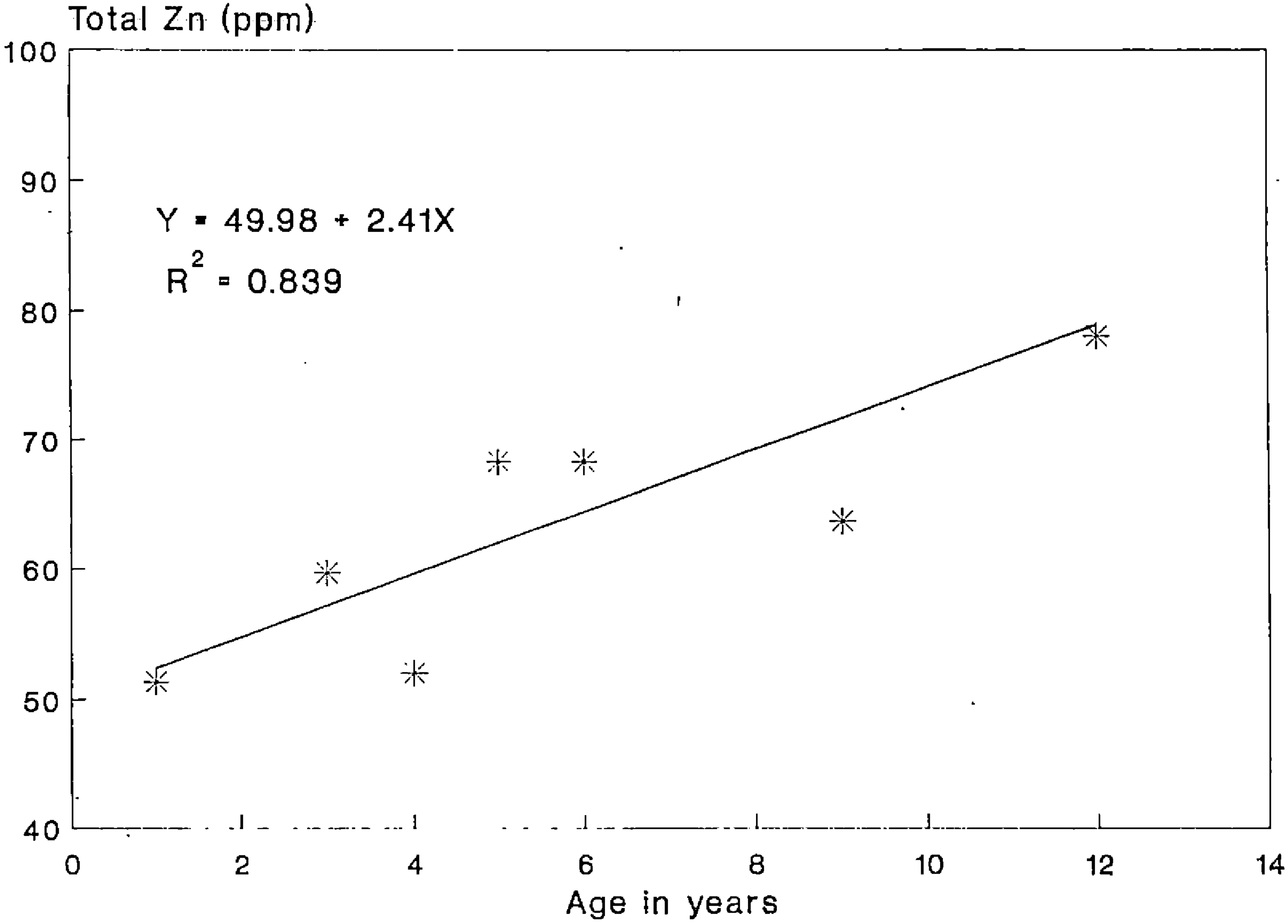

Fig.6. Changes in Zn reserves of cocoa rootzone in relation to age

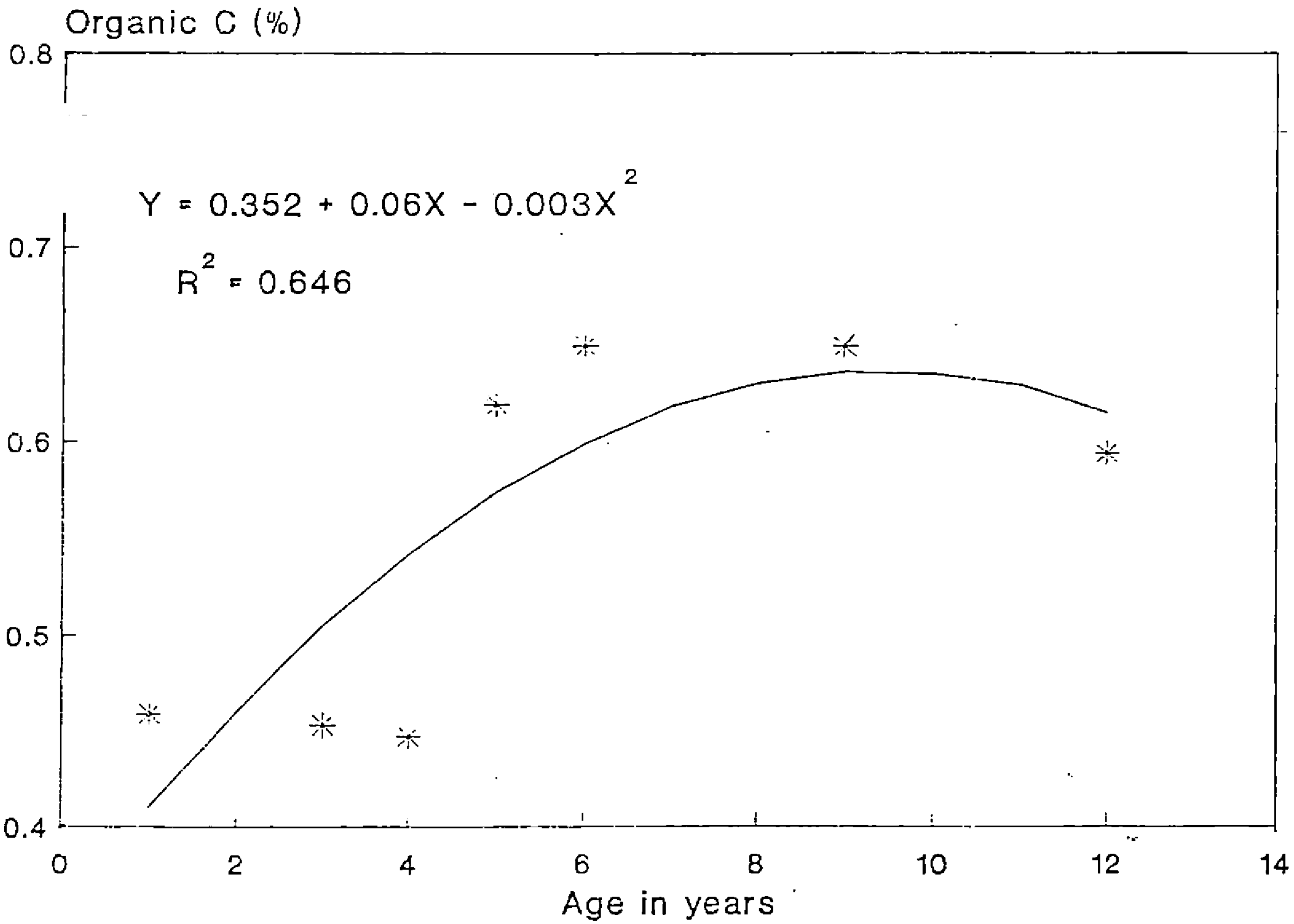

Fig.7. Changes in Organic C content of cocoa rootzone in relation to age

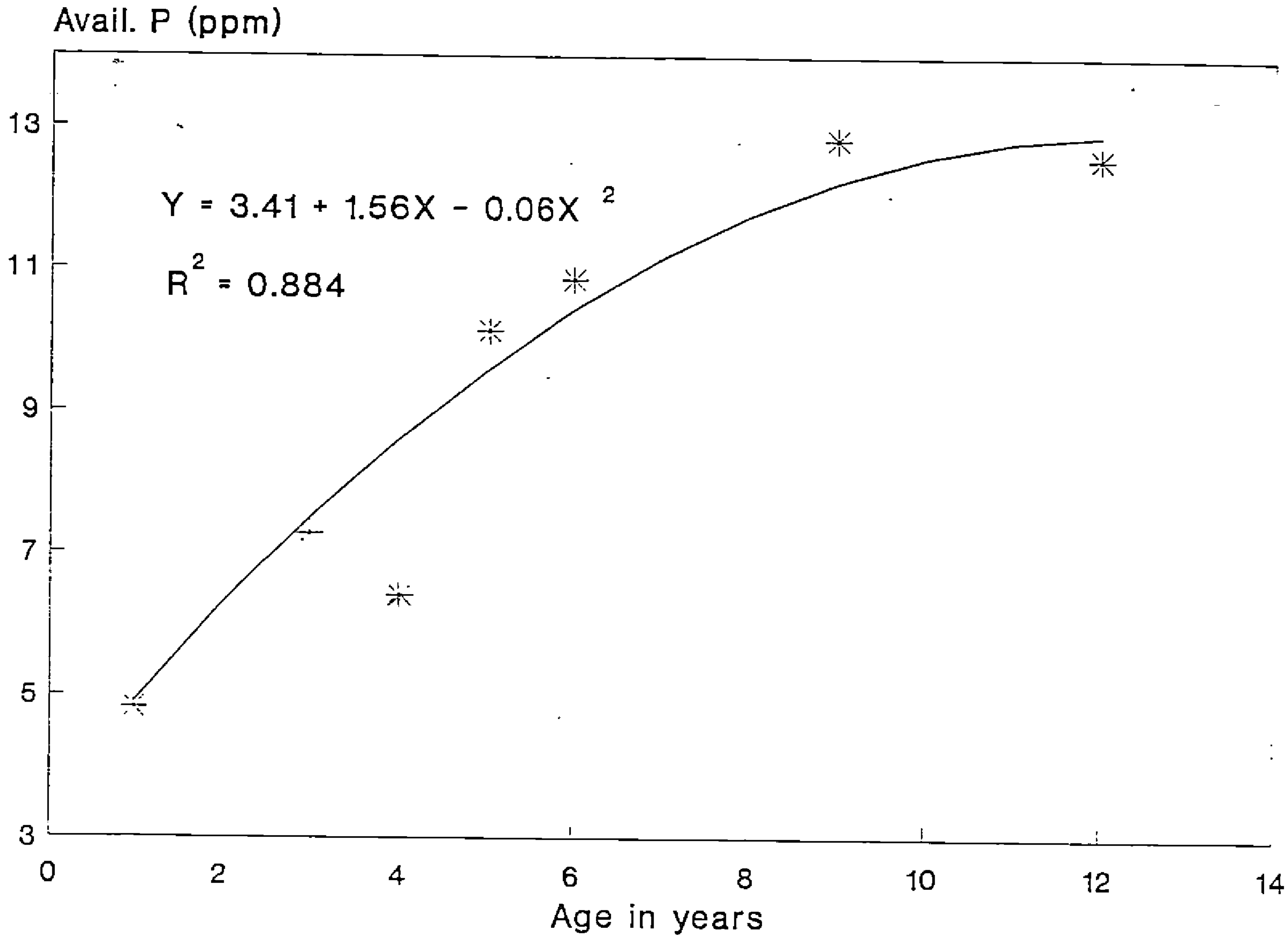

Fig.8. Changes in P availability in the rootzone of cocoa in relation to age

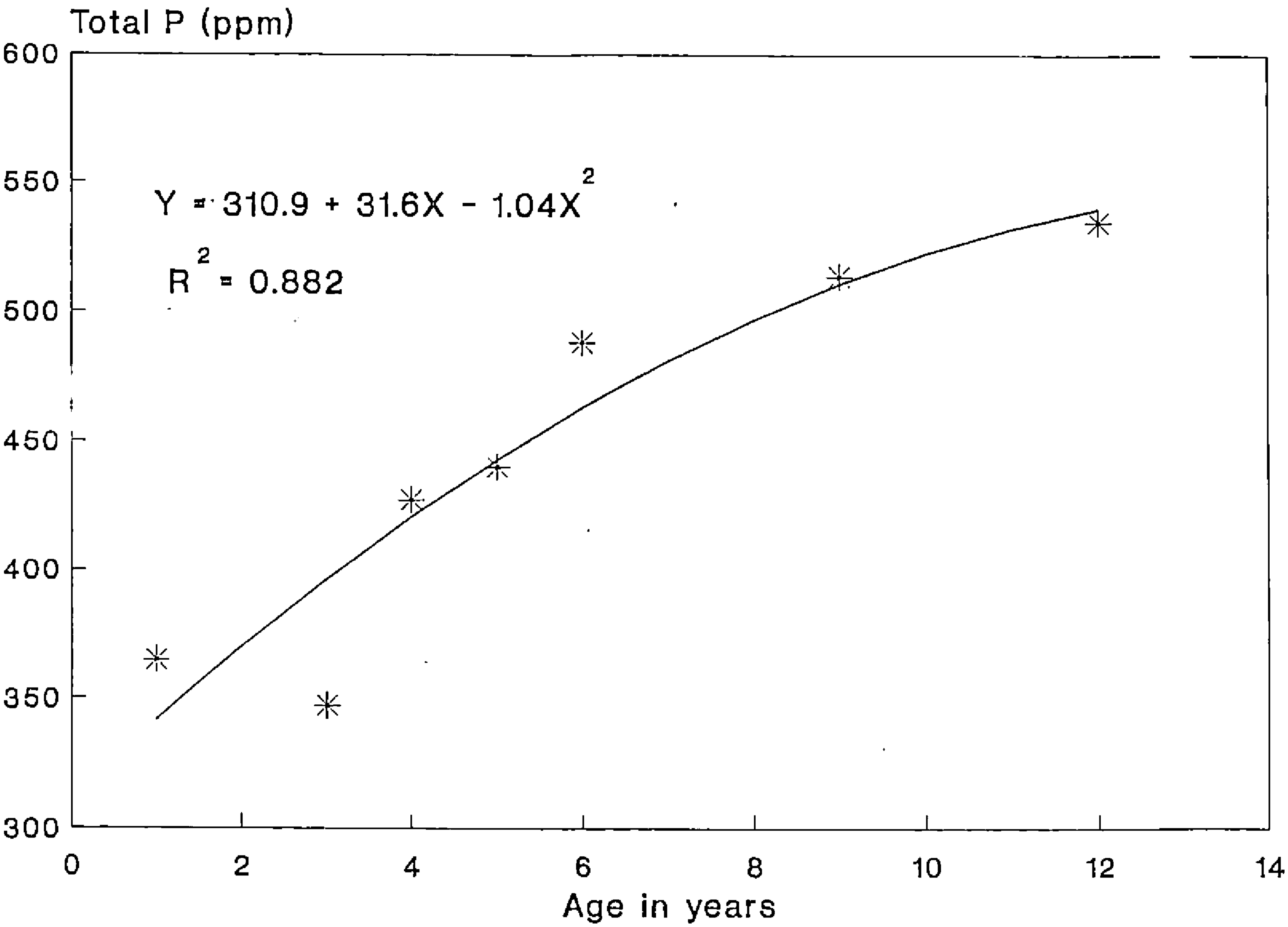

Fig.9. Changes in P reserves of cocoa rootzone in relation to age

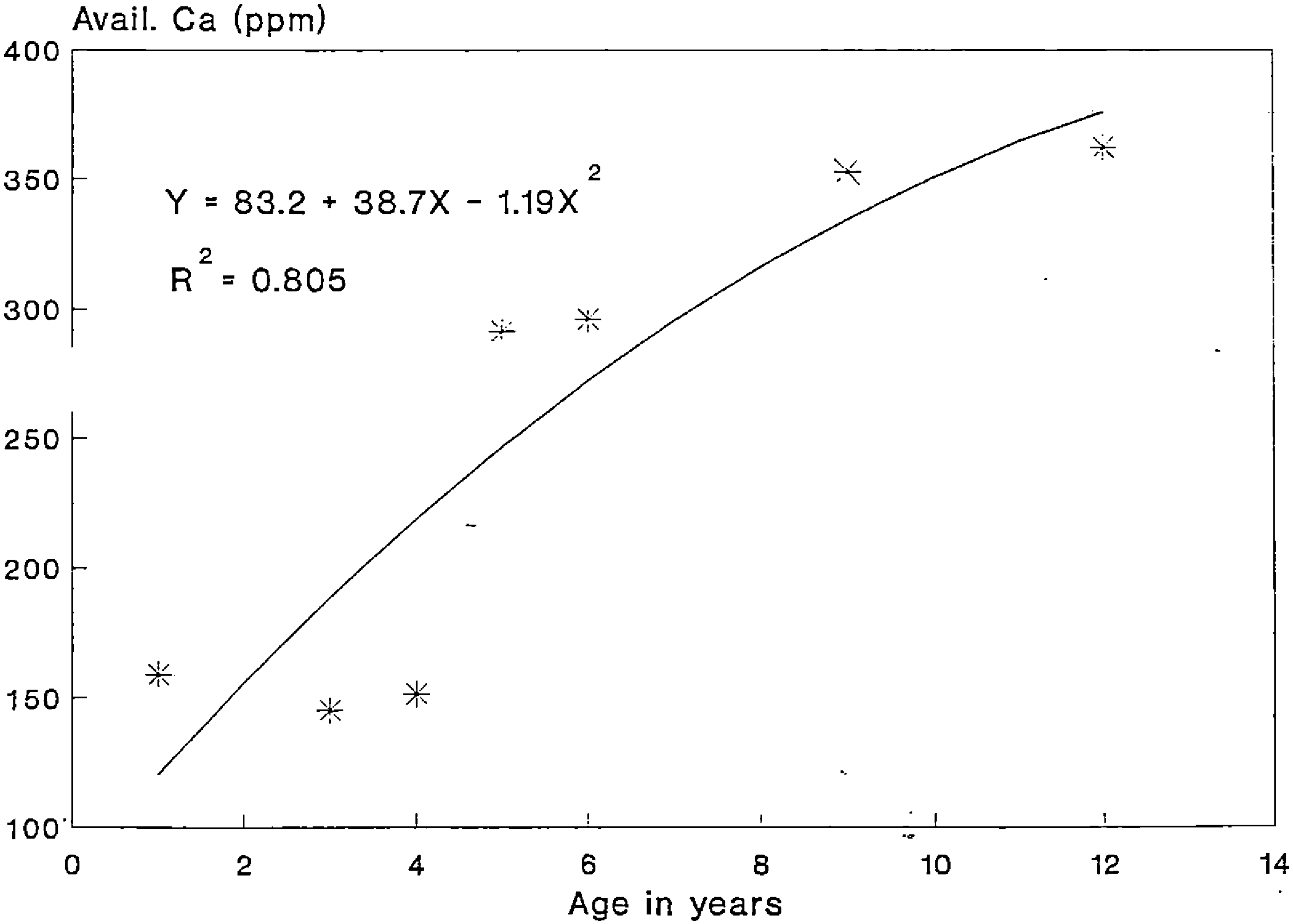

Fig.10. Dynamics of Ca availability in the rootzone of cocoa in relation to age

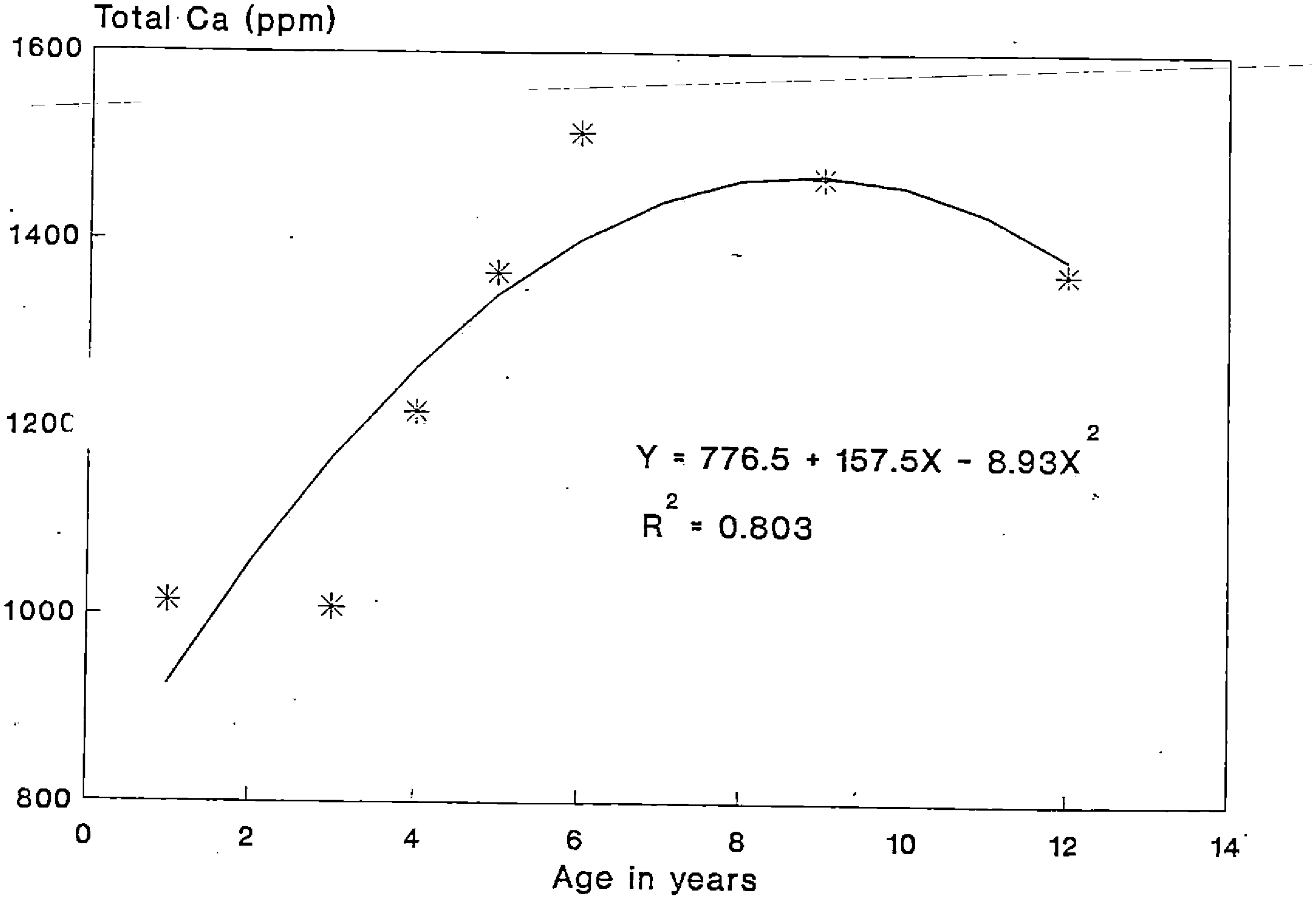

Fig.11. Changes in Ca reserves of cocoa rootzone in relation to age

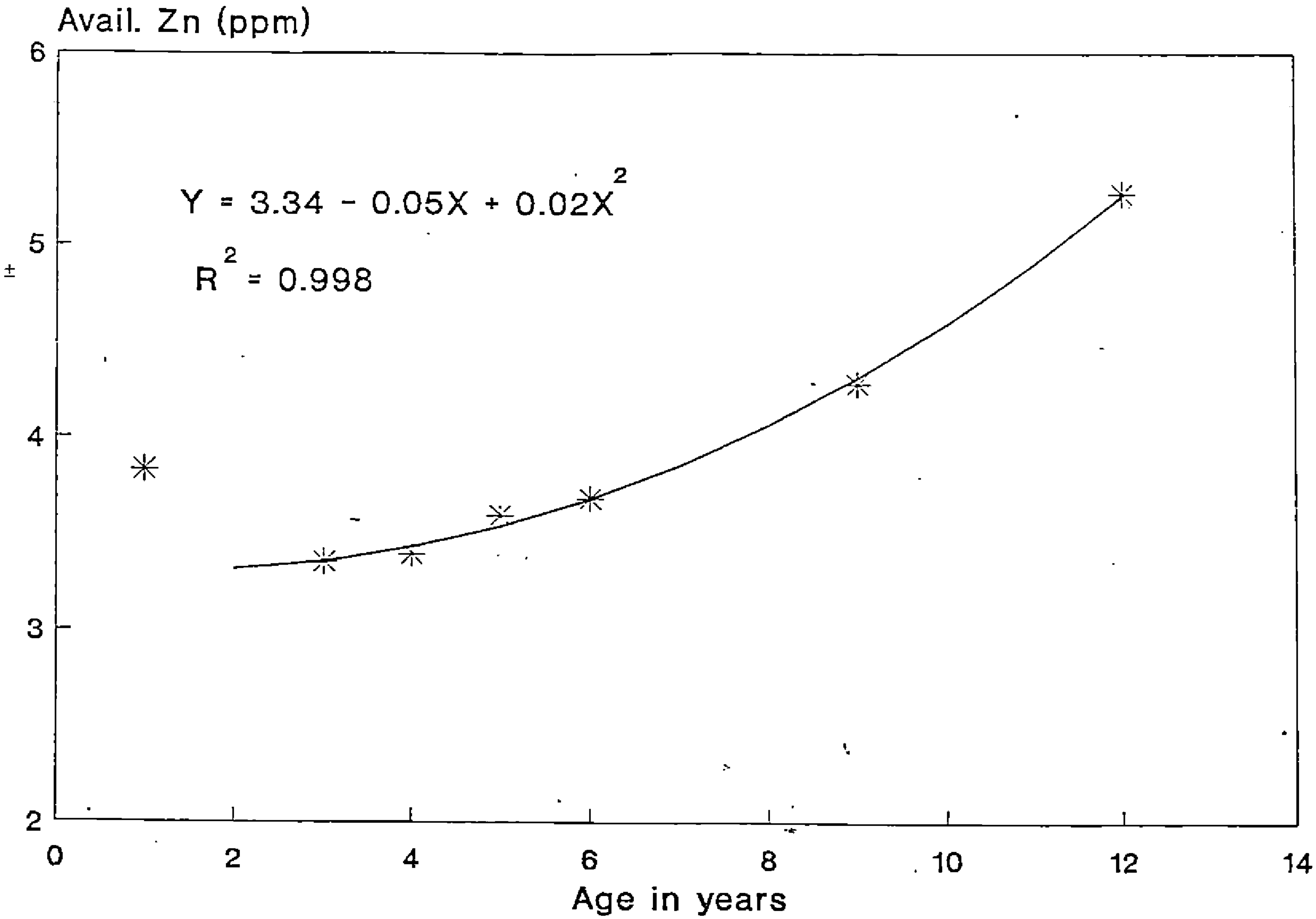

Fig.12. Dynamics of Zn availability in the rootzone of cocoa in relation to age

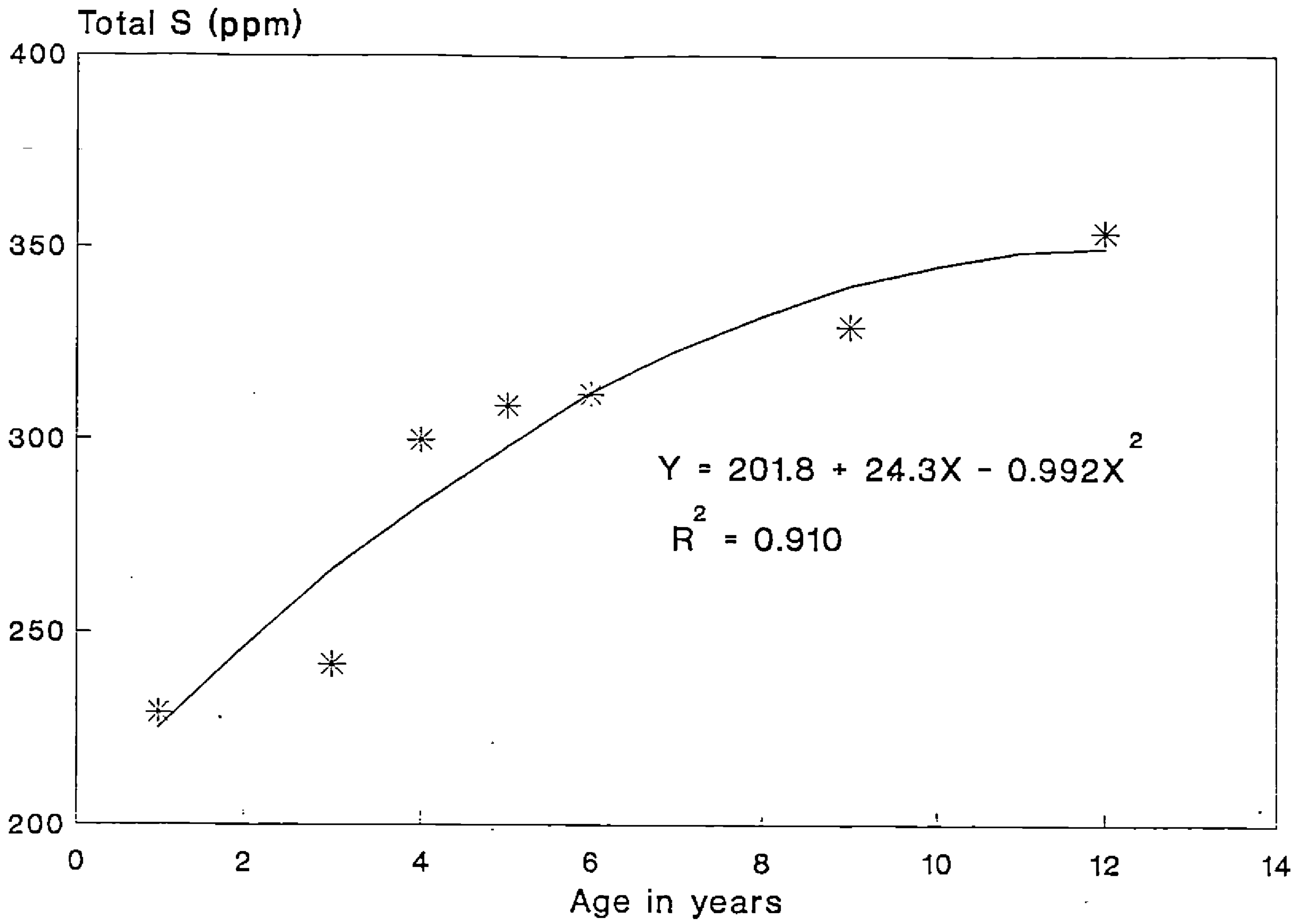

Fig.13. Changes in S reserves of cocoa rootzone in relation to age

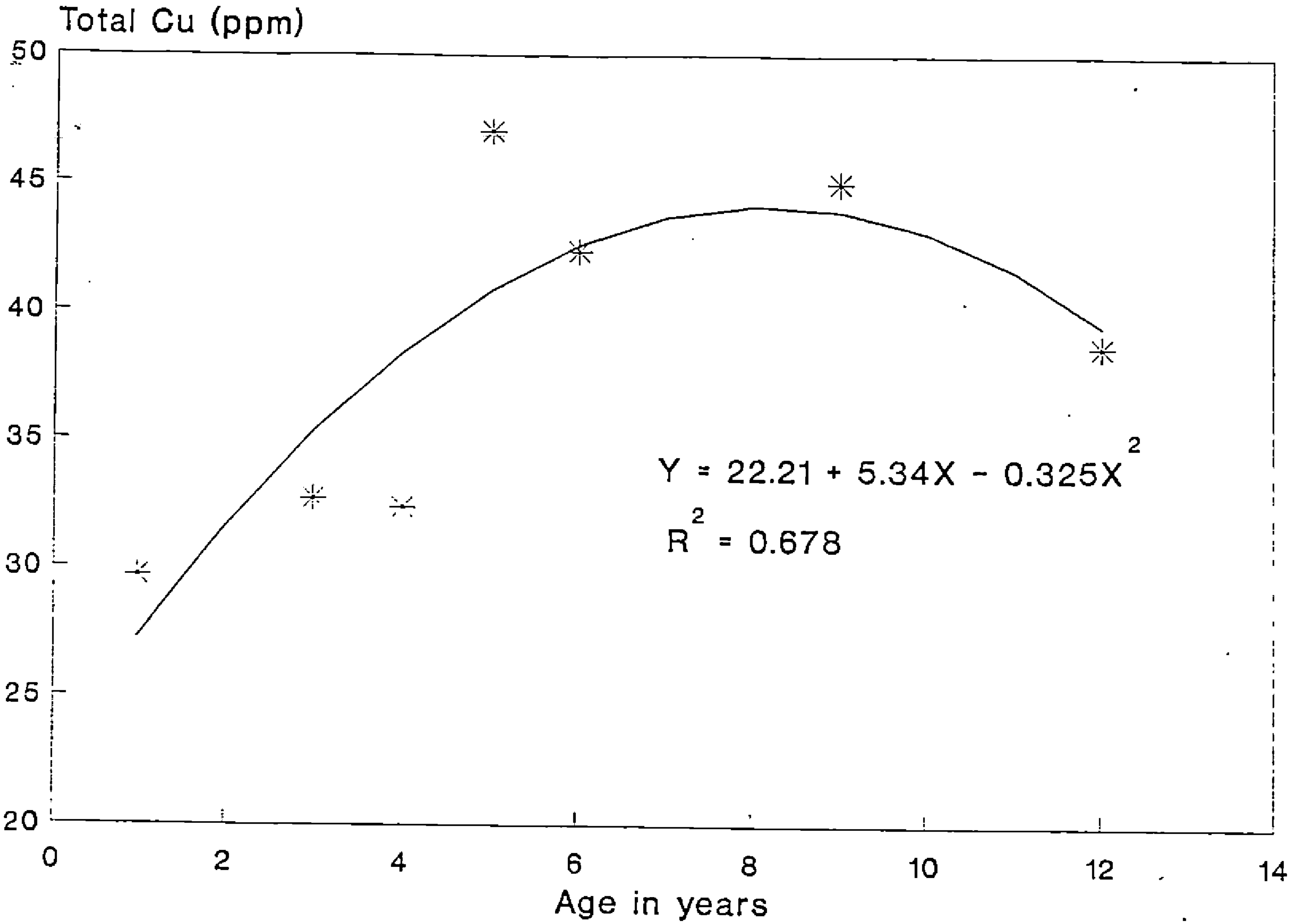

Fig.14. Changes in Cu reserves of cocoa rootzone in relation to age

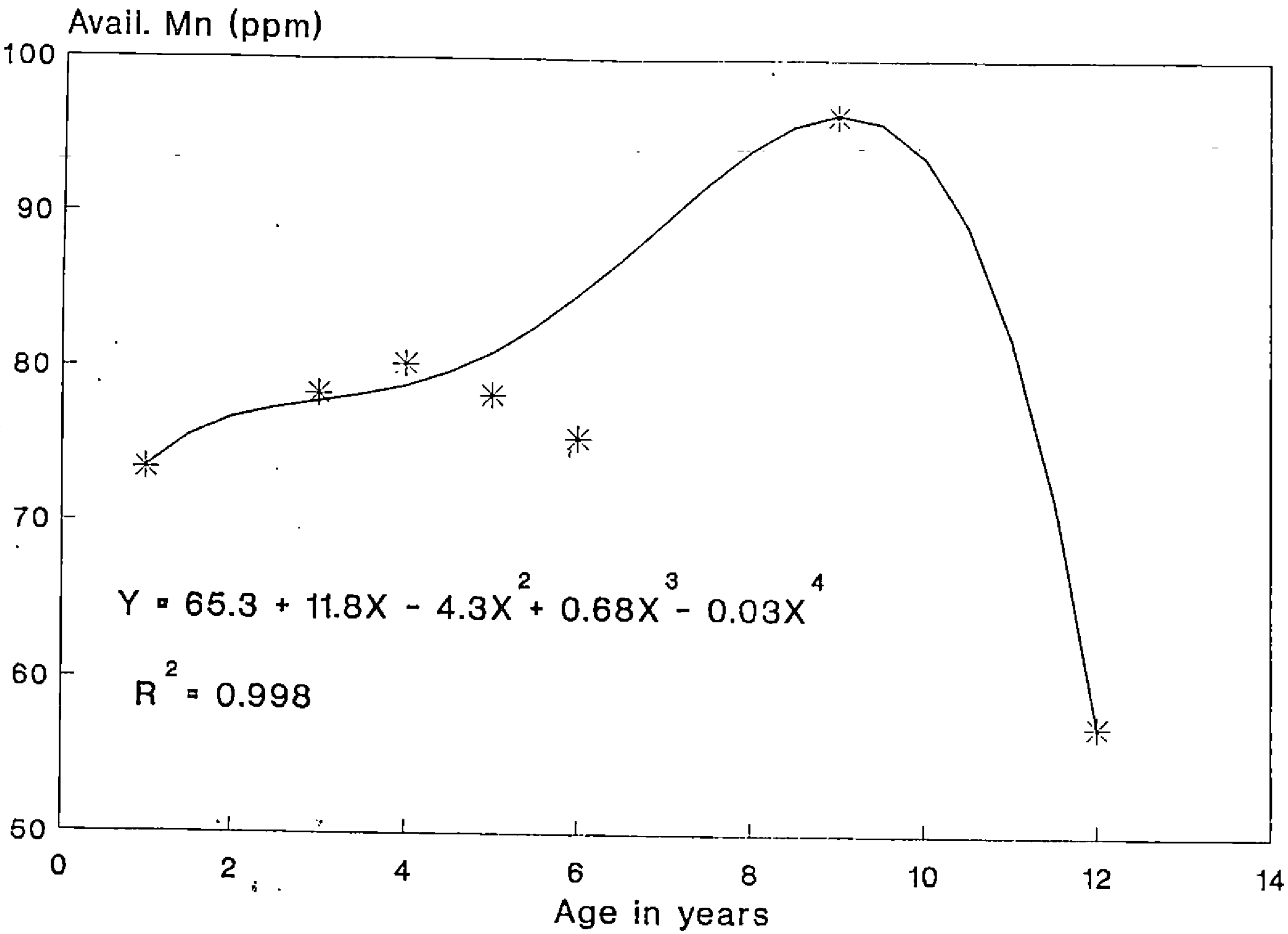

Fig.15. Dynamics of Mn availability in the rootzone of cocoa in relation to age

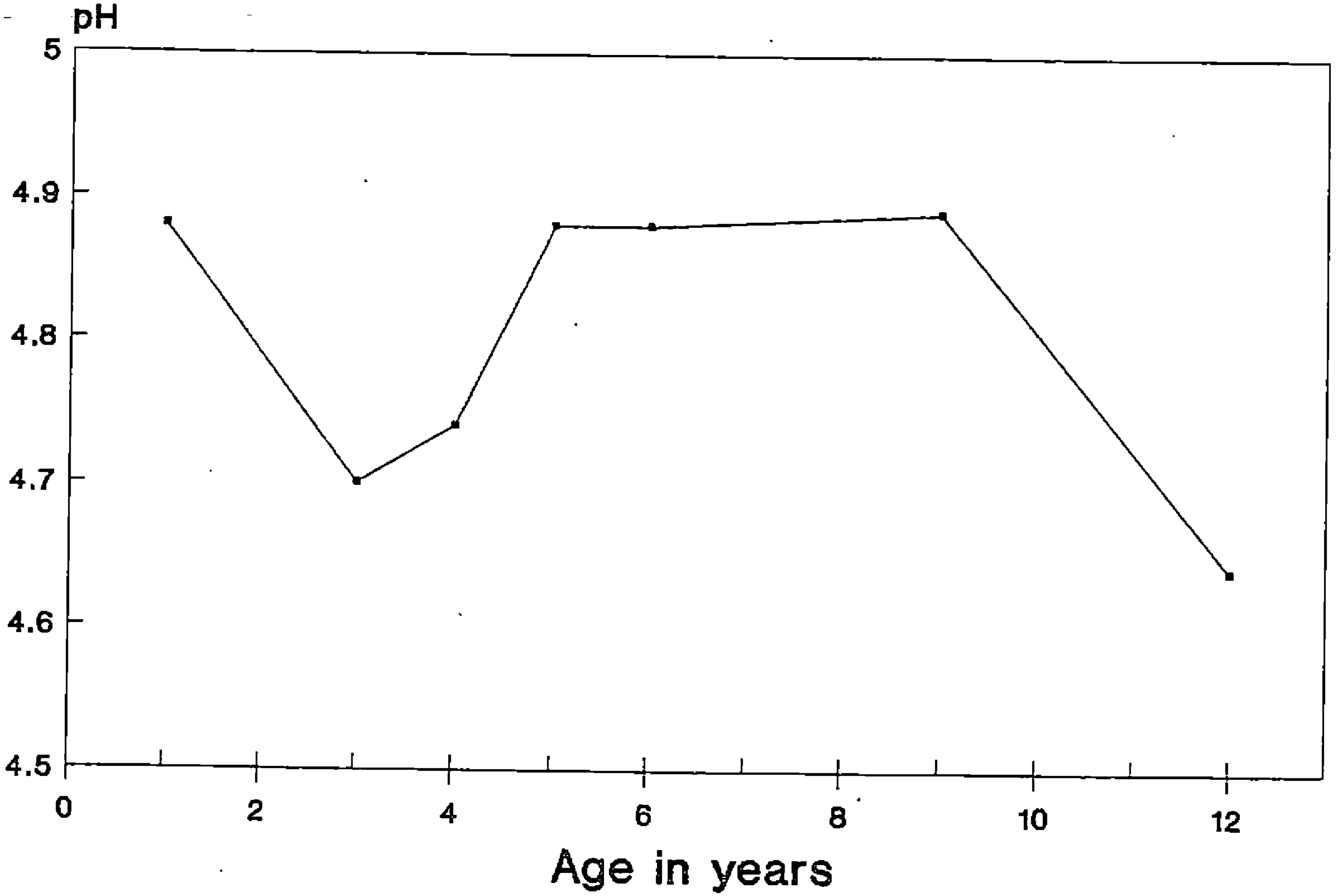

Fig.16. Changes in soil pH of cocoa rootzone in relation to age

5. DISCUSSION

The results generated from the studies on nutrient dynamics in cocoa rootzone following regular application of urea, superphosphate and muriate of potash over a period of nine years as well as those obtained from the studies on irrigation, shade and age are discussed here. In addition to the soil characteristics the impact of their influence on foliar nutrient levels is also assessed.

5.1 Effects of long-term fertilization on soil health

In the experiments reported here a depth of 0-75 cm was considered as the effective rootzone of cocoa. This was based on the results of the study conducted by Wahid *et al.* (1989) who found that root activity of cocoa decreased sharply beyond 60 cm. Nevertheless a depth of 75 cm was considered in this study to account for the variability and for better accomodation of most of the vertical roots.

The influence of urea, superphosphate and muriate of potash on soil nutrient reserves and nutrient availability was quantitatively and qualitatively different (Tables 3 and 14). An increase in proton activity and a decrease in soil organic matter, available K, Ca, Mg and Zn were very much evident in plots receiving urea (Table 3). A perusal of the data on nutrient reserves in the soil indicated depletion of Zn and Mn and build-up of P and Fe (Table 14). The decline in available K and Zn and bases like Ca and Mg may be attributed to the exchange reactions in the soil between their ions and H ions generated during nitrification of ammonium, product of urea hydrolysis. Depletion of available cations in soil due to long-term application of nitrogenous fertilizers has been reported by earlier workers (Negi *et al.*, 1981; Patra and Khora, 1983; Prasad *et al.*, 1983). It is however noteworthy that in the case of Zn there was a depletion in the soil reserve. In the other cases namely K, Ca and Mg only the exchangeable forms were affected. The results are indicative of the likelihood of depletion of soil reserves of K, Ca and Mg within a few more years of urea application.

Increased availability of Mn in an acidic soil due to regular application of ammoniacal fertilizer for five years was reported by Devi *et al.* (1975). In the present study nine years of regular application of urea resulted in significant improvement in the available Mn status of the soil. The improvement in available Mn status of the soil due to urea application could be partly due to the increase in soil acidity and consequent dissolution of tetravalent Mn (IV) forms.

Considerable build-up of available P (approximately 320%) as well as P reserves were observed following regular application of superphosphate. In addition, Ca and S fertility of the soil was also improved. These are, in fact, direct impact of superphosphate application, as the material supplied not only P but also Ca and S. Soil build-up of P following annual application of phosphatic fertilizers has been reported by several workers (Wahid *et al.*, 1977; Khan *et al.*, 1983; Anilkumar, 1987; De Datta *et al.*, 1988 and Muthuswamy *et al.*, 1990).

The decrease in H ion activity of the soil as well as the decrease in K in plots treated with superphosphate must be considered as indirect effects, through replacement of these ions by Ca present in the material. Thus the ill-effects of urea application, namely increasing soil acidity and the consequent enhancement of Mn, could be to some extent counteracted by the application of superphosphate, as revealed from the significant interactions between urea and superphosphate (Tables 4, 6 and 8).

A major consequence of muriate of potash application was the build-up of K in the soil to the extent of about 24 per cent in total K (Table 14) when muriate of potash was applied at the rate of 280 g K_2O tree^{-1} year^{-1} for a period of nine years. Over the same period, available K status of the soil increased by 122 per cent (Table 3). The improvement of P and K reserves in the soil following regular application of superphosphate and muriate of potash respectively is a strong indication of the possibility of either skipping these fertilizers for certain period or for reducing the frequency of application from annual to once in two years or once in three years, without affecting the nutrition and productivity of cocoa trees. There is much scope for conducting further studies in this line.

5.2 Fertilizer - depth interactions

The influence of NPK fertilizers was manifested throughout the root zone profile up to a depth of 75 cm, in most of the cases. Among these, increase in soil acidity due to urea application (Table 18); enrichment of S and Ca due to superphosphate application (Table 19) and decrease in available P and S due to muriate of potash application (Table 20) were the most perceptible. Nutrient enrichment of subsoil could only be due to the leaching of the nutrient during heavy rains. The average annual rainfall received at the experimental location is about 3000 mm. It is noteworthy that accumulation of P following the application of superphosphate did not occur in the lower soil layers. Obviously leaching of P during the period was insignificant. The downward movement of P is governed by the P fixing capacity of the soil (Schwab *et al.*, 1990). Laterite soils being rich in Fe and Al sesquioxides are known for their high P-fixing ability (Deb *et al.*, 1977). Perhaps a greater saturation of P in the surface layer than that attained during nine years at the rate of P application used in this study may be required to mobilise P to lower layers.

5.3 Effects of irrigation

Regular irrigation over a period of five years had differential impact on the availability and accumulation of nutrients in the rootzone of cocoa. The pattern of distribution of P, K and S in the rootzone profile is indicative of their leaching to lower layers (Table 23). In the irrigated plots, total and available P were significantly less in the surface layer compared to unirrigated plots (Tables 23 and 24). In the case of Ca and Mn, the data indicated virtual erosion of available fraction of these nutrients from the rootzone of irrigated cocoa.

Apart from leaching of nutrients, another cause of reduction of available nutrient concentrations including that of P in the irrigated soil may be the greater uptake of these elements by the tree. Irrigation was found to favour increased uptake of all the nutrients excepting Ca and Mg, as could be judged from their foliar nutrient levels (Table 31). The results thus indicated that irrigation had two-pronged effects, one enhancing the utilization of applied nutrients i.e. absorption and the other depleting the nutrients from the rootzone by way of leaching. In effect the impact of irrigation must be considered as the resultant of these two processes.

5.4 Effects of shade

Compared to the effects of irrigation, the effect of shade was more variable. The imposition of shade led to greater absorption of N, P, Fe and Mn as was evident from their foliar levels (Table 31). The soil data on the fertility status of these nutrients also corroborate this view. Soil organic carbon content recorded higher values under shaded conditions. On the other hand soil K concentrations (available and total) were higher under open conditions. Similar results were obtained by Leite (1985). The author attributed this effect to the higher quantity of K recycled in the cocoa ecosystem under open conditions, compared to shaded conditions. Absorption of K was depressed by shade and as a result, foliar K levels were much less in shaded condition compared to that under open. Gopinathan (1981) observed higher content of K in open-grown cocoa.

Foliar N content recorded higher values under shaded conditions. Similar results were obtained by many workers (Murray, 1965; Guers, 1971; Purseglove, 1969). Based on this observation Murray (1965) opined that N recommendation of cocoa tree should be done based on overhead shade and for trees grown under dense shade N recommendation should be reduced.

When the combined effect of irrigation and shade was considered, N absorption was found to be the most affected. Cocoa trees growing under irrigated and shaded conditions absorbed more N than those growing under rainfed and open conditions (Table 32).

5.5 Foliar nutrient concentrations

Although for evaluating the soil fertility status in relation to fertilizer doses only two levels of application were considered, for assessing the impact of fertilizer application on the inorganic nutrition of cocoa all the three levels of fertilizer application were considered.

Application of urea increased the foliar N level at N_1 level of application. But at still higher level urea decreased not only foliar N level but also its K content. Presumably decrease in foliar K content is a reflection of depletion of K level at higher rates of urea application. Owuor *et al.* (1987) obtained similar results in tea plants receiving higher levels of urea application.

Substantial decrease in foliar Zn content was observed at higher level of superphosphate application. This result is indicative of the P-Zn antagonism occurring in the plant during nutrient absorption. High accumulation of available P in the soil following regular application of superphosphate can also, therefore, lead to decline in the absorption of Zn by the tree. Pereira *et al.* (1988) observed decreased foliar Zn concentration in rubber trees receiving higher doses of P application.

The foliar Zn content in cocoa is also found to be generally high as revealed by the present study as well as earlier reports (Manikandan *et al.*, 1987). This would mean that P-Zn interactions leading to antagonism can assume importance in long-term fertilization. The decreased absorption of Zn with increase in levels of urea application could be perhaps due to the depletion of available Zn in these plots.

Another case of nutrient antagonism that could be identified from the results was K-Mg interaction. An increase in foliar K level due to muriate of potash application tended to depress Mg concentration in the foliage. The antagonism between mono - and divalent cations, especially between K and Mg is well documented in literature. Anilkumar (1987) and Jegannathan (1990) observed decreased foliar Mg concentration in coconut palms receiving higher doses of K. Turner and Barkus (1983) obtained similar results in banana.

5.6 Effects of age of the crop

The dynamics of soil fertility parameters in the rootzone of cocoa (0-75 cm depth) over a period of 12 years of inorganic fertilization showed two general trends namely, either conforming to a linear model or to a quadratic model. These models showed very good fit as evidenced from their very high coefficients of determination.

The changes in available and total K, available and total Mg, available Cu and total Zn increased with time and could be described by simple linear equations with high predictability (Figs. 1 to 6). The linear positive correspondence of these soil parameters is indicative of their accumulation in soil with time. The slopes observed for the linear plots of available K and total K suggest annual accumulations of 10.63 and 144.5 ppm respectively, within the rootzone of cocoa. Although the annual increment in total K is very high, the available K content extracted by N ammonium acetate reagent was very less. The large annual increment of K must be seen not only the result of annual K application but also of return of K to the soil through recycling processes, especially litter fall and through fall (Tukey, 1969; Leite and Valle, 1990).

Available and total Mg also showed linear increases with time. The slopes of the regression equations indicated annual increments of 15.21 and 42.99 ppm Mg for these two forms respectively. The other parameters which showed accumulation in soil were total Zn and available Cu. Whereas the magnitude of accumulation of available Cu is 0.23 ppm, it was 2.41 ppm for total Zn. The results thus indicate the probability for further enrichment of these nutrients in the rootzone of cocoa beyond 12 years.

In contrast to the above, the changes in organic carbon, available and total P, available and total Ca, available Zn, total S and total Cu could be better explained by quadratic models (Figs. 7 to 14). Barring available Zn all the parameters followed the quadratic model of the form,

$$y = a + b_1x - b_2x^2$$

where y is the soil parameter and x is the age of the tree in years. The model indicates that a plateau has already been attained for these parameters. In all these cases it took about nine years to reach the equilibrium. A comparison based on the nature of linear and quadratic models would reveal further the trends in nutrient dynamics of cocoa rootzone.

The linear increasing trends observed for K, Mg and Zn indicate that their annual influxes in the soil are much more than their outgo from the system. On an average urea contains 0.3 to 0.6 ppm Cu, 0.5 ppm Zn and 0.5 ppm Mn, ordinary superphosphate contains 0.3 per cent Mg, 12 per cent S, 19.5 per cent Ca, 20 ppm Cu, 50 ppm Zn and 65 ppm Mn and muriate of potash contains 3 ppm Cu, 3 ppm Zn and 8 ppm Mn (Kanwar, 1976). On this basis it may be calculated that application of 100 g N as urea, 40 g P_2O_5 as ordinary superphosphate and 140 g K_2O as muriate of potash, the recommended fertilizer dose tree^{-1} year^{-1} (KAU, 1993) add 0.7 g Mg, 26.6 g S, 43.3 g Ca, 6.6 mg Cu, 11.9 mg Zn and 16.4 mg Mn to the rootzone of cocoa annually. The inputs include not only the applied fertilizers but also leaf fall and through fall while the outgo from the system include the quantity of the nutrient removed through harvested produce and also leaching losses from 75 cm deep soil cylinder. The results suggested that the supply of K, Mg and Zn were in surplus quantities in the rootzone. On the other hand, goodness of fit of organic carbon, P, Ca, S and Cu, to quadratic model indicated that in the cocoa rootzone their fluxes were initially more but in about nine years, the system has more or less attained an equilibrium with regard to influx and outgo of these components.

Summary

SUMMARY

A study of the dynamics of soil nutrients in the rootzone of cocoa (*Theobroma cacao*) was conducted during 1993-94 at the College of Horticulture, Vellanikkara. The main objectives of the experiment were to evaluate the impact of regular annual application of NPK fertilizers, impact of irrigation and shade, and age of the crop on soil chemical characteristics, of cocoa rootzone. An attempt was also made to assess the nutrition of cocoa as influenced by continuous fertilization, irrigation and shade based on foliar analysis. Plants under on-going field trials were made use of for the present study. The soil at the experimental site was lateritic (Oxisol) and the cocoa variety used in field trials was Forastero. For the chemical analyses of soil and leaf samples, spectrophotometric, flame photometric and atomic absorption spectrophotometric methods were adopted. The salient findings from these studies are summarised below.

Continuous application of urea for a period of nine years decreased the soil pH from 5.16 to 4.67. Decreases in available K, Ca, Mg and Zn and soil Zn and Mn reserves were observed in plots receiving regular annual application of urea. However a reverse trend was observed in the case of available P, S, Fe, Mn and total P and Fe.

Long-term application of superphosphate improved the available P status of the soil from 9.58 to 40.64 ppm. Soil P reserves also improved considerably following long-term superphosphate application. Application of superphosphate

reduced the concentrations of available K, Mg, Zn and Cu and total K, Zn, Mn and Cu in the cocoa rootzone. Dynamics of soil pH, available P, Ca, S and Mn were also influenced by urea-superphosphate interaction in the soil.

Continuous application of muriate of potash increased available K as well as K reserves of the soil. But it significantly reduced the status of available P, Ca, S, Mn and Cu and soil Ca and Mg reserves. Urea x muriate of potash interaction significantly influenced available K, Ca and Mn contents of the soil.

Available K, S and total P, K and S contents were highly influenced by superphosphate x muriate of potash interaction.

The effect of urea on increasing acidity, available S, Fe, Mn and Cu and total S and Fe varied with depth.

Results of the present study indicated that accumulation of P as a result of regular application of superphosphate was more in the surface soil than in deeper layers. In addition, long-term superphosphate application resulted in build-up of available S and reserves of Ca and S with depth, but had an adverse effect on soil acidity, available, K, Cu and total Zn contents of the soil with depth.

Depth x muriate of potash interaction were also significant in the case of available P, S and Cu and total Ca contents of the soil. Long-term application of muriate of potash reduced available P, S and Cu and total Ca contents of the soil with depth.

Regular irrigation over a period of five years decreased available P, Ca, Mn, Cu and total P and Mn in soil. On the other hand available K, Zn and S and total S tended to increase with irrigation. In irrigated plots, total and available P concentrations were significantly lower in the surface soil than in unirrigated plots. In addition to soil P, irrigation x depth interaction showed to be significant in the case of available K, Ca, S, Mn and total S and Mn. In the case of available Ca, Mn and total P the effect was visible throughout the soil depths sampled. All the three parameters showed significant reduction under irrigation. The depletion in total Mn was pronounced in the lower soil layers (25-50 and 50-75 cm). On the other hand available K, S and total S contents of the soil increased with irrigation.

Soil organic carbon, available P, Fe and soil reserves of P, Ca, S, Fe, Zn and Mn were more in cocoa plots under shade for 13 years. On the other hand available K, S, Zn and total K and Mg were higher under open conditions.

Shade x depth interactions were significant in respect of available P, Fe, total P and total Fe. Available P content of the surface soil layer only was influenced by shade. But total P content of the 0-75 cm soil layer, was significantly influenced by shade. In all the three depths total P recorded higher values under shaded conditions. Available Fe and total Fe contents of the soil also showed significant interaction with depth.

Available P content of the soil was found to be significantly influenced by interaction between irrigation and shade with shaded but unirrigated plots recording higher concentrations of available P.

Application of urea increased the foliar concentrations of N, Fe, Mn and Cu. But at higher levels of urea application foliar K contents decreased significantly.

Long-term superphosphate application depressed foliar Zn content from 121.2 ppm to 98.6 ppm.

Application of muriate of potash increased foliar K content, the highest leaf K level was recorded by trees receiving 140 g K_2O tree^{-1} year^{-1}. Increasing K levels reduced foliar Mg content significantly.

Nitrogen and K contents of cocoa leaves were highly influenced by N x K interaction. Foliar Zn content was found to be influenced by N x P interaction. {Zero} level of application recorded highest foliar Zn content.

Leaf nutrient concentrations of N, P, K, S, Fe, Zn, Mn and Cu tended to increase with irrigation. On the contrary, foliar CA content was reduced by irrigation, while leaf Mg content remained unaffected.

Foliar concentrations of N, P, Mg, Fe and Mn and Cu were higher in plants grown under shade while leaf K concentration was more in open grown cocoa leaves.

Foliar N content was highly influenced by irrigation x shade interaction. Irrigated and shaded conditions resulted in highest leaf N content (2.29%).

Nutrient dynamics in the rootzone of cocoa over a period of 12 years of crop growth and fertilization showed mainly two diagnostic trends, namely, linear and quadratic.

The changes in available K, total K, available Mg, total Mg, available Cu and total Zn followed a linear regression model of the form $y = bx + c$ where y is the nutrient concentration and x is time.

The changes in organic matter, available P, total P, available Ca, total Ca, available Zn, total S and total Cu could be described by a quadratic model of the form $y = a_0 + b_1x + b_2x^2$.

Available Mn showed a steady increase with age of the tree until about nine years and then decreased sharply.

References

REFERENCES

Adams, M.A. and Attiwill, P.M. 1985. Nutrient cycling and nitrogen mineralization on the forests of South East Australia. *Pl. Soil.* 92:319-339

*Adams, S.N. and Mc Kelvie, A.D. 1955. Environmental requirements of cocoa in the Gold Coast. *Rep. Cocoa Conf.*, London, p.22-24

Ahenkorah, Y. and Akrofi, G.S. 1971. Recent results of fertilizer experiments on shaded cacao in Ghana. *Proc. 3rd Int. Cocoa Res. Conf.*, Accra, 1969, p.65-78

Ahenkorah, Y., Akrofi, G.S. and Adri, A.K. 1974. The end of the first cocoa shade and manurial experiment at the Cocoa Research Institute of Ghana. *J. Hort. Sci.* 49:43-51

Ahenkorah, Y., Halm, B.J., Appiah, M.R., Akrofi, G.S. and Yirenkyi, J.E.K. 1987. Twenty years' results from a shade and fertilizer trial on Amazoan Cocoa (*Theobroma cacao*) in Ghana. *Exp. Agric.* 23:31-39

Alvim, 1959. Water requirements of Cacao. *Proc. Ist FAO Technical Cacao Meeting*, Accra, Ghana, 1959, p.412-419

Anilkumar, K.S. 1987. Chemistry of coconut rhizosphere. M.Sc.(Ag.) thesis, Kerala Agricultural University, Trissur, Kerala.

Anilkumar, K.S. and Wahid, P.A. 1989. Impact of long-term inorganic fertilization on soil nutrient availability and nutrition of coconut palm. *Oleagineuxe*. 44:282-284

Aranguren, J., Escalente, G. and Herrera, R. 1982. Nitrogen cycle of tropical perennial crops under shade trees. II. Cacao. *Pl. Soil.* 67:259-269

Bakheistad, M. and Burhan, H.O. 1973. Long-term effects of N, P and K fertilizers on soil properties and nutrient composition of cotton leaves in the Sudan Gezira. *African Soils*. 18:174-185

Bandyopadhyay, B.K. and Goswamy, N.N. 1988. Dynamics of potassium in soil as influenced by levels of applied K, Ca and Mg. *J. Indian Soc. Soil Sci.* 36:471-475

Bates, J.A.R. and Baker, T.V.N. 1960. Studies on Nigerian forest soils. The distribution of P_2O_5 in the profile in various soil fractions. *J. Soil Sci.* 11:2572-263

Bergstrom, L. and Brink, N. 1986. Effects of differential applications of fertilizer nitrogen on leaching losses and distribution of inorganic nitrogen in the soil. *Pl. Soil.* 93:333-345

Bhat, K.S. and Bavappa, K.V.A. 1972. Cocoa under palms. *Cocoa and Coconuts in Malaysia* (ed.) Wastie, R.L. and Earp, D.A. The Incorporated Society of Planters, Kuala Lampur, Malaysia, p.116-121

Biswas, P.P., Joshi, O.P. and Rajpot, M.S. 1989. Q/I relationships of potassium in soil as influenced by long-term fertilization in mango orchard. *J. Indian Soc. Soil Sci.* 37:254-267

Cassman, K.G., Roberts, B.A., Korby, T.A., Bryant, D.C. and Hugashi, S.L. 1989. Soil potassium balance and cumulative cotton response to annual potassium additions on a vermiculite soil. *Soil Sci. Soc. Am. J.* 53:805-812

Coelho, B.B., Salcedo, I.H., Tiessen, H. and Stewart, J.W.B. 1993. Short and long-term phosphorus dynamics in a fertilized ultisol under sugarcane. *Soil Sci. Soc. Am. J.* 57:1027-1033

Dalal, R.C. and Mayer, R.J. 1986. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queenzland. *Aust. J. Soil Res.* 24:281-292

Darusman, P., Stone, L.R., Whitney, D.A., Jansen, K.A. and Long, J.H. 1991. Soil properties after twenty years of fertilization with different nitrogen sources. *Soil Sci. Soc. Am. J.* 55:1097-1100

Deb, D.L., Sachdev, M.S. and Wahid, P.A. 1977. Some aspects of soil fertility problems of major coconut growing acid soils of Kerala. *J. Indian Soc. Soil Sci.* 11:260-276

De Datta, S.K., Gomez, K.A. and Descalsota, J.P. 1988. Changes in yield response to major nutrients and in soil fertility under intensive rice cropping. *Soil Sci.* 146:356-358

Devi, C.B.K., Wahid, P.A., Pillai, N.G. and Sankaranarayanan, M.P. 1975. Effect of NPK fertilizer on the trace element nutrition of coconut. *J. Plant. Crops.* 3:11-13

Eaton, J.S., Likens, G.E. and Borgman, F.H. 1973. Through fall and stem flow chemistry in a northern landwood forest. *J. Ecol.* 61:495-508

FAO, 1988. *Sulphur News Letter No. 11.* Fertilizer and plant nutrition service, Land and water development division, FAO, Rome.

*Fassbender, H.W., Alpizar, L., Heuveldop, J. and Folster, E.H. 1985. Ciclos da materia Organica e dos nutrientes em agrossistemas Com Cacaueiros. *Reuniao Brasileira de Fertilidade de Solos.* Ilheus, Bahia, p.231-257

Fotyma, M., Czyba, R. and Gosek, S. 1993. Interaction of soil-K and fertilizer-K on crop yield in long-term field experiments in Poland. *Potash Rev.* Subject 4, 9th Suite, No.1. p.13-15

Franklin, W.T. and Reisenauer, H.M. 1960. Chemical characteristics of soils related to phosphorus fixation and availability. *Soil Sci.* 90:192-199

Ghanem, S.A. and Mikkelsen, D.S. 1988. Sorption of zinc on iron hydrous oxide. *Soil Sci.* 146:15-21

Gopinathan, R. 1981. Effect of shade and moisture regimes on the growth of cocoa (*Theobroma cacao* L.). M.Sc.(Ag.) thesis, Kerala Agricultural University, Trissur, Kerala.

Govindan, M. and Nair, R. V. 1984. Studies on the occurrence of nitrogen fixing bacteria *Azospirillum* in the root environment of cocoa. *Proc. PLACROSYM. VI* p. 255-260

Guers, J. 1971. Effect of light on the morphology and physiology of cocoa leaves. *Cafe Cacao.* 15:191-201

Hardy, F. 1958. Cacao soils. *Proc. Soil and Crop Sci. Soc.* Florida, 18. p.75-87

Hart, M.G.R. 1961. A turbidimetric method for determining elemental sulphur. *Analyst*. 86:472-475

Hartnez, H. 1992. The influence of long-term fertilizer rate on the phosphorus status of a sandy soil. *Vomwasser* 8:173-186

Herrera, R., Jordan, C.F., Longe, H. and Mediana, E. 1978. Amazoan ecosystems, their structure and functioning with particular emphasis on nutrients. *Interciencia* 3:223-236

Hesse, P.R. 1971. Sulphur. *A Text Book of Soil Chemical Analysis.* John Murray (Pub) Ltd., London, p.319-322

Hudcova, 1990. The influence of long-term fertilization on the factors of the soil potassium regime. *Rostlinna Vyroba*. 38:9-16.

Issaсс, K. 1992. The effect of potassium applied by drip irrigation on growth, fruit quality and storage of apples on a soil with marginal Mg content. *Potash Rev.* Subject 9, 5th Suite, No.1. p.1-7

Iyengar, S.S., Martens, D.C. and Miller, W.P. 1981. Distribution and availability of soil zinc fractions. *Soil Sci. Soc. Am. J.* 45:735-739

Jackson, M.L. 1958. *Soil Chemical Analysis*. Prentice Hall Inc. Engle Wood Clifts, N.J., U.S.A., reprint (1973) by Prentice Hall of India (Pvt.) Ltd., New Delhi.

Javed, Z. and Fischer, R.F. 1990. Fertilization influences nitrogen dynamics in soils under *Dalbergia sissoo*. *Pl. Soil.* 123:67-71

Jegannathan, M. 1990. Studies on potassium magnessium interaction in coconut (*Cocos nucifera*) *Cocos* 8:1-7

Jones, L.H.P., Cowling, D.W. and Lodeyer, D.W. 1972. Plant available and extractable sulfur in some soils of England and Wales. *Soil Sci.* 114:104-114

Joseph, J. 1993. Soil fertility of coconut rootzone as influenced by long-term inorganic fertilization. M.Sc.(Ag.) thesis, Kerala Agricultural University, Trissur, Kerala.

Kanwar, J.S. 1976. *Micronutrients in Soil Fertility - Theory and Practice*. ICAR, New Delhi, p. 229-300

KAU. 1993a. *Package af Practice Recommendations*. Kerala Agricultural University, Directorate of Extension, Mannuthy, Kerala.

KAU, 1993b. NPK fertilizer experiment on budded cocoa plants. *Research Report 1993-94*. Kerala Agricultural University, Trissur, Kerala. p.68

Khan, H.H., Sankaranarayanan, M.P. and Narayaran, K.B. 1978. Characteristics of coconut soils of India 1. Morphology, some physico-chemical characteristics and taxonomy. *Proc. PLACROSYM-1* p.54-67

Khan, H.H., Sankaranarayanan, M.P., George, M.V. and Narayanan, K.B. 1983. Effect of phosphorus skipping on the yield and nutrition of coconut palm. *J. Plant Crops*. 11:129-134

Khan, H.H., Sundaram, G.P., Joshi, O.P. and Nelliat, E.V. 1986. Effect of NPK fertilization on the mineral nutrition and yield of three coconut genotypes. *Fert. Res.* 10:185-190

Khrustova, T.N. and Chernaya, Z.A. 1988. Alteration in the chemical properties of southern chernozem under irrigation with mineral waters. *Agrokhimiya*. 3:47-52

Krishnakumari, M. and Khora, M.S. 1983. Effect of long-term N and P fertilizer application in an intensive cropping system on K fixing characteristics of an inceptisol. *Fert. News*. 28:27-30

Kudeyarova, A. and Kvaratskheliya, M.Z. 1989. Effect of fertilizer phosphates on soluability of Ca, Mg, Mn, Zn, Al and Fe compounds in gray forest soil. *Pochvovedeniye*. 8:26-34

Leite, O.J. 1985. Relacao entre O fosforo, O potassio e o calcio contidos em quatro componentes de ecossistema cacau na Bahia. *Rev. Bras. Ci. do Solo,* 9:95-101

Leite, O.J. 1987. Characteristicas do manto detritico e sua relacao com a fertilidade da camada superficial do solo em plantacoes de cacau. *Rev. Bras. Ci. do-solo* 11:108-112

Leite, O.J. and Valle, R.R. 1990. Nutrient cycling in the cocoa ecosystem : Rain and through fall as nutrient sources for the soil and the cocoa tree. *Agriculture, Ecosystems and Environment.* 32:143-154

Lemee, G. 1955. Influence de l'alimentation en eau et de l'ombrage due l'economic hydrique et la photosynthese du cacaoyer' *L'Agronomic Tropicale* 10:592-603

Malenga, N.E.A. and Grice, W.J. 1991. Correction of potassium deficiency in replanted tea in Malawi by remedial application of P and K fertilizers. *Potash Rev.* Subject 9, 4th Suite, No. 6. p.1-3

Malhi, S.S., Haraipak, J.I., Nybrog, M. and Flore, N.A. 1991. Soil chemical properties after long-term nitrogen fertilization of bromegrass. *Commun. Soil Sci. Pl. Anal.* 22:1447-1458

Mandal, B. and Mandal, L.N. 1990. Effect of phosphorus application on transformation of zinc fraction in soil and on the zinc nutrition of lowland rice. *Pl. Soil.* 121:115-123

Manikandan, P., Joshi, O.P., Khan, H.M., Mohapatra, A.R. and Biddappa, C.C. 1987. Nutrient profile in an arecanut-cacao system on a laterite soil. *Trop. Agric.* 64:13-16

Mathew, P.K. 1977. Better coffee through balanced fertilizers. *Indian potash J.* 2:17-19 and 28

Mekenzie, R.S., Steward, J.W.B., Dormaar, F.F. and Schalje, G.B. 1992. Long-term crop rotation and fertilizer effects on P transformations in a chernozemic soil. *Can. J. Soil Sci.* 4:569-572

* Messiek, D.L. 1982. The movement of calcium and magnesium in selected Virginia soils from surface applied dolomitic limestone. M.S. thesis, Virginia Polytechnic Inst. and State Univ., Blacksburg.

Mohapatra, A.R. 1991. Fe, Mn and Al contents of soil and leaf in arecanut palm as affected by fertilization. *J. Indian Soc. Soil Sci.* **39**:805-807

Mohapatra, A.R. and Bhat, N.T. 1983. Availability of phosphorus from different P sources in the lateritic soils of arecanut garden. *Indian Cocoa Arecanut and Spices J.* **3**:33-34

Morais, F.I. 1988. Effect of fertilizers and ammendments on cocoa growth and production in the soils of Amazonia, Brazil. *Proceedings of the 10th International Cocoa Research Conference*. Santo Domingo, Dominican Rep., p.17-23

Murray, D.B. 1965. A shade and fertilizer experiment with cocoa. *3rd Report on Cocoa Res.* 1953. Trinidad, p.32-36

Murray, D.B. 1967. Leaf analysis applied to cocoa. *Cocoa Growers Bull.* 9:25-31

Murray, D.B. 1975. Shade and nutrition. *Cocoa* (ed.) Wood, G.A.R., Longman, London and Newyork, p.105-123

Muthuswamy, P., Shanthy, P. and Ramanathan, G. 1990. Long term use of fertilizer on soil fertility and yield of crops in irrigated inceptisol. *J. Indian Soc. Soil Sci.* **38**:541-542

Nakayama, L.H., Santana, C.J.L. and Pinto, L.R.M. 1988. Response of young cocoa to liming. *Revista Theobroma*. 18:229-240

Negi, A.S., Sharma, K.C., Sud, K.C. and Bist, B.S. 1981. Effect of long term manurial application on soil potassium and sustainability of different chemical methods for determining available K. *J. Indian Soc. Soil Sci.* 29:86-91

Nelliat, E.V. 1978. K nutrition of plantation crops. A review of work done in India. *Potassium in Soils and Crops*. Potash Research Institute of India. New Delhi, p.367-378

Nemath, T., Kovars, G. and Kadar, I. 1987. Accumulation of NO_3^-, SO_4^{2-} and water soluble salts in the profile of a long term fertilizer experiment. *Agrokhimiya es Talajtan Res. Inst.* and *Agric. Phem. Acad. Sci.* Budapest, Hungary, p.171-176

Nguyen, M.L. and Goh, K.M. 1992. Sulphur mineralisation and release of soluble organic sulphur from camp and non-camp soils of Grazed pastures receiving long-term superphosphate applications. *Biol. Fertil. Soils.* 14:272-279

Ohno, T. and Grunes, O.L. 1985. Potassium-Magnesium interactions affecting nutrient uptake of wheat forage. *Soil Sci. Soc. Am. J.* **45**:685-690

Olsen, S.R., Watanabe, F.S. and Bowman, R.A. 1983. Evaluation of fertilizer phosphate residues by plant uptake and extractable phosphorus. *Soil Sci. Soc. Am. J.* **47**:952-958

Ollagnier, M., Daniel, C., Fallavier, P. and Ochs, R. 1987. The influence of climate and soil on potassium critical level in oil palm leaf analysis. *Oleagineuxe.* **42**:446-449

Oluobi, A. 1989. Long-term effects of the continuous cultivation of a tropical ultisol in south western Nigeria. *Exp. Agric.* **25**:207-215

Opeke, L.K. 1982. *Tropical Tree Crops.* John Wiley and Sons. New York, p. 133

Owuor, P.O., Wanyoko, J.K. and Otheno, C.O. 1986. Effect of urea and ammonium sulphate on sulphur nutrition of tea. *Sri Lankan J. Tea Sci.* **55**:77-83

Owuor, P.O., Wanyoko, J.K. and Otheno, C.O. 1987. Effect of nitrogenous fertilizers on leaf K contents of tea (*Camellia sinensis* (L.)) *Tea.* **8**:4-13

Page, A.L. 1982. *Methods of Soil Analysis.* Part 2. 2nd ed. Am. Soc. Agron. Inc., Madison, Wisconsin, USA. p.301-334

Panse, V.G. and Sukhatme, P.V. 1985. *Statistical Methods for Agricultural Workers.* 4th ed., ICAR, New Delhi, p. 348

Patiram, S. and Prasad, R.N. 1983. Yield response to fertilizer potassium and balance sheet of potassium in potato-rice crop sequence. *J. Indian Soc. Soil Sci.* 31:502-505

Patiram, S. and Singh, K.A. 1993. Effect of continuous application of manure and nitrogenous fertilizer on some soil properties of acid inceptisol. *J. Indian Soc. Soil Sci.* 41:430-433

Patra, D.P. and Khora, M.S. 1983. Effect of long-term fertilization with nitrogen and phosphorus on Q/I parameters of potassium on an inceptisol under an intensive cropping system. *J. Indian Soc. Soil Sci.* 37:495-501

Pereira, E.B.C., Pereira, A.V. and Silva, S.E.L. 1988. Study of N, P, K and Mg levels for a rubber rootstock nursery in a very clayey yellow latosol. *Revista Brasileira de ciencia do solo.* 12:143-146

Perkins, A.F. 1970. *Analytical Methods for Atomic Absorption Spectrophotometry.* Perkin Elmer Corporation, U.S.A.

Perrott, K.W. and Munsell, G.P. 1989. Effect of fertilizer phosphorus and liming on inorganic and organic soil phosphorus fractions. *N. Z. J. agric. Res.* 32:63-70

Peterson, L.A. and Krueger, A.R. 1980. Variation in content of available P and K (Bray-I) in soil samples from a cropped N, P and K fertility experiment over 8 years. *Commun. Soil Sci. Pl. Anal.* 11:993-1004

Petric, S.E. and Jackson, T.L. 1984. Effects of nitrogen fertilization on manganese concentration and yield of barley and oats. *Soil Sci. Soc. Am. J.* 48:319-322

Potti, S.N., Mathew, M., Punnoose, K.I. and Palaniswamy, R. 1978. Results on fertilizer experiments on young rubber trees grown with legume and natural ground cover. *Proc. PLACROSYM I.* p. 141-147

Prasad, B., Singh, R.P., Roy, H.K. and Sinha, H. 1983. Effect of fertilizers, lime and manure on some physical and chemical properties of a red loam soil under multiple cropping. *J. Indian Soc. Soil Sci.* 31:601-603

Purseglove, J.W. 1969. *Tropical Crops. Dicotyledons* 2., 2nd ed., Longmans, Green and Co. Ltd., London, p.589-590

Rao, A., Babrekar, P.G. and Ghosh, A.B. 1982. Total nitrogen and phosphorus balance-sheet in a typic ustochrept soil under intensive cropping and fertilizer use. *Pl. Soil.* **68**:125-129

Rao, A. and Ghosh, A.B. 1983. Result of intensive cropping and fertilizer use for seven years on fraction of soil zinc in a typic ustochrept. *J. Soil Sci.* **31**:619-621

Raju, T. 1978. Influence of continuous use of inorganic fertilizers on the nutrient status of oxisol cropped to coffee. *Proc. PLACROSYM I.* p.29-38

Rasmussen, P.E. and Rhode, C.R. 1988. Long term tillage and nitrogen fertilization effects on organic nitrogen and carbon content. *Soil Sci. Soc. Am. J.* 52:114-117

Rasmussen, P.E. and Rhode, C.R. 1989. Soil acidification from ammonium-nitrogen fertilization in mould board plow and stubble - mulch wheat - fallow tillage. *Soil Sci. Soc. Am. J.* **53**:119-122

Rechaigel, J.F., Reneau, R.B. and Starner, A.E. 1985. Movement of subsurface fertilizer and limestone under irrigated and non irrigated conditions. *Soil Sci.* **140**:442-448

Reddy, S.M. and Shastry, V.V.K. 1983. Effect of irrigation levels on phosphorus and potassium movement in a red sandy loam soil of Andra Pradesh. *J. Indian Soc. Soil Sci.* 31:81-82

Salam, A. and Sahu, D. 1990. Influence of successive cropping and nitrogen fertilization on changes in inorganic and organic forms of -N- in soils. *Annls agric. Res.* 11:39-46

Santana, M.B.M., Rosand, P. and Serodio, M.H. 1990. Recycling of nutrients in cocoa agro ecosystem. *Agrotropica* 2:68-74

Schwab, A.P., Ransom, M.D. and Owensby, C.E. 1989. Exchange properties of an argiustoll : Effect of long term ammonium nitrate fertilization. *Soil Sci. Soc. Am. J.* 53:1412-1417

Schwab, A.P., Owensby, C.E. and Kulyngyong, S. 1990. Changes in soil chemical properties due to forty years of fertilization. *Soil Sci.* 149:35-45

Sharma, S. and Tripati, B.R. 1983. Effect of long-term application of fertilizers on transformation of P and K in alfisols. *Indian J. agric. Sci.* 53:149-151

Sharply, A. 1990. Reaction of fertilizer potassium in soils of differing mineralogy. *Soil Sci.* 149:44-51

*Sherbakov, A.P., Stalin, A.F., Kosolapova, A.V. and Raikhinshtein, M.V. 1989. Changes of chernozem properties under systematic application of mineral fertilizers. *Nauchneje Doklady Vyssheishokly, Biology Cheskie Vanki.* Moscow, 4:101-108

Shinde, D.A. and Ghosh, A.B. 1964. Effect of continuous manuring and cropping on the crop yields and characteristics of medium black soil. Proceedings of International Symposium on soil fertility Evaluation I. 6-8 March, 1964, Madras.

Shuman, L.M. 1988. Effect of phosphorus levels on extractable micronutrients and their distribution among soil fractions. *Soil Sci. Soc. Am. J.* 52:136-147

Singh, L., Verma, R.N.S. and Lohia, S.S. 1980. Effect of continuous application of farmyard manure and chemical fertilizers on some soil properties. *J. Indian Soc. Soil Sci.* 28:170-172

Smyth, A.J. and Montogomery, R.F. 1962. *The Soils and Land Use of Central Western Nigeria.* The Government Printer, Ibadan, Western Nigeria.

Srilatha, A.K. and Saifuddin, N. 1994. Effect of long-term fertilizer application on soil chemical environment of coconut plantation with special reference to potassium fractions. Proceedings 6th Kerala Science Congress, 27-29 January, 1994. Thiruvananthapuram.

Sureshlal,S.and Mathur, B.S. 1989. Effect of long term application of manures and fertilizers on the DTPA extractable micronutrients. *J. Indian Soc. Soil Sci.* 37:588-590

Sureshlal, S. and Mathur, B.S. 1992. Effect of long term application of fertilizers, manure and lime on cationic and anionic status of red loam soils of Ranchi. National Seminar on Development in Soil Science (ed.) Narayanaswamy, O. and Biswas, T.D. 57th convention of *Indian Soc. Soil Sci.* 26-29, November, New Delhi, p.166

Swarup, A., Beese, F. and Ulrich, B. 1994. Movement of Zn, Pb and Cd through an undisturbed column of a soil under forest. *J. Indian Soc. Soil Sci.* 42:182-184

Thakur, R.S., Chadha, K.L., Sharma, J.S. and Rajput, M.S. 1983. Yield and leaf potassium status as influenced by potassium application in Mango (*Mangifera indica* L.). *Potash Rev.* Subject 27, 108 th suite, No. 10. p.1-5

Tripati, D., Singh, K. and Upadhyay, G.P. 1994. Distribution of micronutrients in some representative soil profiles of Himachal Pradesh. *J. Indian Soc. Soil Sci.* 42:143-145

Tukey, H.B. 1969. Leaching of substances from plants. *Ann. Rev. Pl. Physiol.* 21:305-324

Turner, D.W. and Barkus, B. 1983. The uptake and distribution of mineral nutrients in banana in response to supply of K, Mg and Mn. *Fert. Res.* 4:89-99

Uexkull, V.H.R. 1978. Potassium requirements of some tropical tree crops (Oil palm, coconut palm, rubber, coffee, cocoa). *Potassium Research - Reveiw and Trends. Proc. 11th Congr.*, Int. Potash Inst., Bern, p.291-324

*Usherwood, N.R. 1982. Interacao do potassio com outros ions. *Piracicaba* : 240-247

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

Wahid, P.A., Devi, C.B.K. and Haridasan, M. 1977. A critical review of phosphate fertilization of coconut. *Philipp. J. Cocon. Stud.* 2:1-8

Wahid, P.A., Kamalam, N.V., Ashokan, P.K. and Nair, R.V. 1989. Root activity pattern of cocoa. *J. Nucl. Agric. Biol.* **18**:153-156

Watanabe, F.S. and Oleson, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCo_3$ extracts from soil. *Proc. Soil Sci. Soc. Am.* 29:677-678

Webb, M.J. and Loneragan, J.F. 1988. Effect of zinc deficiency on growth, phosphorus concentration and phosphorus toxicity of wheat plants. *Soil Sci. Soc. Am. J.* **52**:1676-1680

Wessel, M. 1966. Review of the use of fertilizers on cacao in Western Nigeria. CRIN Annual Report. 1965. p.173

Wessel, M. 1970. Fertilizer experiments on farmers cocoa in South Wester Nigeria. *Cocoa Growers' Bull.* 15:22-27

Yoo, S.H. and Jung, Y.S. 1991. Cycling of micronutrients in a cacao agroecosystem. *Trop. ecol.* **32**:223-230

Zasoski, R.J., Meyer, R.D., Schulbach, H. and Edstrom, J.P. 1992. Effects of urea applications on bulk and rhizosphere soil properties in drip irrigated almonds. *J. Pl. Nutr.* **15**:977-989

* Zevallos, A.C. 1970. Estudo do sistema radicular do cacaueiro em alguns tipos de solo da regiao Cacaueira do sul da Bahia. *Boletim Tecnico no.5. Centro de Pesquisas do Cacau.* Bahia, p. 31

* Originals not seen

Appendices

APPENDIX-1
Analysis of variance table for the chemical characteristics (Available nutrients)

Source	Degrees of freedom	pH	Org.C	Avail. P	Avail. K	Avail. Ca	Avail. Mg	Avail. S	Avail. Fe	Avail. Zn	Avail. Mn	Avail. Cu
Replication	2	0.068**	0.000	8.102	454.87	1505.91	1114.84	15.93	1.123	96.37	73.27	0.009
Urea (UR)	1	4.401**	0.092**	818.123**	26350.43**	753971.54**	37583.68**	460.05**	32.43**	9612.37**	3154.83**	0.681
Superphosphate (SP)	1	0.269**	0.05**	17365.74**	2318.81**	439937.63**	12933.68**	174837.56**	0.46	16753.04**	25.92	37.27**
UR x SP	1	0.534**	0.154**	727.99**	63213.83	75887.59**	88.89	1624.50**	36.98**	1743.25**	6708.68**	19.42**
Muriate of potash (MOP)	1	0.257**	0.029*	474.61**	626453.55**	59806.11**	168.06	16744.5**	0.002	63.99	1424.00**	16.05**
UR x MOP	1	0.031	0.004	474.61**	18050.00**	15856.84**	17518.68**	5904.22**	5.83*	3404.23**	74.42**	0.320
SP x MOP	1	0.003	0.275**	1898.27**	24938.88**	5092.09	1485.12	14168.06**	28.78**	688.95**	78.13**	4.302**
UR x SP x MOP	1	0.073*	0.021	1669.40**	4867.56**	43951.19**	1800.00	1352.00**	1.24	4175.76**	3.74	18.402**
Error (a)	14	0.022	0.008	11.58	773.81	1173.58	1170.41	82.41	2.61	20.95	8.90	0.419
Depth (D)	2	0.675	0.928**	7222.59**	52296.41**	22374.18**	11574.04**	9534.05**	403.15**	359.09**	9632.09**	69.14**
UR x D	2	0.078**	0.009	421.28**	312.46	3738.50**	15128.21**	425.39**	12.37**	264.77**	1435.39**	3.088**
SP x D	2	0.046*	0.005	8880.67**	4912.35**	34573.57**	215.19	2737.39**	9.10**	55.01*	60.57**	1.50**
MOP x D	2	0.001	0.001	161.57**	231.001*	34828.61**	456.89	708.67**	5.08**	77.03*	1934.95**	1.536**
Higher order interactions	8	0.062	0.019	1982.76	9392.44	112032.29	53762.14	2377.62	24.53*	145.65	1205.67	10.376
Error (b)	32	0.007	0.007**	8.76	236.81	1467.21	580.35	43.14	0.92	14.37	6.84	0.234
Total	71											

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

APPENDIX-II

Analysis of variance table for the chemical characteristics (nutrient reserves)

Source	Degree of freedom	Mean sum of squares								
		Total P	Total K	Total Ca	Total Mg	Total S	Total Fe	Total Zn	Total Mn	Total cu
Replication	2	1151.441	3952.431	858.287	2732.651	109.895	0.012	224.764	31.764	121.931**
Urea (UR)	1	98961.820**	34892.014	18521.710	7902.340	154.587	0.916**	32597.556**	11806.722**	60.500
Superphosphate (SP)	1	57601.276**	711028.125**	3665368.354**	2880920.069**	319879.988**	2.457**	24790.222**	16683.566**	410.889**
UR x SP	1	211240.231**	6708.681	442771.860**	27506.851**	11963.469**	0.889**	533.556	8.000	968.000**
Muriate of potash (MOP)	1	19349.052*	3638253.125**	300674.282**	53535.373**	867.361**	4.361**	180.500	15022.222**	144.500*
UR x MOP	1	38553.548**	1579753.125**	289788.851**	426934.199**	8635.169**	0.307**	7896.056	36630.222**	501.389**
SP x MOP	1	39654.445**	1196833.681**	5692.444	156772.002**	3676.531**	0.836**	98.389**	2964.500**	64.222
UR x SP x MOP	1	25428.507**	876708.681**	366539.213**	559452.792**	3888.151**	0.339*	16.056	1073.389**	320.889**
Error (a)	14	7039.372	32801.240	10622.790	587574.804	49866.465**	1.444**	530.494	224.177	51.026
Depth (D)	2	65203.342**	2677027.431**	1679373.427**	99699.694**	147802.533	8.564**	11050.514	36232.597**	18.722*
UR x D	2	39999.548**	17517.014	57887.755**	930.636	6183.331**	0.103**	210.014**	1275.097**	98.000
SP x D	2	255228.596**	5819.792	173101.439**	53308.866**	4227.080	0.367**	1548.764	501.514*	65.722*
MOP x D	2	7011.751	64471.875	73688.282**	40160.599**	129.226	0.069*	222.792**	201.931	107.167
Higher order interactions	8	58200.084	370108.334	45102.288	130648.641	5101.75	0.948	5093.139	8480.528	2685.000
Error (b)	32	1241.247	26676.910	4351.179	1943.962	31.845	0.015	173.132	100.000	8.326
Total	71									

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

SOIL NUTRIENT DYNAMICS IN COCOA
(*Theobroma cacao*)

By

SMITHA, B.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara, Thrissur

1995

ABSTRACT

An investigation on the dynamics of soil nutrients in the rootzone of cocoa (*Theobroma cacao*) was conducted during 1993-94 at the College of Horticulture, Vellanikkara. Soil and leaf samples were taken from cocoa trees under the Cadbury-KAU Co-operative Cocoa Research Project, Vellanikkara. Cocoa variety used for the study was Forastero. The soil of the site was laterite (Oxisol). The treatments consisted of factorial combinations of N, P and K fertilizers each at two levels (with and without), two levels (with and without) of irrigation and shade and seven age groups namely 1, 3, 4, 5, 6, 9 and 12 years. Soil samples were also collected from an uncropped and unfertilized area nearby. The impact of long-term inorganic fertilization, irrigation and shade and age of the tree on soil chemical characteristics as well as foliar nutrition of cocoa influenced by long-term inorganic fertilization, irrigation and shade were assessed.

Continuous application of urea for a period of nine years increased soil acidity and availability of P, S, Fe and Mn. It also increased total soil P and Fe. But it resulted in depletion of available K, Ca, Mg, Zn and Zn and Mn reserves of the soil. Long-term application of superphosphate resulted in the build-up of available and total P in soil. It also improved the status of soil available Ca, S and soil reserves of Ca and S. But it depleted soil available and total K, available and total Zn, available Mg and Cu and total Mn.

Muriate of potash application increased the available and total K content of the soil. On the other hand it caused depletion of available P, Ca, S, Mn, Cu and

soil Ca and Mg reserves. Interactions among urea, superphosphate and muriate of potash were also significant with regard to the fertility of the cocoa rootzone is concerned. Increasing soil acidity due to urea application, enrichment of S and Ca due to superphosphate application, and decrease in available P and S due to muriate of potash application were highly influenced by depth.

Regular irrigation over a period of five years resulted in reducing the availability of P, Ca, Mn and Cu. It also reduced the total P and Mn in soil. But available K, Zn, S and total S tended to increase with irrigation. In the irrigated plots, total and available P were significantly lower in the surface layers compared to that in unirrigated plots.

Provision of shade for a period of 13 years resulted in the build-up of soil organic carbon, available P, Fe and soil reserves of P, Ca, S, Fe, Zn and Mn. On the other hand it decreased the concentrations of available and total K, available S, and Zn and total Mg. Irrigation x shade interaction significantly influenced the available P content of soil.

Urea application increased the foliar concentrations of N, Fe, Mn and Cu, but it decreased the leaf K content significantly. Long-term superphosphate application reduced Zn content of cocoa leaf. Application of muriate of potash increased leaf K content, but depressed foliar Mg content significantly. Leaf N and K contents of cocoa were highly influenced by N x K interactions. N x P interaction significantly affected foliar Zn concentration of cocoa. Foliar Zn recorded higher values in plants receiving no nitrogen and phosphorus. Irrigation resulted in increased foliar concentrations of almost all nutrients except that of Ca and Mg. Foliar Ca content was higher in unirrigated plants. Effects of irrigation on leaf Mg was not significant. Cocoa trees under shade recorded higher concentrations of N, P, Mg, Fe and Mn and Cu in their foliage while K content was higher in open grown plants. Irrigation x shade interaction significantly influenced foliar N content. Shaded and irrigated conditions resulted in highest foliar N content.

Nutrient dynamics in rootzone of cocoa over a period of 12 years of crop growth and fertilization could be described by linear or quadratic model. The linear model was found to be a better fit for available and total K, available and total Mg, available Cu and total Zn. In the case of available and total P, available and total Ca, available Zn, total S and total Cu the changes in concentrations with time could be described by a quadratic model. Available Mn content of the soil showed steady increase with age up to nine years followed by a sharp decrease.