NUTRIENT MANAGEMENT MODEL FOR COMPENSATING SPATIAL SOIL VARIABILITY IN RUBBER PLANTATIONS IN AMBOORI AREA

BY

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THESIS

submitted in partial fulfilment of the

requirement for the degree

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DECLARATION

I hereby declare that this thesis entitled "Nutrient management model for compensating spatial soil variability in rubber plantations in Amboori area" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Vellayani,
26-7-1989

CERTIFICATE

Certified that this thesis entitled 'Nutrient management model for compensating spatial soil variability in rubber plantations in Amboori area' is a record of research work done independantly by Sri. Anil Kumar J.R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CONTENTS

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INTRODUCTION

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The spatial variability of soils is an important feature in the identification of soil properties relative to various aspects of crop production including fertility management of soil.

Soils are known to have both lateral and vertical variability which can be expressed in terms of spatial difference in particular attributes or properties of soil (Beckett and Webster, 1971; Warrick and Nielsen, 1980) or in terms of response of plants growing on the soil (Bresler et al 1981; Wallace et al 1982a & 1982b). Spatial variability, thus assumes the role of an important property to be accounted in the management and utility of soils for various agricultural and non-agricultural purposes. Eventhen, it is not fully appreciated or understood by the majority of persons who use the soil data for various purposes.

This aspect of study of soil has been the concern and interest primarily of those responsible for describing, classifying and mapping soils. Recently attempts have been made to use the concept of soil variability in other areas of soil research also. Beckett and

Webster (1971), Burgess and Webster (1980), Malik et al (1983), Raman et al (1983) and Dahiya et al (1984) have been largely responsible for advanced studies in this direction.

Variation in soil properties from point to point in the landscape derives from many causes. Some of these (such as burrowing worms, individual trees) affect small volume of soil and introduce differences over short distances while other such as regional gradients in climate introduce long range soil gradients (Burrough, 1983; Pomeroy, 1983). The nature of variation will be further complicated if it is associated with the loss, retention or burial of land surface of varying degrees of development due to soil erosion on slopes.

The physical and chemical processes of soil tend to increase lateral variability of properties even within the soil. This ultimately results in the variation of plant nutrients present in soil in their degrees of persistence, mobility and residence time irrespective of their forms of existence whether organic or inorganic.

Much pronounced spatial variability is visible in cultivated areas where contrasting crops, soil amelioration and addition of fertilisers or other chemicals superimpose differences between fields on a variation already present in a native soil.

Since the line of approach to soil studies emphasizing spatial variability of soil is rather recent, available literature on its effect on soil chemical properties is not complete. Hence further studies have to be made in this respect.

High variability often offered by closely related soil groups within themselves creates much difficulty in interpreting response patterns of crops imposed by treatment variables or environmental conditions. It further complicates the efforts of planters who are seriously involved in tree crop management.

Tree crops, especially plantation crops like rubber are subjected to intensive management and great care by the planters for economic and sustained yield. Higher average yields of the economic product appears to result from the achievement of greater uniformity among all the trees. This necessitates the management of each plant as a separate entity instead of a wholesome approach with a general package of nutrient management. A knowledge of spatial variability of nutrient content in the soil can enable prescription of nutrients for individual trees to achieve this objective.

Such an attempt has been made to study soil spatial variability in rubber plantations with the objective of ultimately working out models for application of fertilizers for individual trees to achieve uniformity of stand.

The present study entitled "Nutrient management model for compensating spatial soil variability in rubber plantations in Amboori area " has been undertaken with above mentioned over-riding objective. The studies thrust at the following aspects:-

1. relating spatial variability of soil especially in the horizontal plane with the girth of the rubber tree prior to tapping.

2. working out compensating models for nutrient application to attain maximum uniformity at the earliest tapping age and obliterate the effects of spatial variability of soil during the gestation period based on extensive studies on soil properties and girth of trees.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Spatial variability has been identified as an important feature of soil properties relative to crop production, land reclamation, fertilizer management and mapping of soils. Research on spatial variability however, is of recent origin. Hitherto, variability of many soil properties have not been fully appreciated or understood by persons using soil data. In recent years, increasing interest on environmental problems and the proliferation of model development, the temptation exists to use soil data without adequate appreciation of limits imposed on such data by spatial variability. Hence research work account for soil spatial variability, is limited. Eventhough a few studies had been undertaken earlier, greater importance had been given to those on hydraulic properties of soil in relation to spatial variability rather than to those involving chemical properties and fertility aspects of the soil.

Some of the important information accumulated through research on soil spatial variability are reviewed and presented in this chapter.

Spatial variability

Spatial variability assumes the role of an important property to be accounted for in the management and utility of soils for various agricultural and non-agricultural purposes. The inherent spatial variability of soil is brought about due to soil forming factors themselves and pedoturbations besides many other factors.

Zinke and Crocker (1962) found that variation in soil pH, bulk density, total nitrogen, CEC of soils adjacent to several tree species, could be influenced by the differential radial distribution of littoral components away from the trunks. Specific patterns of variability were dependent on the quantity and nature of tree litter.

Mader (1963) studied the degree of variability and its effect on accuracy of mean plot values for soil properties in the north east red-pine plantations and found that variability in properties such as organic matter, nitrogen, silt and clay, exchangeable Ca plus Mg, CEC and bulk density between plots was much higher than within plots.

Beckett and Webster (1971) cited several examples to show the variability of chemical properties to be greater in a grazed than in cultivated area.

Correlograms were computed by Webster and Cuanalo (1975) to show on an average the relation of soil at one point to that at another and showed that for all properties, the relation between sampling points weakened steadily over distances from 10 m to about 230 m and the major source of variation occurred within 10 m.

Courtin et al (1983) reported in a study of variability, coefficient of variation of the order of 50, 23, 10, 48, 54, 53, 219, 81, 36, 82, 155 and 51 for coarse fragments, bulk density, pH, total carbon, total nitrogen mineralizable nitrogen, extractable phosphate, sulphate, potassium, magnesium and calcium respectively in high productivity soils of some forests in British Columbia.

Carter and Pearen (1985) studied the general and spatial variation of several soil profile characteristics and properties of agronomic and ameliorative importance on a regional and local area of solonetzic soil, found that variograms for most of the various soil properties did not reveal strong spatial variability.

Kachanosky et al (1985) examined the effects of a 30 year of cultivation on the magnitude and spatial variance relationship of selected soil properties and used spatial relationship observed in the native soil for predicting the soil surface on the cultivated site that existed before cultivation. Spectral analysis indicated that redistribution of soil due to tillage in past years was not random, but was related to the spatial distribution of the past surface curvature.

It was found out by Obenauf and Seabold (1986) that the spatial variability of soil fertility parameters in the top 30 cm of a sandy soil increased in the order pH, organic matter, total nitrogen, magnesium, potassium and phosphorus.

O'halloran et al (1986) found that the spatial variability of sand content on a crop rotation study site located on a Brown chernozemic loam soil was considerably longer than experimental plots. They found that since the sand content was not randomly distributed in space, all soil properties correlated to sand would also be non-randomly distributed in space.

Hammer et al (1987) studied the temporal and spatial variability of soil properties such as extractable Ca, Mg and K and pH in H_2O and KCl within and among three forested mid cumberland plateau land types at two locations. They found that magnitudes of soil variability were significantly related to land types and only 3 of 16 soil variables differed in magnitudes of spatial versus temporal variability. Variability on sites was of the order: Slopes $>$ bottoms $>$ uplands.

In another study Sharma et al (1988) observed that heterogeneity in sodic soil reclaimed for about 12 years and under continuous cropping since then, was stochastic.

Soil Moisture Characteristics

Biggar and Nielsen (1976) found that estimates of the pore water velocity based on measures of solute displacement within each sub plots and the entire field in their study to know the spatial variability of leaching characteristics, were logarithmically normally distributed and in agreement with volumetric measures of water infiltration rates.

Differences both in shape and magnitude of the average moisture content characteristic curves from one location to another in the 225 m^2 in Bainsville clay loam were shown by Cameron (1978).

Delhomme (1979) while in a study of spatial variability and uncertainty in groundwater flow parameters could propose a geostatistical approach to characterise the uncertainty about the transmittivity field of an acquifer and to analyse its effect on predicted head values.

Smith and Hebbert (1979) studied the effects of random distribution of soil properties on distribution of ponding time, composite areal rate and bias due to variability in space using monte-carlo simulation. They used a distributed watershed simulation model for the purpose to demonstrate hydrograph bias due to deterministic spatial variability, and from random variation plus the relation of bias to rainfall rate.

The study of Sharma and Luxmoore (1979) on the effects of soil spatial variability on the water balance components of a grass land watershed near Chiksha measured properties of scaling factor which is related to the microscopic characteristic length of the soil. Their studies revealed the complexities of soil plant atmospheric interactions in evaluating the influence of soil variability on water balance and underlined the limitations of drawing generalizations.

Bell et al (1980) showed that moisture variability within any given large field area are inherent and are normally distributed about the mean. Neither a single constant value of the s.d. or CV in analysis of surface moisture variations within large field sites, uniquely defined the variability over the complete range of mean field moisture contents examined.

Philip (1980) was of opinion that difficulties frequently arise in the quantitative predictions of soil water properties in lab for areas of appreciable size in the field since being vitiated by soil heterogenity.

Dunin and Aston (1981) assessed systematic spatial variability in the soil water content from data obtained from a 5 ha catchment area and suggested that soil moisture variability in a catchment could be accounted for systematically by domains.

It was noticed by Greyminger et al (1985) that spatial variability of field measured soil water characteristics were accountable if the separation distances of tensiometers or neutron meters access-tube were greater than 10 m. They opined that for greater precision in the measurement of soil water characteristics the above said separation distance should be less than 10 m.

Jimyeh et al (1986) studied the field variability of soil water pressure along a 290 m transect through a field near Socorro, New Mexico and found that the observations showed a gradual increase of soil water tension over time and a high degree of spatial variability. Covariance analysis of the pressure data showed that the variations were spatially correlated over distance of at least 6 m. They also found that the variation was spatially correlated and dependent upon its means. This finding supported the hypothesis obtained from a stochastic analysis that the variation of soil water pressure is mean dependent.

Hydraulic conductivity

Stockton and Warrick (1971) studied the spatial variability of unsaturated hydraulic conductivity for

40 ha of Pima clay loam where one standard deviation to either side of the average moisture release curve resulted in a 20-30 per cent variation in the hydraulic conductivity.

Peck et al (1977) studied the effect of spatial variability of soil hydraulic properties in water budget modelling and found that appreciable spatial variability of soil properties existed on the scale of a watershed or a field even in a single soil type.

Baker (1978) in a study on the variability of hydraulic conductivity within and between nine Wisconsin soil series obtained conductivity curves for each series which were revealed as a family of curves.

Gelhar et al (1979) showed that longtitudinal dispersions were produced as a result of vertical variations of hydraulic conductivity in a stratified acquifer. The longitudinal dispersions so obtained were analysed by treating the variability of conductivity and concentration as homogenous stochastic process.

Smith and Freeze (1979 a) observed that hydraulic conductivity values in neighbouring blocks of a flow domain when auto-correlated by assuming spatial variations in conductivity, could be expressed or represented by a first order nearest neighbour stochastic process model. The model led to a realistic representation of the spatial variability in hydraulic conductivity in a discrete block medium.

Smith and Freeze (1979 b) suggested that the probability distribution for hydraulic head must be interpreted in terms of the spatial variations of the expected head gradients, standard deviations in the hydraulic conductivity distribution, the ratio of the integral scales of the auto correlation function for conductivity to the distance between boundaries on the flow domain and the arrangement of statistically homogeneous units within the flow domain. They concluded that the uncertainties in the predicted hydraulic head values are strongly influenced by the presence of a spatial trend in the mean hydraulic conductivity.

Smith et al (1981) pointed out that given a moderate number of data points, the unknown pattern of spatial variation in hydraulic conductivity are more important sources of uncertainty, then errors in estimating the means and standard deviations of the hydraulic conductivity distribution.

Infiltration rate

Luxmoore et al (1981) in their study on spatial variability of infiltration rate into a weathered shale sub soil discovered that the semivariogram analysis of infiltration rate showed a random aerial variability which highlighted the occurrence of some spatial patterning at a small scale than 2 m.

Maller and Sharma (1981) in an analysis of aerial infiltration considering spatial variability showed that the effect on the expected infiltration flux of variability of s (sorptivity) only is significant when s and A are considered independently while variability of A has a small but not negligible effect, when considered in conjunction with that of s. The distribution of infiltration flux was calculated under the assumption of joint log normal variability of parameters s (sorptivity) and A of Philip's infiltration equation $i = 1/2\ st^{1/2} + A$ where i is the infiltration flux at time t.

Malik et al (1983) carried out 30 infiltration tests at randomly selected sites at the Haryana Agricultural University Research Farm to measure quantitatively spatial variability of infiltration parameters. They observed that integrated parameters viz. infiltration at 15, 30, 60 and 180 minutes and the derived ones viz. hydraulic conductivity and sorptivity were normally distributed over space.

BenHur et al (1987) found from a study on variability of infiltration in a field with surface sealed soil, that no spatial dependence of the steady state infiltration rate values existed when they were measured by methods using a portable infiltrometer and a double ring infiltrometer.

Nutrient status

a) Nitrogen

Biggar (1978) concluded that the coefficient of variation may be greater for fertilized than unfertilized plots by 100-150 per cent for soil nitrogen. Fertilizer application tends to increase the within field soil variability.

Broadbent et al (1980) obtained a coefficient of variation of 16 per cent for total nitrogen as a measure of its variation in space when he analysed soil samples from all depths in a fine sandy loam field of 650 m^2 area in Davis, California. The relatively low value of CV indicated that total nitrogen was much less affected by spatial variability resulted from management.

Broadbent et al (1980) also showed with the help of a frequency distribution analysis of ^{15}N values and of total N that they were log-normally distributed in about half the groups of samples from some virgin and cultivated soil. CVs of total nitrogen were somewhat lower in cultivated soils than in virgin soil. They again observed that there were greater natural variation both laterally and vertically in the case of ^{15}N values at a given sampling site.

Karamanos et al (1981) with the analysis data of 58 surface soil samples covering nearly 74,000 km^2 in Central Saskatchewan, suggested that total N enjoyed a spatial variation with a CV of 39 per cent.

Hunter et al (1982) observed a coefficient of variation of 22 per cent for soil nitrate. He found that the soil nitrate levels produced a log-normal distribution over space.

In a study conducted in a sequence of Moraines, British Columbia, Sondheim and Standish (1983) obtained a coefficient of variation of 18 per cent for total nitrogen based on an analysis of 180 samples from three depths.

Dahiya et al (1983) found that soil management of different degrees affected relatively the nitrate content of soil. He attributed a higher level of spatial variability to this, which was characterised by a CV of 23 per cent.

However, Mueller et al (1985) found that nitrogen experienced a high short-range variability in forest-cleared cultivation site of sourth Nigeria when considerable amount of mineralization was in progress.

Tabor et al (1985) when studied the spatial variability of nitrate in irrigated cotton where soil nitrate was correlated with other variables such as percentage of sand, silt and clay, pH, Na, K and P plus petiole nitrate found that soil nitrate had a largest correlation with ECE and had a high spatial dependence and spatial structure.

b) Phosphorus

Beckett and Webster (1971) showed that there were 45 per cent coefficient of variation in the available phosphorus content of soils which accounted for a high degree of spatial variability.

Webster and Butler (1976) found that 2/3 of variation of soil phosphorus at Ginninderra occurred within 5 m and the remainder at more than 180 m.

A high spatial variation for available P in soil with a CV of 78 per cent was reported by Courtin et al (1983) in their studies on lateral variability in some properties of disturbed forest soils of British Columbia.

Sondheim and Standish (1983) in a study conducted on a sequence of Moraines, British Columbia, observed a medium variation for total P in soil.

Bos et al (1984) during the study of spatial variability of one type of phosphate Mineland in Central Florida having 6 x 21 sampling grid, with 10 m interval, observed the mean values to be very high for total P (8.3 g/kg) and extractable P (0.9 g/kg).

Mueller et al (1985) reported that total and organic phosphorus had a high long range variability which is related to the clay content, in a southern Nigeria soil which was made into a cultivation site after clearing the forest.

c) Potassium

Pahm (1967) obtained a coefficient of variation of only 15 per cent for total K when his studies were directed towards the assessment of spatial variability of total K with 27 samples within a soil series, in central England. He came to the conclusion that soil management could not bring about a substantial variation in total K of soil in space.

Pahm (1967) also found that exchangeable K too had only a lesser CV of 19 per cent which discarded the possible spatial variation in exchangeable K content.

However, he found that available K was subjected to considerable degree of spatial variability with a CV of 30 per cent due to different degree of soil management.

Beckett and Webster (1971) found that the spatial variability of available K in soil was with a CV of 70 per cent which was rather significant as far as the variation of other nutrients were concerned.

Webster and Butler (1976) observed that soil K varied little between points 5 m apart but varied considerably over distances 56-180 m in soil classification and soil survey studies at Ginninderra.

d) Calcium and magnesium

Beckett and Webster (1971) observed a greater spatial variability for available calcium with a CV of

30 per cent in their studies of soil spatial variability for chemical properties.

Indorante and Jansen (1981) found that exchangeable calcium had undergone medium variation in space in surface mined and undisturbed land in Southern Illinois. They obtained a coefficient of variation of 16 per cent. They also obtained a CV of 22 per cent for exchangeable Mg in the same study.

In the study on lateral variability in a variety of physical and chemical properties in the surface 30 cm of mineral soil taken from beneath young (5-12 yrs) Douglas-fir plantations, Courtin et al (1983) found that exchangeable Ca concentration and quantities tended to be the most variable.

Bos et al (1984) observed very high mean values for Ca (2.3 g/kg) in a study on spatial variability of a phosphate mineland in Central Florida.

Carter and Pearen (1985) found that extractable calcium in the Bnt horizon and depth of the Ap and Bnt horizons were anisotropic showing significant spatial dependence with direction of sampling.

But Sarma et al (1988) in an analysis of spatial variability in sodic soils found that the distribution of $CaCO_3$ contents within a 1.56 ha field were found to be isotropically spatially dependent to various degrees depending upon the depths.

e) Organic carbon

Dahiya et al (1984) when studied 50 samples from 0-30 cm depth in about 10 ha of a cultivated loess soil in West Germany, found that organic carbon showed a lower variability with CV of 8 per cent. He pointed out that variation in organic matter content was less affected by spatial variability caused by management of the field.

Mueller et al (1985) suggested a high short range variability for carbon content in a forest cleared soil in South Nigeria.

f) Other nutrients

Mueller et al (1985) found that sulphur in a forest cleared land of South Nigeria appeared to have a high short range variability.

In a study on the variability of DTPA extractable micronutrients for A and B horizons of a cultivated site and its native prairies counterpart, Singh et al (1985) came to the conclusion that there was a high degree of variability in samples taken every metre on a 46 m long transect. There were large differences among the cultivated and native prairie soils, the two soil horizons and the four micronutrients studied. In cultivated lands, larger numbers of samples were required for Cu and Mn than for Zn and Fe to obtain a precise estimate of the means.

g) Soil Reaction - pH

Campbell (1977) found that measurements of pH and silt changed slowly within the study area whereas the sand measurements exhibited a very sharp change at the contact of two soils.

In another study of an 1.6 ha silty clay loam soil in Kansas, USA using 160 samples (56-71 cm) Campbell (1978) could establish that soil pH suffered very low changes due to spatial variability. He obtained a CV of only 3 per cent for soil pH in his study and suggested that management had only little role in the spatial variation of soil pH.

Courtin et al (1983) found that pH was the least variable among 19 soil properties studied in the surface 30 cm of mineral soil taken from a Douglas fir plantation.

Trangmar et al (1987) observed that crop yields on cleared forest land of the humid tropics were often highly variable due to spatial heterogenity of soil properties. They found that the range of spatial dependence for soil acidity and exchange characteristics was 3 to 4 m but increased to 7 m for organic carbon, total N and extractable P.

Sarma et al (1988) in an analysis of spatial variability in sodic soils, found that the distribution of pH and SAR within a 1.56 ha field were found to be isotropically spatially dependent to various degrees depending upon the depths.

MATERIALS AND METHODS

MATERIALS AND METHODS

To study the effect of spatial variability of soil and to make a quantitative assessment of its effect on rubber plantations, for relating it with one of the most significant growth parameters viz. the girth of the tree prior to tapping, soil samples were taken from five representative plantations in Amboori area in Trivandrum district. All the plantations selected had the rubber variety RRII-105. Besides the soil, leaf samples from index leaves were analysed and measurement of girth of marked trees were also conducted.

(i) Selection of site

The site of the experiment was selected in the rubber plantations near Amboori tribal area. Soils of the area selected, belong to the Kottoor and Mayam series.

(ii) Selection of plantations

The selection of plantations for the study was made in relation to the slope of the plantation, age of trees and variety.

(a) Slope of plantation

The slope of plantation was chosen to be between 20-30^{o} with the horizontal plane.

(b) Age of trees

Plantations coming under three age groups viz. 1-2 years, 4-5 years and 6-7 years but prior to commencement of tapping were selected.

(c) Variety

The rubber variety RRII-105 which is currently more popular in the area was selected.

Five plantations satisfying the above conditions of slope, age and variety were accordingly selected for the study.

(iii) Collection of soil samples

Soil samples were collected from the grid points fixed throughout the entire area of each plantation under study. Grid points were marked at every 6 m distance - double the spacing provided between trees- along each row and at every 8 m between rows from the top to bottom as lag distance (Fig.1).

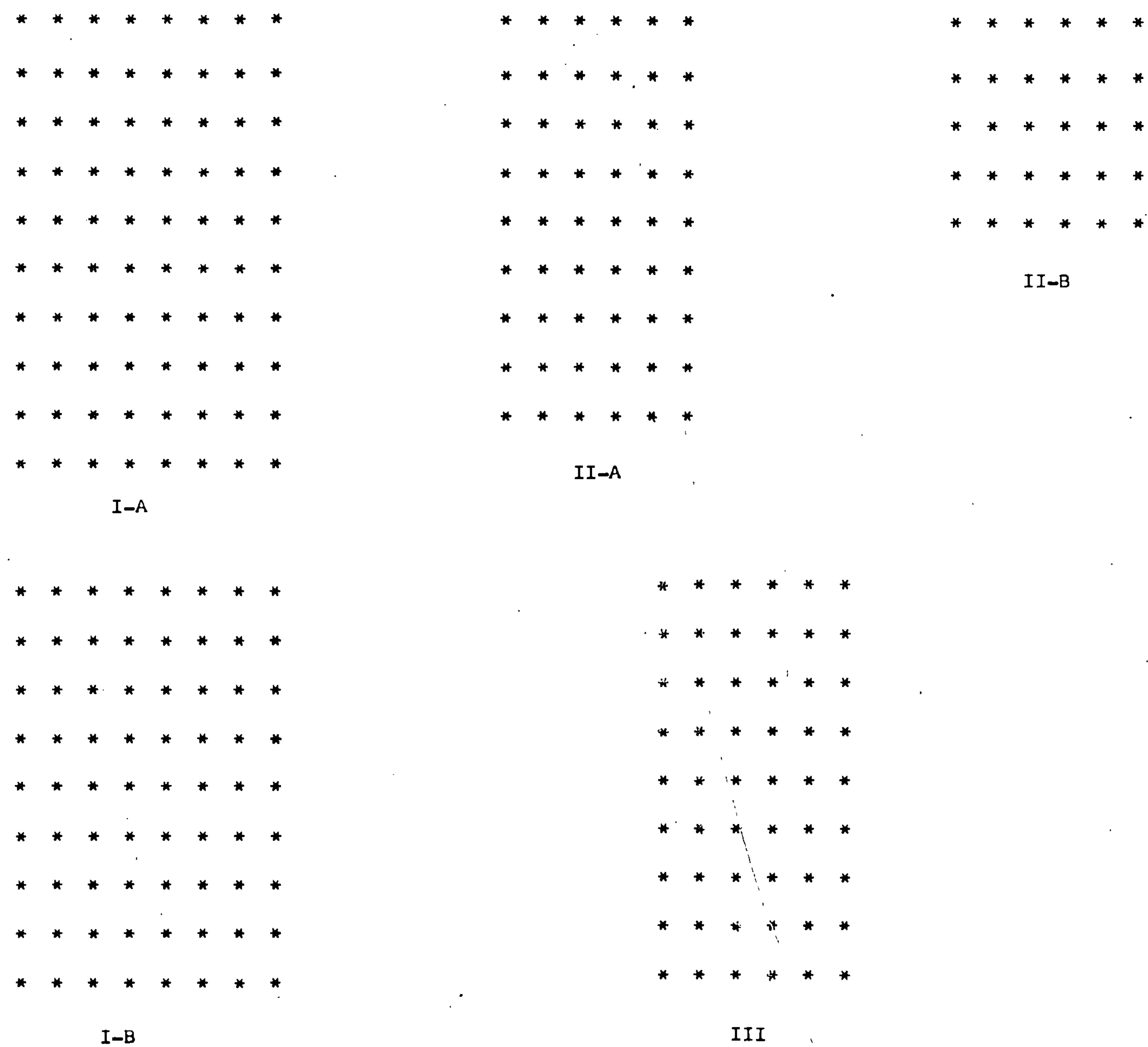

Fig. 1. Lay out of grid points

The number of grid points fixed in each plantation varied depending on the size of the plantation as given below:

Plantation No.	Age of plants	No.of grid points
Plantation I A	1 -2 years	80
Plantation I B	1 -2 years	72
Plantation II A	4 -5 years	54
Plantation II B	4 -5 years	30
Plantation III	6 -7 years	54

Composite soil samples were collected from 0-50 cm depth for each grid point.

(iv) Collection of leaf samples

Leaf samples were collected from trees very close to the grid points, during the months of September-October in 1986. From each of the selected trees, four basal leaves of lower branches in shade were collected.

(v) Measurement of girth

Girth, the important yield component of rubber which positively indicates the number of latex vessels present, was measured along with leaf sample collection. The girth was measured at the height of 50 cm from the base of the tree.

(vi) Soil analysis

Preparation of the soil samples

The air dried soil samples were gently powdered and passed through a 2 mm-sieve and stored for further analysis.

The prepared soil samples were analysed for total and available N, P, K, Ca and Mg besides pH and organic carbon.

(a) Organic carbon

It was determined by the Walkley and Black's rapid titration method (Jackson,1973)

(b) Soil reaction - pH

The pH of 1 :2.5 soil suspension was determined using a glass electrode (Piper, 1966)

(c) Chemical properties

The soil samples were analysed for the following chemical parameters by the methods noted against each.

1. Total nitrogen	Microkjeldahl method	(Jackson 1973)
2. Total phosphorus	Chlorostannous reduced molybdophosphoric blue colour method	(Jackson 1973)

3. Total potassium	Flame emission spectrophotometry using sulphuric acid extract	(Jackson 1973)
4. Available nitrogen	Alkaline permanganate method	(Subbiah and Asija 1956)
5. Available phosphorus	Bray's extractant No.1	(Jackson 1973)
6. Available potassium	Flame emission spectrophotometry using neutral normal ammonium acetate extract	(Jackson 1973)

7. Available and total calcium and magnesium

The total Ca and Mg were determined in the perchloric acid extract of the soil and the available Ca and Mg in the ammonium acetate leachate (Jackson 1973). The extracts were fed into an Atomic Absorption Spectrophotometer model PE 3030 and the spectrum of absorption was determined at the wave lengths 422.7 nm for calcium and 285.2 nm for magnesium.

Plant Analysis

Preparation of plant samples

The plant samples collected were dried in a well ventilated oven at a temperature of 60-70^{o}C. The dried leaf samples were powdered using a centrifugal mill. The prepared samples were stored for further analysis.

The leaf samples were analysed for the elements N, P, K, Ca and Mg.

1. Plant nitrogen

Plant nitrogen was determined by microkjeldahl method using the leaf sample digest in concentrated sulphuric acid (Jackson 1973).

2. Plant phosphorus

Plant phosphorus was estimated by the chlorostannous reduced molybdophosphoric blue colour method using the leaf sample digest in sulphuric acid. The colour intensity and absorbance were read in Spectronic 2000 (Jackson 1973).

3. Plant potassium

Plant potassium was estimated in the HNO_3-$HClO_4$ digest of the leaf sample using Flame emission spectrophotometry (Jackson 1973).

4. Plant calcium and magnesium

Calcium and magnesium in the HNO_3- $HClO_4$ digest were determined using Atomic Absorption spectrophotometer model PE-3030 for determining the spectrum of absorption at wave lengths 422.7 nm for calcium and 285.2 nm for magnesium.

STATISTICAL ANALYSIS

Analysis of variance was done to establish the significant variations of the different properties of soil and plant over different lag distances.

Correlations were worked out to establish the relationship between nutrient contents in soil and plant, and the girth of trees. Linear regression equations for girth of the plant on soil and plant nutrients were also worked out (Snedecor and Cochran, 1967).

Semi-variance

Semi-variance had been used as the appropriate statistical parameter to quantify spatial variability (Burgess and Webster,1980)

When observations were made at regular intervals to give values z(i), i = 1,2,.... ....n ; the relation between pairs of points 'h' interval apart, the lag, could be expressed as the variance of the differences between all such pairs. The per-observation variance between pairs (Yates, 1948) is half this value thus;

$$\gamma(h) = \frac{1}{2} \text{ var } \left[z(i)-z(i+h) \right]$$

$\gamma(h)$ is called the semivariance between points at a given distance, h, apart and can be estimated for integer values of 'h' from the data.

Semi-variogram

For each integer value of lag distance h, a semi-variance value will be obtained. These values can readily be plotted against lag distances which then gives the semi-variogram for the property.

Figure 1a shows the mode of selection of grid points at lag distances h = 1,2 and 3 for the sake of illustration of the procedure.

Regression equations and nutrient management models

Regression equations were fitted to semi-variograms for each property (Y) on the lag distances (X).

Nutrient management models were constructed based on the regression equations of semi-variances after employing suitable soft-ware in the Versa IWS computer of Keltron in the Department of Agricultural Statistics, College of Agriculture, Vellayani.

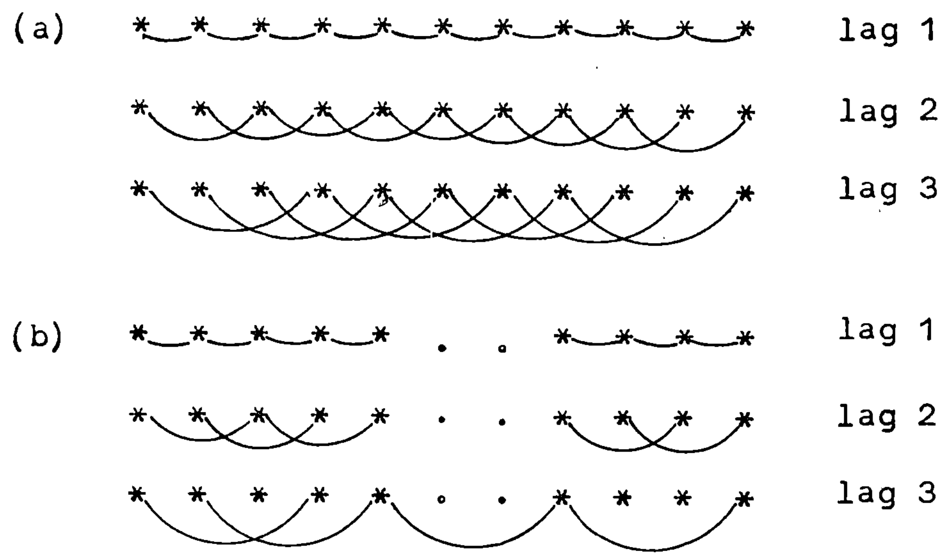

Fig.1a. Comparisons for estimating semi-variances on linear transects at lags of 1, 2 and 3 sampling intervals;
(a) for complete data and
(b) where some observations are missing the dots.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The extent of soil spatial variability on the soil chemical properties of rubber plantations due to slope and heterogenity over distances, has been investigated. Five plantations of three age groups prior to tapping were selected for this study and the results of analysis of the soil samples and leaf samples as well as statistical models and regression equations are presented and discussed in this chapte

SOIL ANALYSIS

Total Nutrients of soils

a. Total nitrogen

The trend of spatial variation of total nitroger is found to be non-significant in three of the five plantations under study. This indicates less impact of lag distances along a slope on the total nitrogen status of the soil.

The content of total nitrogen shows a range of values from 3.760 ppm to as high as 15.400 ppm in the I-A plantation with a CV of 31.6 per cent. But the variation over the increase of lag distance along the slope from top to bottom registered a non-significant trend and is found to be less variable along the slope (Table 1.1).

Similar results are obtained in the case of II-A plantation of 4-5 years old and III plantation of 6-7 years old. In both the cases spatial variability of total nitrogen status is negligible (Table 1.3 & Table 1.5)

But I-B and II-B (1-2 years old and 4-5 years old) plantations, however, stand out to show considerable spatial variation on total nitrogen at 5 per cent level of significance. I-B plantation is characterised by a minimum of 3.238 ppm concentration at the top and a maximum of 9.538 ppm at the bottom of the plantation with a CV of 20.4 per cent showing a general trend of increasing the status of the total nitrogen down the slope over the increasing lag distances (Table 1.2). However the increase does not observe any pattern or trend. Meanwhile, as the lag distances differ, the nitrogen status also varies from one another. Comparatively higher values are obtained for lag distances of 24 m (5.86 ppm), 32 m (5.075 ppm), 48 m (5.16 ppm), 64 m (6.21 ppm) and 72 m (9.538 ppm).

Table 1.1 Chemical properties of soil over different lag distances in I-A plantation - Total nutrients in soil.

Lag distances	Total nutrients				
	Nitrogen (ppm)	Phosphorus (per cent)	Potassium (per cent)	Calcium C mol(p^+) kg^{-1}	Magnesium C mol(p^+) kg^{-1}
1h	7.260	0.0270	0.0086	1.806	1.358
2h	15.400	0.0272	0.0121	1.831	1.342
3h	6.210	0.0273	0.0106	2.138	1.544
4h	4.810	0.0278	0.0062	1.550	1.458
5h	3.760	0.0275	0.0065	1.819	1.439
6h	5.600	0.0277	0.0072	2.038	1.695
7h	6.130	0.0280	0.0058	1.719	1.484
8h	5.080	0.283	0.0070	2.550	2.500
9h	4.200	0.0283	0.0085	2.425	1.733
10h	6.200	0.0288	0.0083	2.113	2.004
F	4.3297	17.7135**	6.9454**	0.9248	1.9101
S.E	1.1063	0.00014	0.0008	0.3282	0.2595
C.D	3.4201	0.00040	0.002	0.9167	0.7247
Range	3.760 -15.400	0.0270-0.0288	0.0058-0.0121	1.550-2.550	1.342-2.500
CV (%)	31.6	0.51	9.40	16.40	15.68

h = 8 m.
* Significant at 5 per cent level
** Significant at 1 per cent level

II-B plantation also registers a more or less similar trend, characterised by a spatial variation at 5 per cent level of significance with a range of 2.570 - 4.200 ppm having a CV of 11.5 per cent (Table 1.4). Unlike the I-B plantation here the total nitrogen status of soil increases as the lag distances along the slope increases without much irregularity.

The spatial variation of total nitrogen is high in I-A plantation which is comparatively an younger plantation of below two years old. Such high values for coefficient of variation of the order of 100-150 per cent ore more was observable with studies conducted by Biggar (1978). He suggested the high variation to be due to fertilizer application. But the variability visible in other plantations falls within a range of 6-20 per cent CV as against the I-A plantation. These plantations are relatively older than I-A plantation and were subjected to more intensive management. Similar results of coefficient of variation could be obtained by Broadbent et al (1980) when he analysed soil samples from all depths in a fine sandyloam field. He attributed the low values for CV to the fact that total nitrogen was much less

Table 1.2 Chemical properties of soil over different lag distances in I-B plantation. Total nutrients.

Lag distances	Total nutrients				
	Nitrogen (ppm)	Phosphorus (per cent)	Potassium (per cent)	Calcium C mol(p^+) kg^{-1}	Magnesium C mol (p^+) kg^{-1}
1h	3.238	0.0269	0.0113	0.8975	0.735
2h	4.638	0.0271	0.0076	0.6125	0.684
3h	5.863	0.0292	0.0063	0.9313	0.874
4h	5.075	0.0287	0.0052	0.8188	0.650
5h	4.988	0.0277	0.0056	1.0188	0.688
6h	5.162	0.0275	0.0061	1.1250	0.563
7h	4.380	0.0274	0.0039	0.8500	0.455
8h	6.210	0.0279	0.0061	0.5188	0.298
9h	9.538	0.0281	0.0053	0.5625	0.326
F	2.6058*	4.8517**	25.3125**	1.5753	4.1909**
S.E	1.09	0.00033	0.00041	0.1671	0.0942
C.D	3.071	0.00093	0.00012	0.4725	0.2664
Range	3.238 -9.538	0.0269-0.0292	0.0052-0.0113	0.5188-1.1250	0.298-0.874
CV (%)	20.4	1.2	6.5	20.5	16.1

h = 8 m

* Significant at 5 per cent level

** Significant at 1 per cent level

affected by spatial variability due to the annuling effects of intensive management.

b. Total phosphorus

Appreciable variation is evident in the case of total phosphorus level in all the five plantations irrespective of age of the plantation.

Except II-B plantation, all the others show significant spatial variation over lag distances for soil total phosphorus content both at 5 per cent and 1 per cent level of significance.

In the case of I-A plantation, total phosphorus exhibited a gradual increase down the slope and registers a minimum of 0.0270 per cent at the top most row and a maximum percentage of 0.0288 at the bottom, with a CV of 0.51 per cent showing a gradual increase in values in between (Table 1.1).

Total phosphorus increases from 0.0269 per cent to 0.0292 per cent along the slope with a CV of 1.2 per cent in the case of I-B plantation (Table 1.2). But the increase is not as smooth as in I-A plantation.

Table 1.3. Chemical properties of soil over different lag distances in II-A plantation - Total nutrients

Lag distances	Total nutrients				
	Nitrogen (ppm)	Phosphorus (per cent)	Potassium (per cent)	Calcium C mol(p^+) kg^{-1}	Magnesium C mol(p^+) kg^{-1}
1h	4.200	0.0270	0.0033	1.392	0.492
2h	3.030	0.0271	0.0043	2.375	0.528
3h	2.570	0.0270	0.0072	9.392	1.712
4h	3.850	0.0272	0.0082	1.733	0.498
5h	4.550	0.0274	0.0032	1.292	0.737
6h	2.800	0.0287	0.0043	1.125	0.662
7h	2.680	0.283	0.0042	2.575	0.682
8h	3.150	0.0278	0.0044	1.242	0.630
9h	3.500	0.0306	0.0051	1.608	0.642
F	1.220	6.4331**	3.0632**	1.8596	1.3863
SE	0.635	0.00047	0.00097	1.9237	0.3206
CD	1.814	0.0013	0.0028	5.498	0.9162
Range	2.570-4.550	0.0270-0.0306	0.0032-0.0082	1.125- 9.392	0.492-1.712
CV (%)	18.8	1.7	19.8	76.0	44.0

h = 8 m

** Significant at 1 per cent level

Since lag distances 24 m, 32 m and 40 m show maximum percentage rather than the still higher lag distances, the highest level of phosphorus is obtained for a lag distance of 24 m from the top.

II-A and III plantations are also found to possess spatial variability for their total phosphorus content. Their range of total phosphorus are 0.0270-0.0306 per cent and 0.0275-0.0291 per cent with coefficients of variation of 1.7 and 0.74 per cent respectively. Maximum values for total phosphorus are exhibited at lag distances 72 m, 64 m and 56 m in the case of III plantation, and 72 m, 48 m and 56 m in the case of II-A plantation (Table 1.3 & 1.5).

The variability of total phosphorus though significant in II-B plantation, is not appreciable to the extent of what is observed in other plantations (Table 1.4). A variation significant at 5 per cent level is characterised by a maximum percentage of total phosphorus of 0.0291 at a lag distance of 40 m. The CV for total phosphorus in all these plantations registers a medium range only and no outstanding trend of variation can be established. Sondheim and Standish (1983) also arrived at a medium variation for total phosphorus in soil in a study conducted on a sequence of Moraines, British Columbia.

c. Total potassium

Considerable significance is obtained for spatial variability on soil total potassium in all the plantations studied except in the III plantation wherein spatial variation is not observed for total potassium.

In I-A plantation highest values for total K_2O with a CV of 9.4 per cent are obtained in the upper portion of the plantation (Table 1.1) with a maximum of 0.0121 per cent at a lag distance of 16 m. But a trend of total potassium content with increase in lag distance cannot be arrived at since they are showing an irregular variation.

High total potassium contents are obtained at lag distance of 8, 16 and 24 m in the case of I-B plantation but the variation is not smooth to arrive at a general trend, though the CV is 6.5 per cent (Table 1.2).

The II-A and II-B plantations too show a similar trend on I-A and I-B plantations and are characterised by high values for total potassium in the upper reaches

Table 1.4. Chemical properties of soil over different lag distances in II-B plantation - Total nutrients

Lag distances	Total nutrients				
	Nitrogen (ppm)	Phosphorus (per cent)	Potassium (per cent)	Calcium C.mol(p+) kg^{-1}	Magnesium C.mol(p+) kg^{-1}
1h	2.570	0.0276	0.0047	0.4417	0.2383
2h	2.800	0.0279	0.0046	0.5083	0.2900
3h	2.680	0.0276	0.0034	0.4417	0.2430
4h	2.920	0.0283	0.0040	0.5500	0.2950
5h	4.200	0.0291	0.0066	1.0583	0.4317
F	3.6599*	3.0577*	6.5833**	4.1356*	1.9659
SE	0.3480	0.00034	0.00047	0.1280	0.0558
CD	1.013	0.00099	0.00138	0.3730	0.1625
Range	2.570-4.200	0.0276-0.0291	0.0034-0.0066	0.4417-1.0583	0.2383-0.4317
CV(%)	11.5	1.2	10.1	21.3	18.6

h =8 m
* Significant at 5 per cent level
** Significant at 1 per cent level

of the plantations rather than in the low reaches. The total potassium content ranges between 0.0032 - 0.0082 per cent for II-A plantation with a CV of 19.8 per cent and 0.0034 - 0.0066 per cent with a CV of 10.1 per cent for II-B plantation (Table 1.3 & 1.4)

The variation in the total potassium content is non-significant down the slope for III plantation. The range of the level of potassium, however, is found to be 0.0035 - 0.0045 per cent with a CV of 5.5 per cent (Table 1.5).

It is quite evident from the results that much variation in total potassium in soil could not be expected since soil management could not bring about a substantial variation in total potassium of soil in space. A study by Pahm (1967) confirmed this, in which he obtained a CV of only 15 per cent for total potassium.

d. Total calcium

The distribution of total calcium do not show significant variation over different lag distances from the top in almost all plantations and reveals that the distribution is not spatially variable to an extent which is considerable.

II-B and III plantations show significant variability; the variability in III plantation being more significant (Table 1.4 & 1.5).

A range of 0.4417-1.0583 Cmol(p^+) kg^{-1} soil is recorded in the II-B plantation with a CV of 21.3 per cent while that of the III plantation was 1.258 to 5.975 Cmol(p^+) kg^{-1} soil with a CV of 31.5 per cent. High values for calcium content are obtained for the lag distance 40 m, 24 m and 8 m for III plantation and 40 m , 32 m and 16 m for the II-B plantation.

A comparatively general increase down the slope, in calcium content can be seen in II-B plantation, but such a trend is not visible in III plantation.

e. Total magnesium

The results revealed by the study points out that total magnesium is generally spatially non-dependent. However, two out of five plantations exhibit some significant variation for total magnesium.

Eventhough I-B plantation is characterised by a significant variation in total magnesium status for

Table 1.5. Chemical properties of soil over different lag distances in III - plantation - Total nutrients

Lag distances	Total nutrients				
	Nitrogen (ppm)	Phosphorus (per cent)	Potassium (per cent)	Calcium C.mol(p+) kg^{-1}	Magnesium C.mol(p+)kg^{-1}
1h	26.130	0.0275	0.0037	2.583	1.068
2h	23.570	0.0275	0.0037	1.763	0.872
3h	27.800	0.0282	0.0038	2.608	0.843
4h	24.200	0.0283	0.0037	1.475	0.710
5h	27.200	0.0289	0.0035	3.775	0.877
6h	23.500	0.0288	0.0045	1.258	0.428
7h	26.100	0.0298	0.0037	1.508	0.380
8h	31.030	0.0296	0.0040	1.325	0.523
9h	24.900	0.0297	0.0043	5.975	0.707
F	1.935	15.578**	2.0157	3.943**	3.297**
SE	1.716	0.00021	0.00021	0.7799	0.1267
CD	4.904	0.00061	0.00061	2.2290	0.3620
Range	23.500-31.030	0.0295-0.0208	0.0035-0.0045	1.258-5.975	0.380-1.068
CV(%)	6.8	0.74	5.5	31.5	17.8

h = 8 m

** Significant at 1 per cent level

different lag distances, it is well demonstrated that magnesium status goes on decreasing as the lag distance increases along the slope from the top, ie. higher values for magnesium are obtained with upper reaches and low values with lower reaches (Table 1.2). Maximum values are found to be at lag distances of 24, 8, 40 and 16 m and the average content varies from 0.298 - 0.874 Cmol(p^+) kg^{-1} soil with a CV of 16.1 per cent.

Similarly III plantation also show higher values at the upper reaches with a maximum of 1.068 Cmol(p^+)kg^{-1} soil at a distance of 8 m (Table 1.5), but the downward decrease is not following any pattern. Average magnesium content exists to be a within 0.380 -1.068 Cmol(p^+)kg^- soil throughout the plantation, showing a CV of 17.8 per cent.

Available Nutrient

a. <u>Nitrogen</u>

A very significant spatial dependence is observed in the case of available nitrogen status in all the five plantations under study. Generally the availabl nitrogen status follows a variability with an increas along the slope downwards over different lag distances. Results of analysis of soil samples reveal that all the plantations without any exception showed considerable spatial variability with respect to available nitrogen.

The average range of available nitrogen in I-A plantation is between 7.236 - 10.650 kg ha^{-1} with a CV of 2.7 per cent and exhibit an increase in the content over lag distances except for 56 m (Table 1.6).

But in I-B plantation similar exception is observed at distances 56 and 64 m, though the trend was an increase in available nitrogen content along the slope downwards. Maximum nutrient level is with the lag distance of 64 m from the top, the value being 12.101 kg ha^{-1}. The plantation shows a CV of 1.3 per cent (Table 1.7).

A maximum and minimum of 5.215 and 3.372 kg ha^{-1} of soil available nitrogen with a CV of 3.3 per cent are obtained in II-A plantation wherein the trend of variability is an increase along the slope with lag distances, without any intermittent decrease in nutrient status (Table 1.8).

Total 1.6. Chemical properties of soil over different lag distances in I-A plantation - Available nutrients, organic carbon and pH.

Lag distances	Available nutrients					Organic carbon (per cent)	pH
	Nitrogen kg.ha^{-1}	Phosphorus kg.ha^{-1}	Potassium kg.ha^{-1}	Calicum C.mol(p^{+})kg^{-1}	Magnesium C.mol(p^{+}) kg^{-1}		
1h	7.236	269.5	430.000	0.036	0.078	1.508	5.31
2h	7.394	145.351	365.000	0.036	0.110	1.105	5.09
3h	7.787	254.365	352.500	0.033	0.137	1.790	5.43
4h	8.313	432.490	285	0.033	0.130	1.418	5.38
5h	8.558	307.715	285	0.039	0.068	1.608	5.14
6h	9.188	191.664	525	0.068	0.091	1.405	5.61
7h	8.915	372.285	377.500	0.036	0.070	1.213	5.51
8h	9.345	172.605	390	0.030	0.065	1.458	5.06
9h	10.080	65.195	347.500	0.034	0.74	1.308	4.84
10h	10.650	88.707	500	0.048	0.087	1.575	4.75
F	22.936**	5.801**	1.394	0.902	17.185**	1.7017	3.324
SE	0.2334	49.6088	67.879	0.0117	0.0063	0.1527	0.156
CD	0.6515	138.561	189.592	0.0329	0.0176	0.4264	0.441
Range	7.236-10.650	65.195-432.490	285-525	0.030-0.068	0.065-0.137	1.105-1.790	4.75-5.6
CV(%)	2.7	21.6	17.6	29.5	6.9	10.6	3.0

h = 8 m

** Significant at 1 per cent level

II-B plantation also gives a similar trend like II-A plantation with values ranging from 5.250 6.008 kg ha^{-1} and shows a CV of 1.8 per cent(Table 1.9).

However, the III plantation exhibits maximum nitrogen status of 6.241 kg ha^{-1} at a distance of 64 m from top; half the way along the slope soil available nitrogen exhibits a gradual increase, thereafter the increase is in a haphazard manner. The plantation also shows a 3.3 per cent coefficient of variation (Table 1.10).

Eventhough the CV values for these plantations with respect to available nitrogen, are lower, it can be stated that much spatial dependence was in vogue in these plantations as revealed from the statistical analysis. The management of soil could cause variation to a greater extent. Dahiya et al (1983) was of the opinion that different degrees of soil management affected relatively much less the nitrate content of soil. He got a CV value of 23 per cent for the nutrient. However, Mueller et al (1985) observed that nitrogen experienced a high short range variability in forest cleared soil which again suggested greater spatial dependence for soil nitrogen.

Table 1.7 Chemical properties of soil over different lag distances in I-B plantation - available nutrients, organic carbon and pH.

Lag distances	Available nutrients: Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calicum C.mol(p^{+})kg^{-1}	Magnesium C.mol(p^{+})kg^{-1}	Organic carbon (per cent)	pH
1h	10.955	762.910	287.500	0.036	0.156	1.903	4.96
2h	10.876	828.100	287.500	0.078	0.113	1.765	5.13
3h	11.174	881.900	310	0.036	0.057	1.658	5.58
4h	11.445	917.700	230	0.025	0.069	1.518	5.36
5h	11.585	827.050	185	0.031	0.059	2.190	5.66
6h	11.821	809.050	252.500	0.020	0.055	2.200	6.03
7h	11.795	791.400	202.500	0.025	0.032	2.325	5.68
8h	12.101	807.800	225	0.018	0.058	2.495	5.41
9h	12.038	827.050	150	0.025	0.050	2.343	5.78
F	8.5807**	2.0249	2.6408*	27.9658**	53.0957**	8.6028**	4.2710**
SE	0.1543	32.9352	32.5076	0.0034	0.0054	0.1170	0.1575
CD	0.4364	93.1549	91.9455	0.0097	0.0148	0.3308	0.4454
Range	10.876-12.101	762.910-917.700	150-287.500	0.018-0.078	0.032-0.156	1.518-2.495	4.96-6.03
CV	1.3	4.0	13.7	10.4	7.3	5.7	2.9

h = 8 m

* Significant at 5 per cent level
** Significant at 1 per cent level

b. Phosphorus

The analysis of soil sample from the five plantations for available phosphorus reveals that only the plantations I-A and II-A exhibit significant spatial variation along the lag distances while other three plantations do not conform with the trend.

I-A plantation registers a range of 65.195 kg ha^{-1} - 432.490 kg ha^{-1} with a CV of 21.6 per cent. The variation do not follow a patterned trend but a rather irregular one (Table 1.6).

Similarly II-A plantation also shows an irregular trend in spatial variation of soil available phosphorus. But the soil available phosphorus content in the upper reaches of soil is comparatively more than that at the lower portions of the plantations (Table 1.8).

Significant variation is not existing in I-B, II-B and III plantations for available phosphorus (Table 1.7, 1.9 & 1.10) and the spatial dependence is negligible. The studies conducted on these five plantations enable to establish spatial variability for soil available phosphorus in some of them. At least two plantations exhibit much higher spatial variability in concordance with the results obtained by Beckett and Webster (1971) which showed a CV of 45 per cent. Similarly a study of Courtin et al (1983) also suggested a high spatial variability for available phosphorus in soil.

c. Potassium

Three of the five plantations viz. I-B, II-A and III plantations are found to show a significant variation in available potassium content in soil in different grid points separated by different lag distances. However, greater variation is observed only with II-A plantation.

The level of available potassium is higher in the upper portions of the plantation I-B where lag distances are much lower ie. at 8, 16 and 24 m. But a definite pattern of variation cannot be pointed out (Table 1.7,.

II-A plantation shows greater variation along the slope between lag distances and each lag distance is significantly different from the other (Table 1.8).

Variation exhibited by III plantation with respect to soil available potassium is not as much significant as what obtained with II-A plantation (Table 1.10).

Table 1.8 Chemical properties of soil over different lag distances in II-A plantation - available nutrients, organic carbon and pH

Lag distances	Available nutrients					Organic carbon (per cent)	pH
	Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium C.mol(p^{+})kg^{-1}	Magnesium C.mol(p^{+})kg^{-1}		
1h	3.372	409.583	160	0.030	0.018	1.277	4.98
2h	3.745	299.375	173.300	0.033	0.023	1.190	4.50
3h	3.780	212.292	190	0.018	0.031	1.100	4.55
4h	4.748	197.917	163.300	0.051	0.051	1.253	4.20
5h	4.843	166.250	160	0.026	0.020	1.393	4.52
6h	4.457	172.709	173.300	0.022	0.29	1.767	4.50
7h	4.865	171.867	180	0.055	0.025	1.723	3.88
8h	4.993	143.538	340	0.036	0.030	2.117	4.12
9h	5.215	108.958	346.700	0.027	0.031	1.847	4.48
F	19.379**	4.948**	3.0471**	2.7544	4.8684**	4.9394**	4.8955**
SE	0.1482	41.2504	43.7896	0.0075	0.0044	0.1588	0.1419
CD	0.4236	117.899	125.156	0.0214	0.0125	0.4539	0.4056
Range	3.372-5.215	108.958-409.583	160-346.700	0.018-0.055	0.018-0.051	1.100-2.117	3.88-4.98
CV (%)	3.3	20	20.9	22.7	15.3	10.5	3.2

h = 8 m

** Significant at 1 per cent level

Here also a patterned variation cannot be suggested. Maximum potassium content was shown at a lag distance of 72 m.

But in I-A and II-B plantations the variation of available potassium content between lag distance is found to be non-significant and worth no consideration (Table 1.6 & 1.9).

The significance of spatial variability of soil available potassium, as other nutrients have, can be understood from the range of values for coefficient of variation it exhibited. The CV ranges from 13.7 to 75.5 per cent and is suggestive of a possible greater spatial dependence. Pahm (1967) obtained a valuable observation that available potassium was subjected to considerable degree of spatial variability with a CV of 30 per cent. He attributed this variation to be due to different degrees of soil management. But Beckett and Webster (1971) happened to have a still higher CV of 70 per cent for soil available potassium which is very close to what is obtained in this study in III plantation.

d. Calcium

Appreciable variation in available calcium content in soil between different lag distances is recorded by results of analysis of soil samples from I-B, II-A, II-B and III plantations except the I-A plantation.

The I-A plantation shows a range of calcium from 0.030 to 0.068 Cmol(p^+) kg^{-1} soil with a CV of 29.5 per cent and highest value for calcium at a lag distance of 48 m from the top (Table 1.6).

In the case of I-B plantation, the variability is much significant, but shows a decrease in calcium with increase in lag distance from top (Table 1.7). Highest status of 0.078 Cmol(p^+) kg^{-1} soil is registered at a distance of 16 m whereas the lowest 0.018 Cmol(p^+)kg^{-1} soil is found at 64 m down the slope from the top of the plantation. The plantation shows a CV of 10.4 per cent for available calcium.

II-A and II-B plantation also have significant variation and spatial dependence for calcium. In the II-A plantation and II-B plantation, the general trend is to have greater values at the bottom of the

Table 1.9 Chemical properties of soil over different lag distances in II-B plantation - available nutrients, organic carbon and pH

Lag distances	Available nutrients					Organic carbon (per cent)	pH
	Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calicum C.mol(p^+)kg^{-1}	Magnesium C.mol(p^+)kg^{-1}		
1h	5.250	221.183	100	0.018	0.025	1.730	5.47
2h	5.320	183.450	126.667	0.024	0.022	2.103	6.23
3h	5.542	264.402	166.667	0.013	0.021	1.901	4.98
4h	5.927	279.708	160	0.036	0.028	1.963	4.52
5h	6.008	228.67	173.330	0.073	0.029	2.004	4.67
F	11.6705**	1.2996	0.7036	5.0416**	1.7874	1.3055	15.1805*
SE	0.1011	33.262	37.0225	0.0107	0.0028	0.1211	0.1785
CD	0.2946	96.901	107.8569	0.0312	0.0080	0.3527	0.1599
Range	5.250-6.008	183.450-279.708	100-173.330	0.013-0.073	0.021-0.029	1.730-2.103	4.52-6.2
CV (%)	1.8	14.1	25.5	32.8	11.04	6.2	3.5

h = 8 m

** Significant at 1 per cent level

plantation (Table 1.8 & 1.9). They are characterised by coefficients of variation of 22.7 and 32.4 per cent respectively.

Different lag distances greatly differ among themselves in their calcium status in the III plantation with a downward increase as the lag distance increases (Table 1.10). Lowest amount of calcium is observed at the top-most point (0.021 Cmol$(p^+)kg^{-1}$ soil) while the highest value (0.032 Cmol$(p^+)kg^{-1}$) for the same is obtained at the bottom at a lag distance of 56 m.

Significant and considerable variations contributed by spatial differences in occurrence for available calcium in soil showed by many of the results of study is in accordance with the studies by Beckett and Webster (1971). They obtained a greater spatial variability for available calcium with a CV of 30 per cent. Exchangeable calcium concentration and quantities were found to be the most variable by Courtin et al (1983) also.

e. Magnesium

Soil sample analysis reveals considerable variation in available magnesium content in the soils of plantations I-A, I-B and II-A unlike the other two plantations viz. II-B and III plantations.

The average content of magnesium with a CV of 6.9 per cent is between 0.065 C.mol$(p^{+})kg^{-1}$ soil and 0.137 C.mol$(p^{+})kg^{-1}$ soil in the I-A plantation which is characterised by higher status at the upper rows (Table 1.6). Difference in lag distance shows greater influence in available magnesium content.

The I-B plantation also shows a decreased magnesium level down the slope with higher values at the upper reaches (Table 1.7). Highest magnesium content is obtained at grid points 8 m away from top.

Variation in available magnesium content in the II-A plantation ranges between 0.018 and 0.051 C.mol$(p^{+})kg^{-1}$ soil with a CV of 15.3 per cent but do not show any pattern in variation (Table 1.8).

The II-B and III plantations are found to be having no significant variation in magnesium content among different rows though they had a range of

0.021 - 0.029 $C.mol(p^{+})kg^{-1}$ soil with a CV of 11.04 per cent and 0.102 -1.728 $C.mol(p^{+})kg^{-1}$ soil respectively (Table 1.9 & 1.10) with a CV of 29.8 per cent.

f. Organic carbon

The behaviour of soil organic carbon is to show significant spatial variability in their status in many of the plantations viz. I-B, II-A and III plantations. But the plantations I-A and II-B do not differ in organic carbon status between their rows of plants.

I-B plantation shows a gradual decrease in the organic carbon content upto fourth row ie. within a lag distance of 32 m and thereafter gradually increases to a highest value of 2.495 per cent. The plantation gives a CV of 5.7 per cent for organic carbon (Table 1.7)

In the II-A plantation the general trend observed is to give a downward increase in organic carbon content with an increase of lag distance. The organic carbon content varies between 1.100 and 2.117 with a CV of 10.5 per cent (Table 1.8).

Table 1.10 Chemical properties of soil over different lag distances in III plantation - available nutrients, organic carbon and pH

Lag distances	Available nutrients					Organic carbon (per cent)	pH
	Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}	Calcium C.mol(p^+)kg^{-1}	Magnesium C.mol(p^+)kg^{-1}		
1h	5.145	150.397	308	0.021	0.107	2.59	4.7
2h	5.157	80.723	456.667	0.024	0.102	3.49	5.3
3h	5.250	69.780	316.667	0.024	0.089	3.21	5.15
4h	5.518	106.182	286.667	0.030	1.728	3.28	4.92
5h	5.810	110.405	376.667	0.030	0.111	3.53	4.37
6h	5.742	64.038	300	0.030	0.103	2.78	4.52
7h	5.868	116.783	510	0.032	0.110	2.83	4.10
8h	6.242	103.052	540	0.028	0.114	2.44	4.0
9h	6.078	86.112	913.333	0.031	0.115	2.73	4.25
F	4.5508**	2.4550*	2.4771*	9.6663**	1.000	3.466**	6.3021
SE	0.1883	17.087	567.746	0.0012	57.5496	0.2146	0.1834
CD	0.5382	48.836	162.269	0.0030	16.448	0.6133	0.5241
Range	5.145-6.242	64.038-150.397	286.667-913.333	0.021-0.032	0.102-1.728	2.44-3.53	4-5.3
CV (%)	3.3	17.3	75.4	4.2	29.8	7.2	4.0

h = 8 m

* Significant at 5 per cent level

** Significant at 1 per cent level

Organic carbon renders a significant variation in the III plantation also but is characterised by higher values usually in the upper reaches (Table 1.10). The average content is found to be between 2.44 and 3.53 per cent with a CV of 7.2 per cent.

Results obtained shows little variation in space for organic carbon in I-A and II-B plantation. Their average content is found to vary between 1.105 and 1.790 and 1.730 and 2.103 per cent respectively (Table 1.6 & 1.9) and their respective CV values are found to be 10.6 and 6.2 per cent. The extent of spatial variability is to varying degrees for each plantation under study. Some show significant variation which in others the variations are non-significant. Dahiya et al (1984 b) found less variations for organic carbon but Mueller et al (1985) could suggest a high short rage variability for the same due to spatial difference.

g. Soil reaction (pH)

Marked variation is obtained when results of soil sample analysis were studied for all the plantations. It indicates much spatial dependence for pH of soil over distances along a slope.

The I-A plantation gives a soil reaction ranging from 4.75 to 5.61 with a CV of 3 per cent. The highest pH is observed in the sixth row of the plantation.(Table 1.6)

The I-B plantation also follows the same trend with a range of 4.96 -6.03 with a CV of 2.9 per cent for pH. But higher pH values are visible in the middle and lower reaches (Table 1.7).

Greater variability in pH is visible in II-A and II-B plantations over different lag distances showing its nature of spatial dependence (Table 1.8 & 1.9). A highest pH of 4.98 is found in the II-A plantation while the maximum pH showed by II-B plantation is 6.23.

The soil reaction results obtained from soil samples of III plantation are found to vary between 4 and 5.3 with a CV of 4 per cent and significant variation exists between different rows along the slope.

The variability of soil reaction in these five plantations was characterised by a CV of the range of 2.9 - 4.0. Similar results were presented by Campbell (1978) in his study of silty clay loam soil in Kansas, USA where he obtained a CV of 3 per cent. However Courtin et al (1983) found that pH was less variable.

PLANT ANALYSIS

a. Plant nitrogen

Plant sample analysis from marked trees near the grid points reveals that the extent of variation of plant nitrogen, generally is not as wide as soil nitrogen. All the plantations under study except II-A plantation, showed little variability.

I-A plantation has highest plant nitrogen content of 6.5 per cent in the trees of the tenth row, but the range appears to be within 2.9 and 7.1 per cent (Table 1.11).

I-B plantation gives a range of 3.3 - 3.6 per cent with a CV of 5.6 per cent for plant nitrogen and exhibits no difference between the rows of plantations or lag distances (Table 1.12).

However, marked spatial variation is obtained in the II-A Plantation with a range of values between 2.4 and 3.0 per cent with a CV of 2.7 per cent for plant nitrogen. The observed behaviour for plant nitrogen is to show a general downward increase in level with an increase in lag distances along the slopes (Table 1.13).

Table 1.11 Nutrient contents in plant and girth of trees over different lag distances in I-A plantation

Lag distances	Plant nutrient contents					Girth cm
	Nitrogen per cent	Phosphorus per cent	Potassium per cent	Calicum per cent	Magnesium per cent	
1h	3.1	0.161	1.420	1.350	0.305	8.13
2h	3.0	0.176	1.524	1.580	0.329	8.44
3h	3.0	0.242	1.384	1.228	0.339	8.69
4h	3.2	0.208	1.255	1.410	0.303	8.08
5h	2.9	0.218	1.216	1.421	0.347	8.88
6h	3.3	0.263	1.211	1.480	0.312	8.88
7h	3.5	0.185	1.279	1.466	0.296	9.44
8h	3.2	0.325	1.241	1.329	0.317	8.54
9h	6.5	0.299	1.220	22.946	0.319	8.56
10h	7.1	0.286	1.084	1.334	0.318	9.23
F	0.9462	3.9950	2.9377	1.0102	0.3321	1.8982
SE	0.0159	0.0279	0.0761	6.7797	0.0279	0.3167
CD	0.0446	0.0779	0.2126	18.936	0.0779	0.8958
Range	2.9-7.1	0.161-0.325	1.084-1.524	1.228-22.946	0.296-0.347	8.08-9.44
CV	41.2	11.8	5.9	191	8.7	3.65

h = 8 m

** Significant at 1 per cent level

Plant nitrogen varies between 2.6 and 3.2 per cent with a CV of 5.8 per cent in II-B plantation (Table 1.14) and 2.8 and 3.2 per cent with a CV of 6.02 per cent in III plantation (Table 1.15). Yet both of them lack significant spatial variability for plant nitrogen.

b. Plant phosphorus

Phosphorus content of plants shows significant variability only in plantations I-A and I-B. Other plantations register least spatial variation for plant phosphorus.

The average contents of phosphorus in I-A and I-B plantations are found to be within 0.161 and 0.325 per cent with a CV of 11.8 per cent and 0.252 and 0.455 per cent with a CV of 10.3 per cent respectively. The phosphorus content though varies over lag distances, no pattern can be arrived at (Table 1.11 & 1.12).

Least spatial variation is obtained in II-A, II-B and III plantations over lag distances. They are characterised by phosphorus contents within 0.257-0.452 per cent with a CV of 12.1 per cent, 0.279-0.384 per cent with a CV of 8 per cent and 0.133-0.258 per cent with a CV of 19 per cent respectively (Table 1.13, 1.14 & 1.15).

Table 1.12 Nutrient contents in plant and girth of trees over different lag distances in I-B Plantation

Lag distances	Nutrient contents in plant					Girth cm
	Nitrogent per cent	Phosphorus per cent	Potassium per cent	Calcium per cent	Magnesium per cent	
1h	3.5	0.275	0.998	1.099	0.240	8.44
2h	3.6	0.252	0.011	1.169	0.255	8.75
3h	3.5	0.405	1.111	1.179	0.264	8.81
4h	3.4	0.390	1.188	1.446	0.319	9.25
5h	3.6	0.360	0.793	0.936	0.200	9.19
6h	3.4	0.424	1.055	1.243	0.309	9.19
7h	3.4	0.391	1.075	1.245	0.249	9.63
8h	3.3	0.455	1.156	1.291	0.245	9.88
9h	3.4	0.419	1.191	1.225	0.192	10.50
F	0.4360	3.1149**	4.7085**	2.7685*	5.6819**	4.1512**
SE	0.0017	0.0387	0.0572	0.0835	0.0178	0.3098
CD	0.0049	0.1095	0.1618	0.2363	0.0504	0.8763
Range	3.3-3.6	0.252-0.455	0.793-1.191	0.936-1.446	0.192-0.319	8.44-10.50
CV	5.6	10.3	5.4	6.9	7.1	3.3

h = 8 m
** Significant at 1 per cent level
* Significant at 1 per cent level

c. Plant potassium

Almost all the plantations show significant variability for plant potassium in samples taken from different rows of plants separated by different lag distances. II-B plantation alone shows a distinction from the rest in having least variation.

I-A and I-B plantations give a range of 1.084-1.524 per cent with a CV of 5.9 per cent and 0.793-1.191 per cent with a CV of 5.4 per cent respectively for plant potassium and show effective spatial difference among different rows (Table 1.11 & 1.12).

Plant potassium exists in the range of 0.558 - 1.178 per cent with a CV of 4.9 per cent in II-A plantation and 0.462-1.042 per cent with a CV of 11.03 per cent in the III plantation. These two plantations are marked by a gradual increase in potassium content down the slopes (Table 1.13 & 1.15).

But the potassium content in plant generally found within 1.202 and 1.263 per cent with a CV of 5.5 per cent, gives no significant variation in II-B plantation (1.14).

Table 1.13 Nutrient contents in plant and girth of trees over different lag distances in II-A Plantation

Lag distances	Nutrient contents in plant					Girth cm
	Nitrogen per cent	Phosphorus per cent	Potassium per cent	Calcium per cent	Magnesium per cent	
1h	2.4	0.332	0.558	0.937	0.298	57.75
2h	2.6	0.257	0.693	1.007	0.329	57.08
3h	2.8	0.291	0.650	1.170	0.359	53.33
4h	2.8	0.359	0.765	1.020	0.283	52.92
5h	3.0	0.372	0.867	1.035	0.272	53.75
6h	2.9	0.332	0.967	0.995	0.309	58.67
7h	3.0	0.358	1.178	0.938	0.257	57.92
8h	2.9	0.329	0.010	1.150	0.317	58.58
9h	3.0	0.452	1.017	1.237	0.387	63.25
F	7.8198**	1.7303	23.5466**	1.2790	1.0913	2.1574
SE	0.0007	0.0413	0.04195	0.0940	0.0398	2.2378
CD	0.0021	0.1181	0.1199	0.2687	0.1136	6.3960
Range	2.4-3.0	0.257-0.452	0.558-1.178	0.937-1.237	0.257-0.387	52.92-63.25
CV	2.7	12.1	4.9	8.9	12.7	3.9

h = 8 m

** Significant at 1 per cent level

d. Plant calcium

Only two plantations viz. I-B and II-B show any variation in calcium content in plants over different lag distances. However, very significant variability is observed only with II-B plantation.

Calcium content varies between 0.936 and 1.446 per cent with a CV of 6.9 per cent I-B plantation and 0.560 and 0.735 per cent with a CV of 3.9 per cent in II-B plantation (Table 1.12 & 1.14).

The II-B plantation shows a gradual increase in plant calcium down the slopes.

Very little variation is found in other plantations viz. I-A, II-A and III plantations and difference among percentage of calcium in plant samples are negligible.

e. Plant magnesium

Out of the five plantations under study, considerable variability for plant magnesium is observed only from I-B and III plantations. Others proved that

Table 1.14 Nutrient contents in plants and girth of trees over different lag distances in II-B plantation

Lag distances	Nutrient contents in plant					Girth cm
	Nitrogen per cent	Phosphorus per cent	Potassium per cent	Calcium per cent	Magnesium per cent	
1h	2.6	0.279	1.202	0.560	0.356	51.63
2h	2.7	0.306	1.228	0.630	0.376	53.17
3h	3.2	0.308	1.225	0.670	0.392	48.67
4h	3.0	0.384	1.123	0.705	0.399	64.75
5h	3.0	0.350	1.263	0.735	0.407	58.42
F	2.0252	2.5674	0.7096	6.7017**	1.8465	2.1512
SE	0.0017	0.0259	0.0669	0.0263	0.0146	4.3063
CD	0.0049	0.0754	0.1948	0.0767	0.0427	12.5454
Range	2.6-3.2	0.279-0.384	1.123-1.263	0.560-0.735	0.356-0.407	48.67-64.75
CV	5.8	8.0	5.5	3.9	3.8	7.8

h = 8 m

** Significant at 1 per cent level

plant magnesium varies least significantly among different spatially separated samples.

In I-B and III plantations, the average content of magnesium is found to be in the range of 0.192 - 0.319 per cent with a CV of 7.1 per cent and 0.369 - 0.618 per cent with a CV of 8.8 per cent respectively. However, a generalised pattern of variation cannot be observed in either of the two (Table 1.12 & 1.15).

The magnesium content in plant samples however does not vary much in I-A, II-A and II-B plantations but more or less the same (Table 1.11, 1.13 and 1.14).

f. <u>Girth of trees</u>

Distinguishable spatial variation for girth of trees can be seen only in plantations I-B and III. Other plantations do not exhibit appreciable variability for girth.

8.08 - 9.44 cm is the variability range of girth in I-A plantation with a CV of 3.65 per cent which is negligible (Table 1.11).

But in I-B plantation a general increase in girth is observed, which indicates a significant difference

Table 1.15 Nutrient contents in plants and girth of trees over different lag distances in III plantation

Lag distances	Nutrient contents in plants					Girth cm
	Nitrogen per cent	Phosphorus per cent	Potassium per cent	Calcium per cent	Magnesium per cent	
1h	3.1	0.258	0.462	1.317	0.522	42.08
2h	3.0	0.171	0.793	0.992	0.402	44.75
3h	3.1	0.157	0.982	1.135	0.459	46.83
4h	2.8	0.249	0.832	1.193	0.369	45.38
5h	3.0	0.252	0.935	1.062	0.443	41.92
6h	3.0	0.137	0.975	1.215	0.438	43.17
7h	2.8	0.254	1.042	1.355	0.475	51.75
8h	3.2	0.133	0.978	1.323	0.506	52.17
9h	3.0	0.216	0.908	1.270	0.618	50.17
F	0.4281	1.9100	3.2297	0.6335**	3.0803**	4.867**
SE	0.0018	0.0385	0.0971	0.1567	0.0414	1.8213
CD	0.0052	0.1100	0.2777	0.4477	0.1184	5.2055
Range	2.8-3.2	0.133-0.258	0.462-1.042	0.992-1.355	0.369-0.618	41.92-52.17
CV	6.02	19	11.03	13	8.8	3.9

h = 8 m

** Significant at 1 per cent level

among plants with girths from 8.44 to 10.50 cm showing a CV of 3.3 per cent (Table 1.12).

Girth variation among plants in different rows is from 52.92 to 63.25 cm in II-A and 48.67 to 64.75 cm in II-B plantations with CVs of 3.9 and 7.8 per cent respectively. But III plantation shows a lower value of 41.92 cm for girth, though it is much older than II-A and II-B plantations. The highest girth recorded in III plantation is 52.17 cm showing a CV of 3.9 per cent (Table 1.15).

2. Correlation between the girth of trees and nutrients in plant and soil at different lag distances

Correlation studies have been conducted between nutrients in soil and plant, and the girth of trees for each plantation. It has been observed that linear regression equation linking the girth of trees and nutrients brought about relationship of spatial variability of nutrients with girth of the tree prior to tapping.

I-A plantation

It may be seen from Table 2.1 that significant correlation were obtained between plant nitrogen and plant calcium, and between soil available nitrogen and plant phosphorus (r = 0.1829 & 0.2172) in I-A plantation. There is correlation between soil available magnesium and organic carbon content also, but it is not much significant (r = 0.2172). It can also be inferred that plant nitrogen is more significantly correlated to plant calcium than soil available magnesium to organic carbon content of the soil studied.

No positive relationship can be obtained for girth of trees with the nutrients in I-A plantation.

I-B plantation

From table 2.2 it is evident that strong positive correlations existed in I-B plantation between plant calcium and magnesium, plant calcium and potassium, soil available magnesium and calcium and organic carbon content and soil available nitrogen (r = 0.2319 & 0.3017). But girth is strongly and positively correlated only to organic carbon status of the I-B plantation among the

Table 2.1 Inter-correlation among nutrients in soil and plant and the girth of the trees - I-A plantation.

	Plant					Soil available					
	Nitrogen	Phos-phorus	Potassium	Calcium	Magnesium	Nitrogen	Phospho-rus	Potassium	Calcium	Magnesium	Organic carbon
Plant nitrogen											
" Phosphorus	0.1180										
" potassium	-0.0725	-0.0792									
" Calcium	0.6354**	0.0764	-0.1665								
" magnesium	-0.0162	-0.0998	-0.1552	0.0199							
Soil available nitrogen	0.1558	0.3975**	-0.3935	0.0631	-0.0476						
" phosphorus	-0.1753	-0.1911	0.1695	-0.1319	-0.0475	-0.2980					
" potassium	-0.1447	0.1546	0.0507	-0.1058	0.1008	0.1927	-0.0743				
" calcium	0.0302	-0.1890	-0.3747	0.0351	0.1184	0.0810	0.0036	-0.2266			
" magnesium	-0.0978	-0.1021	0.1993	-0.0874	-0.0105	-0.3159	0.0683	-0.0737	-0.0608		
Organic carbon	-0.1000	0.0929	0.0219	0.0462	0.0557	-0.0159	0.0560	0.1025	-0.0209	0.2377*	
girth	-0.1138	-0.0694	-0.0512	-0.0815	0.1336	0.2144	-0.0965	0.0772	0.0073	-0.0972	-0.0715

* Significant at 5 per cent level
** Significant at 1 per cent level

twelve properties studied. Plant potassium also shows positive relationship with plant magnesium. But not as strongly as it does with plant calcium. It has a possible relation with girth of trees also. It is soil available nitrogen content of the plantation which shows positive relationships with greater number of other variables under study.

A strong positive correlation can be demonstrated by the plantation between soil available nitrogen and organic carbon content of soil. However, the correlations between available nitrogen of soil and plant phosphorus content and girth of trees are not as significant as that existed between organic carbon and soil available nitrogen ($r = 0.2319$).

In this plantation, strong positive relationshi can be expected between plant calcium and magnesium and soil available calcium and magnesium. The much more significant relation between organic carbon and available soil nitrogen, and between organic carbon and girth of trees, might have contributed to a positive relationship between girth of trees and soil available nitrogen as evident from the taple.

Table 2.2 Inter-correlation among nutrients in soil and plant and the girth of the trees - I-B plantation.

	Plant					Soil available					
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Organic carbon
Plant nitrogen											
" Phosphorus	0.1678										
" Potassium	0.0177	0.1833									
" calcium	0.0540	0.1172	0.5262**								
" magnesium	0.0033	-0.0733	0.2505*	0.5001							
Soil available – nitrogen	0.2301	0.2941*	0.1120	0.1883	-0.0455						
" phosphorus	0.1894	-0.0643	0.1455	0.1273	0.1277	-0.0525					
" potassium	0.2197	-0.1667	0.0261	0.0986	0.1626	-0.4382	0.0546				
" calcium	0.2212	-0.2896	-0.1135	-0.1259	-0.0217	-0.4965	-0.0399	0.2705*			
" magnesium	0.0413	-0.3993	-0.1056	-0.0877	0.0283	-0.4931	-0.1496	0.2741*	0.4450**		
Organic carbon	-0.1162	0.1028	-0.0395	-0.0181	-0.1830	0.4412**	-0.2074	-0.2696	-0.2968	-0.2200	
girth	-0.1660	0.0747	0.2349*	0.1686	-0.0399	0.2851*	0.0322	-0.1849	-0.2377	-0.3173	0.3277

* Significant at 5 per cent level
** Significant at 1 per cent level

Linear regression equation obtained between girth and different nutrients having positive correlation with girth explains its relationship with spatial variability of the nutrients.

Plant potassium (X) and girth (Y) exhibits a relation of $Y = 7.84 + 1.37X$ and suggests that variability in plant potassium would cause a variability in girth corresponding to the relation.

Soil available nitrogen (X) and girth (Y) establish between themselves a relationship of $Y = 3.65 + 0.49X$. This brings out a direct bearing of soil available nitrogen on the girth of trees.

Similarly a relationship of $Y = 7.76 + 0.75X$ can also be established between the girth and organic carbon content of soil.

<u>II-A plantation</u>

II-A plantation shows significant correlations between some of the properties. The correlations existed between plant nitrogen, and plant potassium and available soil nitrogen are strong (Table 2.3) while those that existed between plant nitrogen and calcium, and plant nitrogen and organic carbon are not so significant ($r = 0.2732$ & 0.3541).

Table 2.3 Inter-correlation among nutrients in soil and plant and the girth of the trees - II-A plantation.

	Plant: Nitrogen	Plant: Phosphorus	Plant: Potassium	Plant: Calcium	Plant: Magnesium	Soil available: Nitrogen	Soil available: Phosphorus	Soil available: Potassium	Soil available: Calcium	Soil available: Magnesium	Organic carbon
Plant nitrogen											
" phosphorus	0.1924										
" potassium	0.6327**	0.1871									
" calcium	0.3232*	0.0463	0.0554								
" magnesium	0.2134	-0.2456	-0.0805	0.5333**							
Soil available nitrogen	0.5709**	0.3348*	0.6763**	0.0984	-0.1008						
" phosphorus	-0.6360	-0.1559	-0.5107	-0.2298	0.0086	-0.5077					
" potassium	0.1462	-0.1544	0.2279	0.1410	0.4380**	0.2741*	-0.1211				
" calcium	0.0107	-0.2527	0.1901	-0.2078	-0.1709	0.2189	-0.0385	-0.0297			
" magnesium	0.1748	-0.0393	0.0770	0.0726	-0.0029	0.3113*	-0.1919	0.0509	0.1536		
Organic carbon	0.3324*	0.0967	0.3419*	-0.0347	0.2518	0.4215**	-0.3027	0.5114**	-0.0154	0.0318	
girth	0.0685	0.2104	0.2281	0.0330	0.1790	0.1734	0.0524	0.1489	0.0137	-0.2240	0.2183

* Significant at 5 per cent level
** Significant at 1 per cent level

Soil available nitrogen, though had a strong positive relationship with plant potassium, its relationship with plant phosphorus is not so strong. In this plantation also plant calcium is strongly correlated to plant magnesium, but similar relationship does not exist between soil available calcium and magnesium. However, soil magnesium shows some extent of positive relationship with soil available nitrogen

Soil available potassium exhibits strong correlation only with plant magnesium and organic carbon content of soil, but it has considerable relationship with soil available nitrogen also.

II-A plantation is characterised by a strong positive correlation between soil available, nitrogen and organic carbon content. Eventhough the relationship between organic carbon with plant nitrogen and plant potassium is considerably positive, it is not much significant.

Another important finding obtained through correlation studies is that the girth of trees in II-A plantation does not show positive relationship with any of the twelve properties studied.

II-B plantation

Table 2.4 brings about different types of relationships existed between plant and soil chemical properties and girth of trees of the II-B plantation under study. From the table it can be understood that soil available nitrogen and girth of trees related positively to a marked extent. No other characters than soil available nitrogen exhibits such an influence on girth.

Soil available nitrogen exhibits a strong relationship with calcium content of the plant also, but it has only a much less influence on plant phosphorus as evident from the table.

The nitrogen content of plant is shown to be significantly correlated to the magnesium content whil its relationship with soil available phosphorus is only to a small extent.

A less significant correlation can also be seen between plant phosphorus and plant magnesium contents.

The correlation between soil available potassium and plant potassium is feeble unlike soil calcium and

Table 2.4 Inter-correlation among nutrients in soil and plant and the girth of the trees - II-B plantation.

	Plant					Soil available					
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Organic carbon
Plant nitrogen											
" phosphorus	0.2549										
" potassium	0.0969	-0.3902									
" calcium	0.1290	0.1951	-0.2684								
" magnesium	0.4645**	0.3818*	0.1273	0.1456							
Soil available nitrogen	0.0893	0.4059*	0.0183	0.5049**	0.2929						
" phosphorus	0.4009*	0.0861	0.0430	0.2529	-0.0047	0.1971					
" potassium	0.0225	-0.1294	0.3670*	0.1086	0.2681	0.3572*	-0.1798				
" calcium	0.2385	0.0622	-0.1615	0.5266**	0.1896	0.3357	0.1457	-0.1430			
" magnesium	-0.2304	0.0625	-0.2998	0.3421	-0.3215	0.2049	-0.0778	0.0439	0.2283		
Organic carbon	-0.0226	0.4127*	0.0111	0.1580	0.4059*	0.2098	-0.1898	0.1417	0.0774	-0.1970	
Girth	-0.2441	0.1779	-0.1742	0.2176	0.0211	0.4558**	0.0310	0.1204	0.2362	0.2316	0.1783

* Significant at 5 per cent level
** Significant at 1 per cent level

plant calcium which establishes a greater and stronger relationship between them. Soil available potassium is also related with soil available nitrogen.

The organic content of soil is characterised by only a less significant relationship with plant phosphorus and magnesium contents.

Linear regression equation $Y = 19.23 - 13.3X$ relates the girth of the trees (Y) and the soil available nitrogen (X) in the II-B plantation. The relation, however, reveals a negative influence of soil available nitrogen on girth, unlike other plantations.

III Plantation

Tree girths registers though not much significantly, positive correlation with some of the properties studied viz. plant potassium, soil available nitrogen and soil available calcium of III plantation (Table 2.5).

Plant nitrogen shows some relationship with plant calcium only ($r = 0.2732$). But plant calcium registers strong correlation with plant magnesium and soil magnesium contents ($r = 0.2732$ and 0.3541).

Table 2.5 Inter-correlation among nutrients in soil and plant and the girth of the trees - III plantation.

	Plant					Soil available					
	Nitrogen	Phospho-rus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Organic carbon
Plant nitrogen											
" phosphorus	0.2688										
" potassium	0.1598	-0.0733									
" calcium	0.2954*	0.1544	-0.1852								
" magnesium	0.0404	0.0190	-0.1985	0.4302**							
Soil available nitrogen	0.0368	-0.0021	0.3690**	-0.0914	0.1012						
" phosphorus	0.1378	0.2184	0.0437	0.1461	0.1296	-0.0961					
" potassium	0.0033	0.0195	-0.2689	0.1395	0.3371*	-0.1366	0.3038*				
" calcium	-0.1409	-0.0491	0.4479**	0.0996	0.0193	0.3909**	-0.0802	-0.3090			
" magnesium	0.1951	0.2038	-0.0449	0.0973**	0.4273**	0.2205	0.2963*	0.3114*	0.0982		
Organic carbon	0.0600	0.1946	-0.0112	-0.1062	-0.3332	-0.0808	-0.2925	-0.2644	0.0733	-0.2524	
Girth	-0.1347	-0.0877	0.2809*	0.1060	0.1430	0.2816*	-0.0886	-0.0777	0.3409*	0.2237	-0.1096

* Significant at 5 per cent level
** Significant at 1 per cent level

Much significant relationship exists between soil available nitrogen and plant calcium and also between soil available nitrogen and soil available calcium.

From the table it is also evident that better correlation existed between plant potassium and soil available calcium.

Less significant are the relationships of soil available potassium with magnesium contents of plants and soil, and soil available phosphorus.

In this plantation, the magnesium contents of both plant and soil are strongly related to each other, but the relationship existed between soil magnesium and potassium levels is not much strong.

A linear regression equation of $Y = 30.43 + 2.84X$ explained the relation of spatial variability of soil available nitrogen (X) with the girth of trees (Y) prior to tapping.

3. Semi-variances; Semi-variogram and Nutrient management models.

Semi-variances have been used as the more suitable statistical parameter to quantify spatial variability. This enables us to relate quantitatively the variation of the properties under study, with different lag distances. Semi-variance values for each property at different lag distances were obtained in the present study by such a statistical approach. Semi-variograms and nutrient management models have also been prepared based on the semi-variance of the soil properties.

I-A plantation

Table 3.1 shows semi-variance for different lag distances with respect to each property studied in I-A plantation. These values follow more or less quadratic regression models excepting some, which show linear relations with lag distances.

Plant nitrogen and plant magnesium contents in I-A plantation shows semi-variance values (Y) for different lag distances (X), obeying quadratic regression equations $Y = 0.00184 - 0.00044X + 0.00009X^2$ and $Y = 0.00575 - 0.00066X + 0.00016X^2$ respectively.

Similarly, total calcium and magnesium of soil and the girth of trees in the I-A plantation are found to possess semi-variances values which undergo quadratic regression models more effectively. It is observed that their respective models viz. $Y = 0.7170-0.0024X + 0.0059X^2$; $Y = 0.5788-0.0927X +0.0133X^2$ and $Y = 0.6176-0.0217X + 0.0102X^2$ are strongly significant.

Among soil available nutrients, only the available potassium exhibits a linear model of $Y = 40392.24-2973.77X$ for semi-variance while others follow quadratic models.

Soil available nitrogen and phosphorus gives regression models such as $Y = 0.2650-0.0920X-0.0123X^2$ and $Y = 349001-225850.4X-29355.2X^2$ respectively, while those of the soil available calcium and magnesium are $Y = 0.00146-0.000009X-0.00002X^2$ and $0.00072 + 0.00094X-0.000019X^2$ respectively.

Semi-variograms are obtained on plotting the semi-variance against lag distance, which are in conformity with the models discussed.

Table 3.1 Semi-variances $\gamma(h)$ of properties at grid points separated by different lag distances - I-A plantation.

Lag distances	Plant nutrient contents					Soil available nutrients				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1h	0.00156	0.0075	0.047	407.5	0.0046	0.26	35225	28244.2	0.00118	6.3×10^{-4}
2h	0.00115	0.006	0.056	227.39	0.0059	0.45	28519	35200	0.00137	9.6×10^{-4}
3h	0.0014	0.0058	0.059	258.27	0.0057	0.54	32238.8	37996	0.00146	9.9×10^{-4}
4h	0.00166	0.0092	0.035	300.47	0.0054	0.45	40516.6	25449	0.00158	6.9×10^{-4}
5h	0.00194	0.0061	0.04	359.1	0.0059	0.35	29154.9	33658.4	0.00104	9×10^{-4}
6h	0.00239	0.0066	0.038	445.03	0.0073	0.35	49890.4	36407.4	0.00011	4.4×10^{-4}
7h	0.00312	0.0094	0.044	584.38	0.0098	0.29	48583.3	6660.8	0.0012	2.8×10^{-4}
8h	0.0044	0.0048	0.039	863.11	0.0105	0.18	72893	12516.4	0.00008	1.5×10^{-4}
9h	0.0052	0.0029	0.052	0.12	0.013	0.15	1006950	13578.4	0.00001	1.4×10^{-4}

	Soil total nutrients					Soil organic carbon	pH	girth
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium			
1h	1.5×10^{-7}	1.1	6.2×10^{-6}	0.69	0.53	0.13	0.19	0.56
2h	1.4×10^{-7}	0.9	7.1×10^{-6}	0.79	0.44	0.13	0.22	0.74
3h	1.5×10^{-7}	1.3	6.6×10^{-6}	0.73	0.35	0.16	0.25	0.66
4h	1.3×10^{-7}	1.4	6.9×10^{-6}	0.83	0.4	0.14	0.22	0.61
5h	1.3×10^{-7}	1.4	9.7×10^{-6}	0.76	0.5	0.09	0.29	0.58
6h	1.7×10^{-7}	1.9	6.6×10^{-6}	0.96	0.57	0.2	0.25	0.94
7h	2.1×10^{-7}	2.2	5.3×10^{-6}	0.89	0.59	0.15	0.14	1.06
8h	2.3×10^{-7}	2.4	4.8×10^{-6}	1.24	0.57	0.22	0.24	1.19
9h	1×10^{-7}	0.9	6.7×10^{-6}	1.09	0.87	0.21	0.4	1.14

Fig.2. Semi-variogram for soil available nitrogen
in I- A plantation.

Fig.3. Semi-variogram for soil available phosphorus
in I- A plantation.

Fig.4. Semi-variogram for soil available potassium
in I-A plantation.

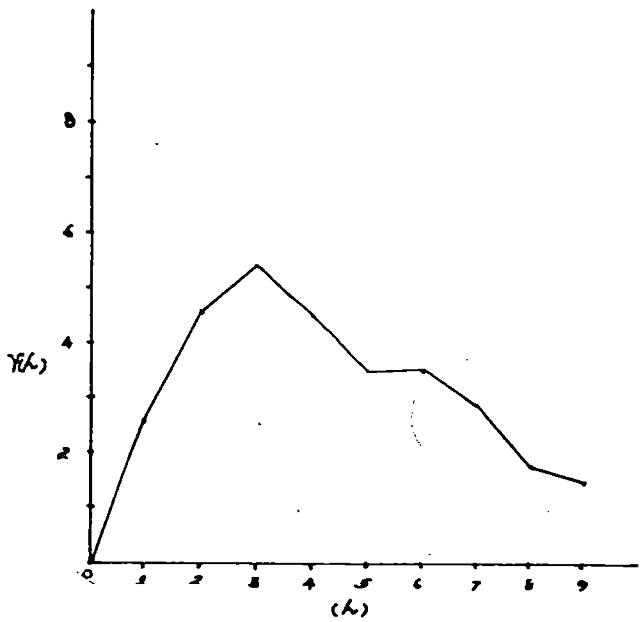

Fig.2

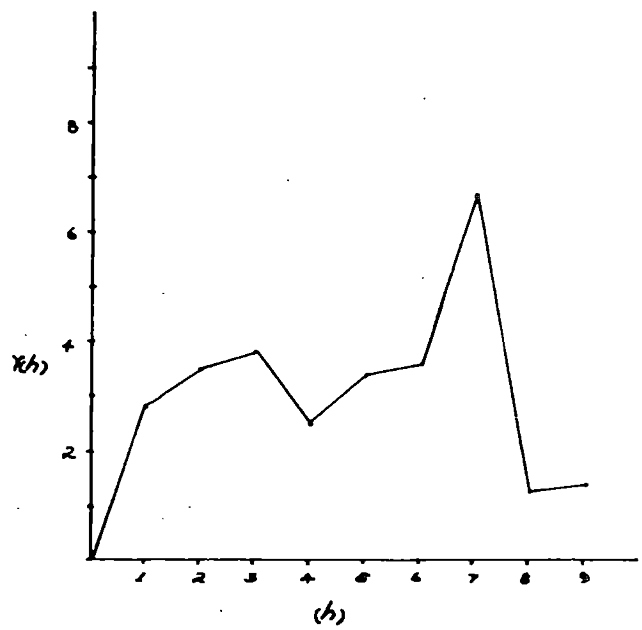

Fig.3

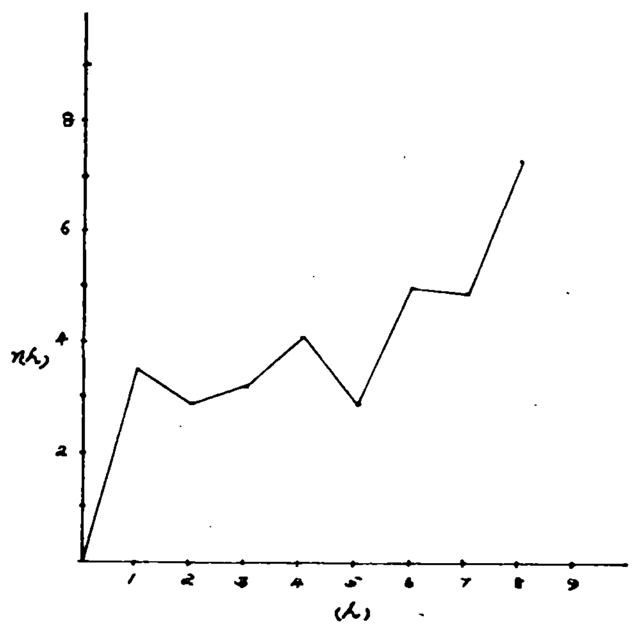

Fig.4

I-B plantation

Table 3.2 gives semi-variance values for different properties studied in the I-B plantation. Some of them exhibit either quadratic or linear relationships with lag distances while others do not follow any regression models.

Linear regression models of $Y = 0.0567-0.0064X$ and $Y = 0.0999-0.0106X$ can be fitted to semi-variance of plant potassium and calcium, while a quadratic regression model of $Y = 0.00420 + 0.00034X - 0.00010X^2$ is more suited to plant magnesium.

It is also seen that total nitrogen and magnesium contents of soil and girth of trees in I-B plantation followed quadratic models such as $Y = 1.10 \times 10^{-7} - 3.52 \times 10^{-8}X + 6.92 \times 10^{-9}X^2$; $Y = 0.0739 + 0.00172X - 0.00076X^2$ and $Y = 0.5796 + 0.1742X - 0.0263X^2$ respectively.

However, the semi-variance for soil available nitrogen prefers to have a linear model with $Y = 0.0836 + 0.0123X$. Soil available phosphorus shows a quadratic regression model for its semi-variogram viz. $Y = 10004.11-2167.18X + 440.06X^2$.

Table 3.2 Semi-variances $\gamma(h)$ of properties at grid points separated by different lag distances - I-B plantation

Lag dist- ances	Plant nutrient contents					Soil available nutrients				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1h	2×10^{-5}	0.013	0.038	0.068	0.0043	0.09	6037.7	9430.4	3.4×10^{-4}	5×10^{-4}
2h	1.5×10^{-5}	0.013	0.047	0.086	0.0039	0.11	8601.9	8799	2×10^{-4}	7.8×10^{-4}
3h	1.4×10^{-5}	0.009	0.045	0.095	0.0055	0.13	10348.2	7574.2	2.2×10^{-4}	6.8×10^{-4}
4h	2.7×10^{-5}	0.013	0.052	0.064	0.0033	0.13	9364.8	7945.5	2.6×10^{-4}	7.5×10^{-4}
5h	2.1×10^{-5}	0.014	0.011	0.036	0.004	0.16	9320.2	5749.2	2.8×10^{-4}	1.1×10^{-4}
6h	3.3×10^{-5}	0.016	0.015	0.025	0.0015	0.14	10057.8	10155.2	3.6×10^{-4}	1.3×10^{-4}
7h	4.5×10^{-5}	0.01	0.008	0.024	0.0013	0.15	14781.4	9600	2.9×10^{-4}	3.8×10^{-4}
8h	2.6×10^{-5}	0.009	0.008	0.019	0.007	0.2	23275.2	3421.9	2×10^{-5}	2.1×10^{-4}

	Soil total nutrients					Soil organic carbon	pH	Girth
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium			
1h	6.2×10^{-8}	9×10^{-7}	2.3×10^{-6}	0.21	0.068	0.11	0.25	0.68
2h	8×10^{-8}	13×10^{-6}	3×10^{-6}	0.24	0.077	0.14	0.2	0.87
3h	7.7×10^{-8}	1.2×10^{-6}	3.2×10^{-6}	0.22	0.082	0.14	0.21	0.92
4h	9.6×10^{-8}	1×10^{-6}	3.5×10^{-6}	0.28	0.076	0.12	0.22	0.91
5h	1×10^{-7}	1×10^{-6}	3.4×10^{-6}	0.18	0.055	0.14	0.28	0.57
6h	1.2×10^{-7}	1.2×10^{-6}	5.7×10^{-6}	0.21	0.046	0.08	0.15	0.76
7h	1.9×10^{-7}	1.3×10^{-6}	3.5×10^{-6}	0.2	0.051	0.1	0.23	0.57
8h	2.9×10^{-7}	1.4×10^{-6}	3.8×10^{-6}	0.1	0.044	0.09	0.07	0.26

Fig.5. Semi-variogram for soil available nitrogen in I-B plantation.

Fig.6. Semi-variogram for soil available phosphorus in I-B plantation.

Fig.7. Semi-variogram for soil available potassium in I-B plantation.

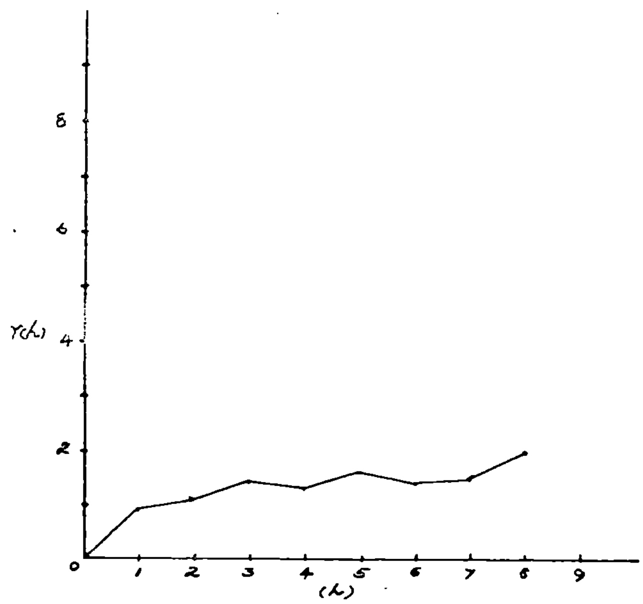

Fig.5

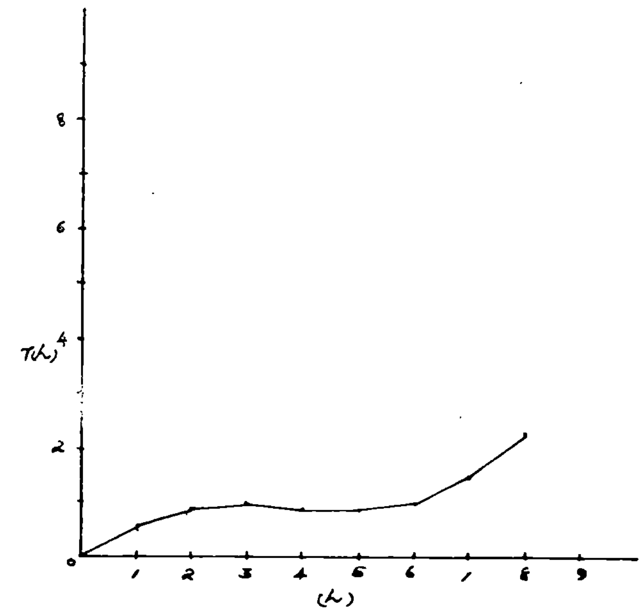

Fig.6

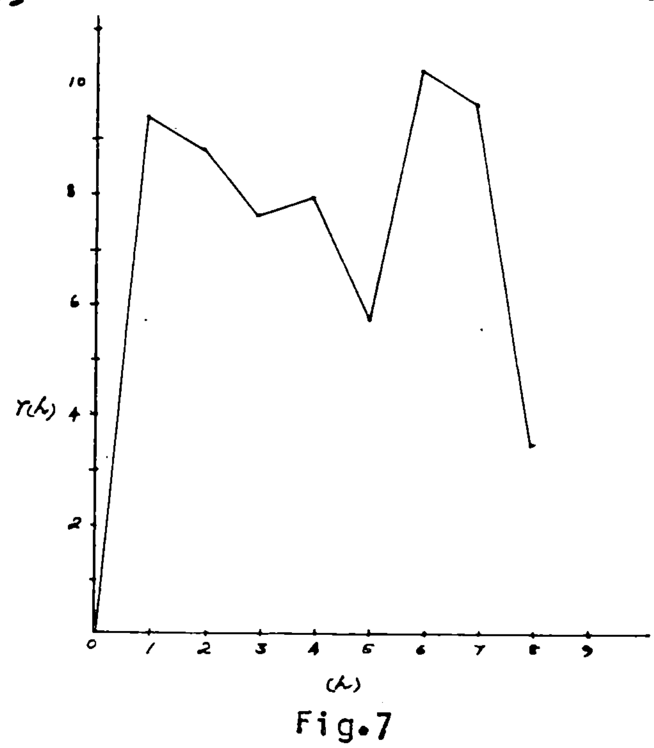

Fig.7

Other nutrient contents and properties including girth of trees fail to show any type of regression models for their semi-variance over lag distances.

II-A plantation

Compared to I-A and II-B plantation, semi-variances for the II-A plantation (Table 3.3) exhibit quadratic and linear regression models for greater number of properties studied.

Semi-variances for plant nitrogen, soil available nitrogen, phosphorus and magnesium, soil total nitrogen, phosphorus and potassium, and girth of trees while showing fitness for quadratic regression models, plant calcium, total calcium and organic carbon contents of soil prefers to follow a linear model.

The quadratic regression models $Y = 3.60 \times 10^{-6} - 5.20 \times 10^{-7}X + 1.24 \times 10^{-7}X^2$ for plant nitrogen, $Y = 0.2020 + 0.0214X - 0.0058X^2$ for soil available nitrogen, $Y = 3898.8 + 4927.6X - 632.5X^2$ for soil available phosphorus, $Y = 2.1550 + 0.2110X - 0.0625X^2$ for soil available magnesium, $Y = 3.24 \times 10^{-8} + 4.89 \times 10^{-10}X - 5.10 \times 10^{-10}X^2$ for soil total nitrogen $Y = 1.86 \times 10^{-6} - 2.64 \times 10^{-7}X + 4.52 \times 10^{-8}X^2$ for total

Table 3.3. Semi-variances $\gamma(h)$ of properties at grid points separated by different lag distances – II-A plantation

Lag distances	Plant nutrient contents: Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Soil available nutrients: Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1h	2.3×10^{-6}	0.011	0.013	0.039	8.1	0.19	8181.3	4.6×10^{-4}	11661.1	2.0
2h	3.6×10^{-6}	0.007	0.017	0.052	8.0	0.22	11467.8	5.6×10^{-4}	9345.1	2.3
3h	4.2×10^{-6}	0.01	0.014	0.046	6.0	0.27	12001.9	2.5×10^{-4}	11090.6	3.0
4h	3.9×10^{-6}	0.006	0.16	0.07	8.3	0.22	13347.4	4.2×10^{-4}	12276.5	1.8
5h	4.1×10^{-6}	0.009	0.012	0.058	0.1	0.16	15401.3	4.7×10^{-4}	15265.3	2.0
6h	3.5×10^{-6}	0.01	0.024	0.064	7.5	0.05	10010.6	4.2×10^{-4}	18129	0.4
7h	5.4 x 10-6	0.019	0.027	0.079	5.5	0.06	4878.3	1×10^{-4}	19161.1	0.3
8h	8.4×10^{-6}	0.004	0.021	0.059	4.7	0.04	4273.12	7×10^{-5}	9711.1	0.3

Lag distances	Soil total nutrients: Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Soil organic carbon	pH	Girth
1h	2.7×10^{-8}	1.5×10^{-6}	7.1	28	0.76	0.15	0.17	26.25
2h	3.7×10^{-8}	1.6×10^{-6}	9.4	34	0.77	0.16	0.19	27.49
3h	3.2×10^{-8}	1.7×10^{-6}	7.9	19	0.46	0.13	0.14	36.86
4h	3×10^{-8}	1.5×10^{-6}	5.9	22	0.62	0.14	0.14	39.52
5h	1.4×10^{-8}	1.6×10^{-6}	6.8	27	0.69	0.17	0.17	39.11
6h	1.6×10^{-8}	1.7×10^{-6}	6.9	30	0.91	0.16	0.19	32.23
7h	1×10^{-8}	2.3×10^{-6}	0.4	1	0.02	0.18	0.12	20.4
8h	6×10^{-9}	2.7×10^{-6}	0.2	1	0.02	0.19	0.02	24-3

Fig. 8. Semi-variogram for soil available nitrogen in II-A plantation.

Fig.9. Semi-variogram for soil available phosphorus in II-A plantation.

Fig.10. Semi-variogram for soil available potassium in II-A plantation.

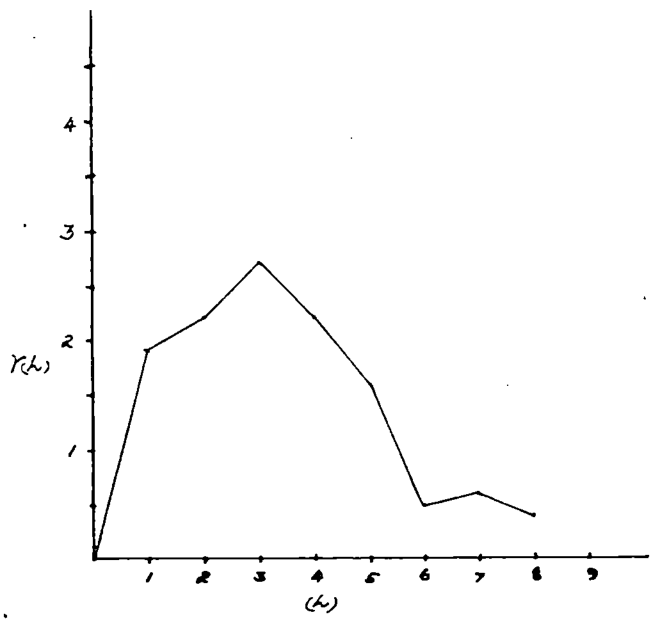

Fig.8

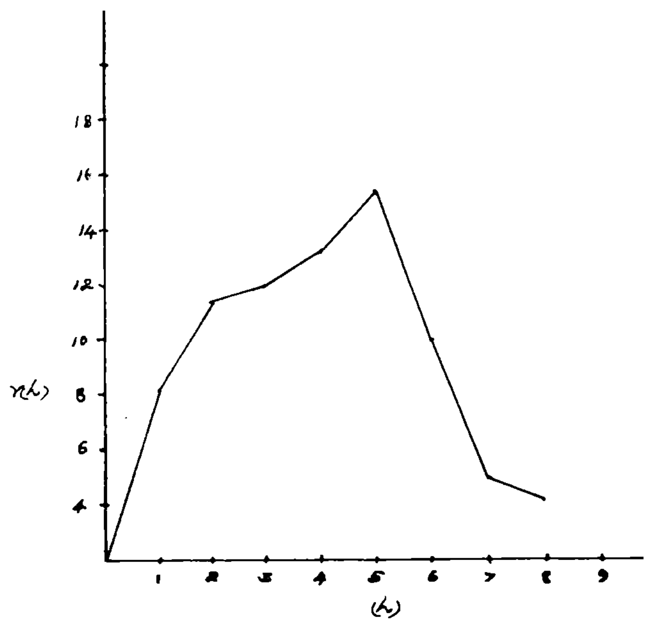

Fig.9

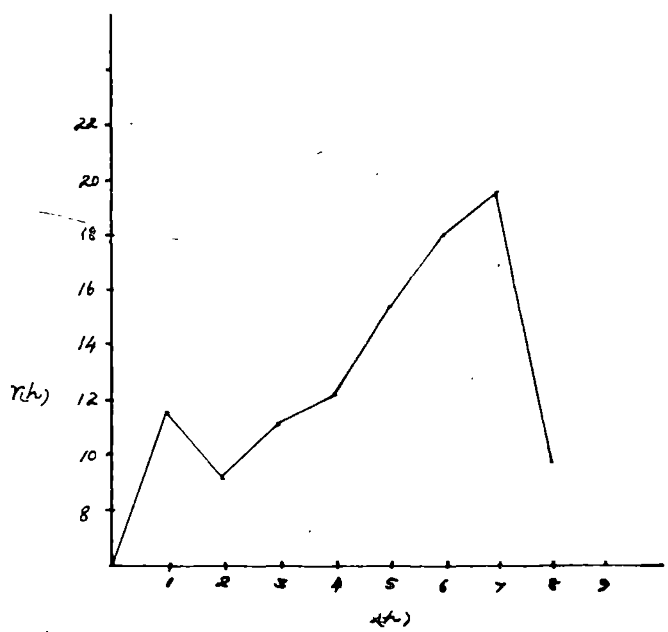

Fig.10

phosphorus, $Y = 6.489 + 1.382X - 0.280X^2$ for total potassium and $Y = 16.247 + 9.889X - 1.183X^2$ for girth of trees are significant and more suitable.

For plant calcium, soil total calcium and organic carbon content of soil, models such as $Y = 0.0414 + 0.0038X$; $Y = 37.179 - 3.762X$ and $Y = 0.133 + 0.006X$ can be suggested respectively.

All other properties cannot be found to possess any significant models for their semi-variances.

<u>II-B plantation</u>

Unlike other plantations, many of the properties do not show semi-variances (Table 3.4) obeying any regression models significantly in the II-B plantation. However, some quadratic and linear regression models can be suggested for soil available nutrients such as available nitrogen, phosphorus, potassium and calcium.

Quadratic regression models viz. $Y = 0.0298 + 0.0380X - 0.0102X^2$ for available nitrogen $Y = 2896.09 + 3486.5\overset{*}{7}X - 7.33X^2$ for available phosphorus and $Y=0.00040 + 0.0033\overset{*}{0}X - 0.00006X^2$ for available calcium are found to be best suited. However, available potassium has a linear regression model of $Y= 12049.20 -1796.37X$ for its semi-variance over lag distances.

Table 3.4. Semi-variances γ(h) properties at grid points separated by different lag distances - II-B Plantation

Lag distances	Plant nutrient contents					Soil available contents				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1h	2×10^{-5}	0.0047	0.029	0.0015	1.6×10^{-4}	0.051	5722.6	8831.9	6.8×10^{-4}	3.3×10^{-5}
2h	3.2×10^{-5}	0.0033	0.025	0.0015	3.5×10^{-4}	0.086	6715.1	9879	8.4×10^{-4}	4.4×10^{-5}
3h	2×10^{-6}	0.0042	0.02	0.002	4.1×10^{-4}	0.032	6974.8	8077.8	9.1×10^{-4}	1.5×10^{-5}
4h	2×10^{-6}	0.0031	0.008	0.0047	7.2×10^{-4}	0.026	5033.4	3444.4	8.5×10^{-4}	3.7×10^{-5}

	Soil total nutrients					Soil organic carbon	pH	Girth
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium			
1h	7.4×10^{-9}	4.6×10^{-7}	2.2×10^{-6}	0.13	0.02	0.055	0.415	112.4
2h	6.6×10^{-9}	6.1×10^{-7}	2.9×10^{-6}	0.15	0.021	0.036	0.389	75.0
3h	7.8×10^{-9}	4.9×10^{-7}	1.9×10^{-6}	0.09	0.012	0.072	0.154	68.7
4h	3.8×10^{-9}	8.8×10^{-7}	2×10^{-6}	0.05	0.02	0.099	0.245	115.7

Fig.11. Semi-variogram for soil available nitrogen in II-B plantation.

Fig.12. Semi-variogram for soil available phosphorus in II-B plantation.

Fig.13. Semi-variogram for soil available potassium in II-B plantation.

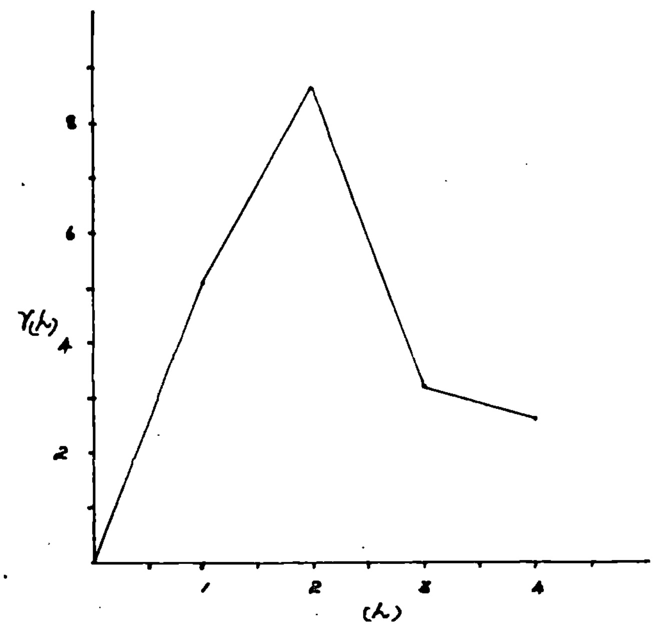

Fig.11

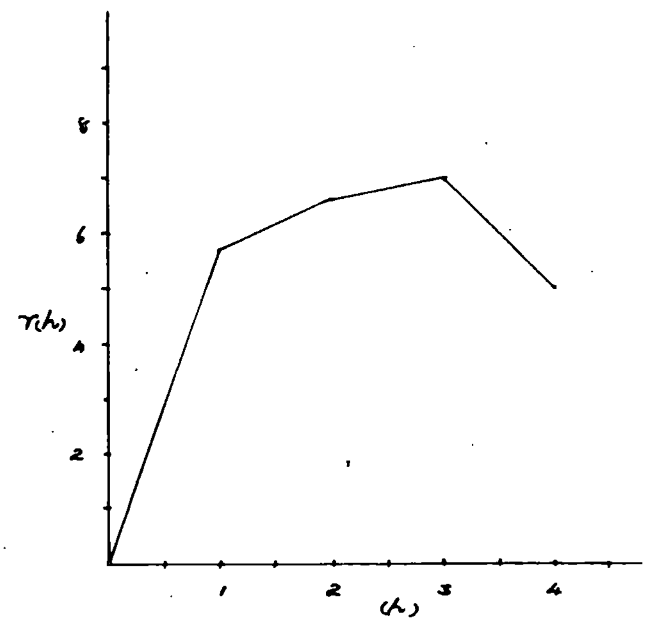

Fig.12

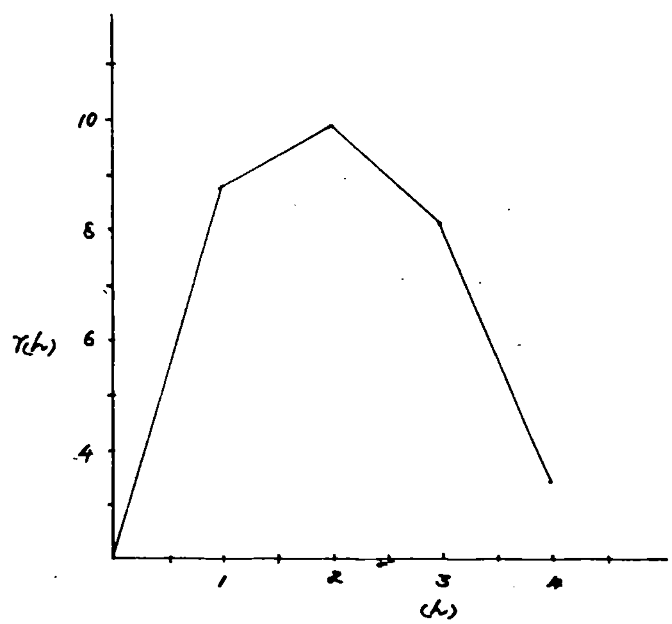

Fig.13

III Plantation

Only a limited number of properties studied, is found to show some of the regression models for their semi-variances in III plantations. Quadratic regression models are seen satisfactory for majority of them.

Semi-variance of plant magnesium exhibits the quadratic regression model of $Y = 0.00957-0.00138X + 0.0004\overset{*}{8}X^2$.

When soil available potassium shows model of $Y = 1996341-590912X + 149421.\overset{*}{3}X^2$, the same for available magnesium is found to be $Y = 2.12x10^{-4}-1.49x10^{-5}X + 1.73x10^{-6}X^2$.

Among total nutrients of soil, only potassium and magnesium are showing significant relationship for their semi-variances with lag distances such as $Y = 1.96x10^{-7} + 2.30x\ 10^{-8}X - 4.30x\ 10^{-9}X^2$ and $Y = 0.0782+ 0.0209X-0.0033X^2$ respectively.

A model satisfying the relation $Y = 0.2220+ 0.0446U-0.0089X^2$ is arrived at for semi-variance of soil reaction also.

The semi-variance values obtained for each property at different lag distances are the principal statistical

Table 3.5. Semi-variances $\gamma(h)$ of properties at grid points separated by different lag distances - III plantation.

Lag distances	Plant nutrient contents					Soil available contents				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1h	1.9×10^{-5}	1.2	0.05	0.09	0.008	0.15	1879.5	1292550	1×10^{-5}	2×10^{-4}
2h	1.6×10^{-5}	1.0	0.069	0.08	0.008	0.23	2075	1554050	8×10^{-6}	2×10^{-4}
3h	1×10^{-5}	0.9	0.074	0.13	0.013	0.26	1685.2	1854015	1.3×10^{-5}	1.7×10^{-4}
4h	2×10^{-5}	0.9	0.06	0.08	0.011	0.16	2416	2200982	1.5×10^{-5}	2×10^{-4}
5h	1.3×10^{-5}	1.3	0.064	0.1	0.014	0.23	3291.5	2770666	1.2×10^{-5}	2.4×10^{-4}
6h	1.9×10^{-5}	0.8	0.076	0.07	0.016	0.17	1910.2	3308872	1.2×10^{-5}	2.4×10^{-4}
7h	5×10^{-6}	0.9	0.08	0.15	0.025	0.22	2408.5	5090516	8×10^{-6}	1.3×10^{-4}
8h	6×10^{-6}	0.5	0.32	0.2	0.029	0.19	1341.6	7108178	3×10^{-6}	2.2×10^{-4}

	Soil total nutrients					Soil organic carbon	pH	Girth
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium			
1h	2.3×10^{-7}	1.6	2.2×10^{-7}	4.5	0.09	0.36	0.25	20.04
2h	1.5×10^{-7}	2.0	2.3×10^{-7}	4.6	0.11	0.42	0.29	33.0
3h	1.9×10^{-7}	3.1	2.1×10^{-7}	6.3	0.12	0.63	0.24	35.8
4h	1.6×10^{-7}	2.9	2.1×10^{-7}	5.2	0.11	0.64	0.32	29.4
5h	2.1×10^{-7}	3.1	2×10^{-7}	5.5	0.09	0.41	0.22	16.7
6h	2.5×10^{-7}	1.9	2×10^{-7}	5	0.09	0.47	0.12	13.0
7h	2.2×10^{-7}	2.6	1.5×10^{-7}	7.9	0.05	0.63	0.11	18.59
8h	1.6×10^{-7}	1.5	9×10^{-8}	6.7	0.04	0.28	0.02	15.1

Fig. 14. Semi-variogram for soil available nitrogen in III plantation.

Fig. 15. Semi-variogram for soil available phosphorus in III plantation.

Fig. 16. Semi-variogram for soil available potassium in III plantation.

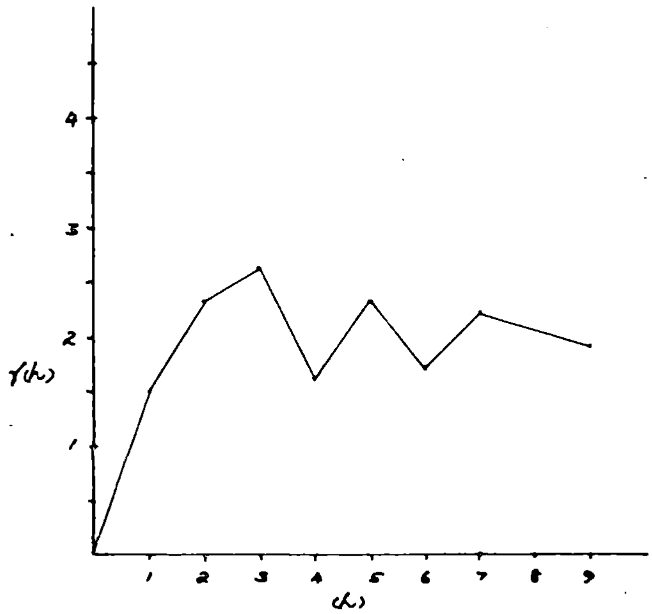

Fig.14

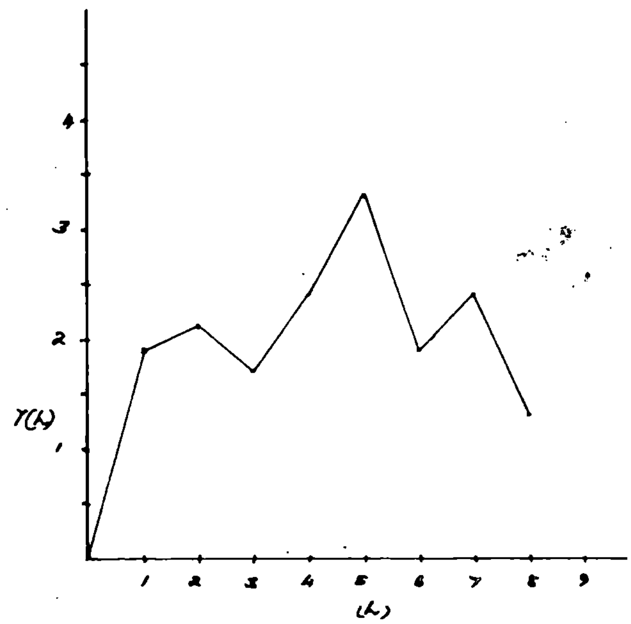

Fig.15

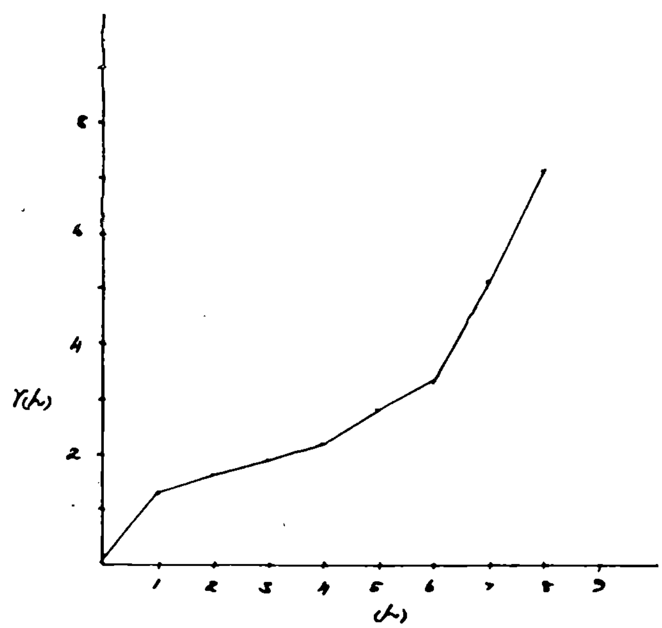

Fig.16

tool to measure the magnitude of spatial variability and hence preferred in soil research as suggested by Burgess and Webster (1980). The semi-variance is further used in optimal interpolation which provides for the prediction of values of a property at unvisited points Similarly the semi-variogram obtained reveals the nature of geographic variation in the property of interest.

Nutrient management models

The main advantage of identification and quantification of soil spatial variability lies in its proper use in nutrient management of the soil. The nutrient management models obtained after accounting for the possible variation in properties of soil helps for the better manipulation of the fertility status of soil as required by any crop of interest.

Table 3.6 gives the nutrient management models for each plantation in terms of semi-variance of the nutrients of greater concern in fertility management of soil, such as available nitrogen, phosphorus and potassium in soil.

It can be seen from the table that nutrient management models for available nitrogen generally exhibit quadratic nature in all the plantations except I-B

Table 3.6 Nutrient management models for the plantations under study.

Plantation No.	Nutrient	Nutrient management models
I-A plantation	Nitrogen	$\gamma(h) = 0.2650 - 0.0920h - 0.0123h^2$
	Phosphorus	$\gamma(h) = 349001.1 - 225850.4h - 0.0123h^2$
	Potassium	$\gamma(h) = 40392.24 - 2973.767h$
I-B plantation	Nitrogen	$\gamma(h) = 0.0836 + 0.0123h$
	Phosphorus	$\gamma(h) = 10004.11 - 2167.18h + 440.06h^2$
	Potassium	$\gamma(h) = 8388.701 + 325.329h - 79.147h^2$
II-A plantation	Nitrogen	$\gamma(h) = 0.2020 + 0.0214h - 0.0058h^2$
	Phosphorus	$\gamma(h) = 3898.82 + 4927.62h - 632.47h^2$
	Potassium	$\gamma(h) = 5915.967 + 3240.933h - 280.694h^2$
II-B plantation	Nitrogen	$\gamma(h) = 0.0298 + 0.0380h - 0.0102h^2$
	Phosphorus	$\gamma(h) = 2896.09 + 3486.57h - 733.47h^2$
	Potassium	$\gamma(h) = 12049.2 - 1796.37h$
III plantation	Nitrogen	$\gamma(h) = 0.163 + 0.022h - 0.0024h^2$
	Phosphorus	$\gamma(h) = 1057.712 + 652.0118h - 73.1697h^2$
	Potassium	$\gamma(h) = 1996341 - 590912h + 149421.3h^2$

plantation where it observes a linear model.

However, the management models in terms of semi-variance of nutrients for available phosphorus are quadratic models in all the plantations studied.

With the exception of I-A and II-B plantation, available potassium also is characterised by management models of quadratic nature.

The management models in terms of the semi-variance $\gamma(h)$ of the nutrients concerned can be used in predicting the possible levels of the nutrients at different lag distance (h) of the plantation from the top of the slope fixed as reference, in the present study. From the semi-variance of the nutrient at a lag distance in question, obtained from the management models, the variance of the nutrient can be found out which is suitably used in the prediction of the nutrient status at the particular lag distance after required manipulations taking into consideration the mean status of the nutrient prevailing in that particular plantation. Since these management models take into account spatial variability of nutrients, they are able to adequately compensate the same and enable better management for attainment of uniformity of the plantation.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A study of the soils of rubber plantations in Amboori area of Trivandrum district has been undertaken to investigate the spatial variability of soil properties in those plantations. Five plantations of three age groups viz. 1-2 years, 4-5 years and 6-7 years old but prior to commencement of tapping were selected for this purpose. From each of these plantations planted to rubber variety RRII-105, soil samples were collected within the depth of 0-50 cm from the previously fixed grid points separated by a lag distance of 8 m along the slope. The plantations selected having a slope of 20-30°. Leaf samples from index leaves were also collected and measurements of girth of marked trees were made as a part of the study.

The soil samples were analysed to determine the spatial variation of chemical properties such as pH, organic carbon, total and available nutrients over different lag distances. The leaf samples also were subjected to analysis to know the nutrient contents in plant. The data have been subjected to statistical analysis so as to establish the existence and significance of spatial variability of soil and to make a

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worthy estimation of the same.

The chief findings from the study are summarised below:

1. Generally, the nutrients in soil are spatially dependent and showed greater variation over greater lag distances. It is believed that major contribution to this effect comes from the influence of slope as well as topographic differences.

2. Total nutrients such as total nitrogen, phosphorus and potassium are found to show considerable spatial variation in soil. However, the trend of spatial variation of total nitrogen is found to be non-significant in three of the five plantations under study indicating less impact of lag distances along the slope on its status in soil.

3. The distribution of total calcium did not exhibit significant variation over different lag distances from the top in almost all plantations and revealed that the distribution was not spatially variable to a considerable extent. However, two of the

five plantations showed some significant variation for total magnesium.

4. A very significant spatial dependence was observed in the case of available nitroger status in all the five plantations under study. Generally the available nitrogen status followed a variability with an increase along the slope downwards over different lag distances.

5. Available P in the plantations generally were reluctant to show any appreciable variability like soil available nitrogen. Yet, it could be seen that younger plantations show variations to some extent. Similar behaviour was observable in the case of available potassium also. Older plantations may have greater uptake and requirements of these nutrients.

6. Unlike total calcium and magnesium contents of soil, it was understood from the study that available calcium and magnesium undergo greater variability as influenced by slope and soil heterogenity.

7. Organic carbon content of soil and soil pH differed over different lag distances and claimed to be having greater spatial dependence. Greater acidity was found in lower reaches of some plantations.

8. Plant sample analysis revealed that the extent of variation of plant nitrogen generally is not as wide as soil nitrogen. Nutrient contents in plants could not exhibit much variation. However, plant potassium characterised itself to show some degree of spatial dependence.

9. Distinguishable spatial variation for girth of trees could not be delineated in all the plantations. But correlation studies suggested significant relationships of girth of trees with spatial variability of nutrient such as available nitrogen and organic carbon etc. and gave linear regression equations.

10. Nutrient management models in terms of semi-variance were obtained for major

nutrients of soil for compensating spatial variability of the nutrients in question. These models when used would be helpful in fertilizer practice to obliterate the effects of spatial variability of nutrients on crop growth.

The results of the present study however do not suggest any regularity in the distribution of various chemical properties of soil suggesting a generalized trend of spatial variation applicable to all the plantations. But proved the existence of spatial variability in soil properties and ascertained its influence on growth of plants.

The different degrees of effective soil and nutrient management adopted seemed partially to annul the possible soil variation created by slope and topographical dissimilarities. This study also, contributes much in this regard to alleviate the undesirable effects of spatial variability of soil properties by way of suggesting suitable compensating models for nutrient management.

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APPENDICES

APPENDIX-I

Table 3.1a Regression equations of semivariances of different properties with lag distances (X) - I-A plantation.

Property	Regression equation	F	R^2
Plant nitrogen	$Y = 0.00184 - 0.00044X + 0.00009X^2$	352.147**	0.99
" Phosphorus	$Y = 0.00505 - 0.00128X - 0.00016X^2$	1.826	0.38
" Potassium	$Y = 0.06174 - 0.00716X + 0.00062X^2$	1.292	0.30
" calcium	$Y = 143.4863 + 99.6148X - 8.1708X^2$	0.278	0.08
" magnesium	$Y = 0.00575 - 0.00066X + 0.00016X^2$	74.882**	0.96
Soil available nitrogen	$Y = 0.2650 - 0.0920X - 0.0123X^2$	9.919**	0.77
" phosphorus	$Y = 349001.1 - 225850.4X - 0.0123X^2$	5.618*	0.65
" potassium	$Y = 40392.24 - 2973.76X$	6.422*	0.48
" calcium	$Y = 0.00146 - 0.000009X - 0.00002X^2$	10.164**	0.77
" magnesium	$Y = 0.00072 + 0.00094X - 0.000019X^2$	11.643**	0.80
Soil total nitrogen	$Y = 1.38 \times 10^{-7} + 3.8 \times 10^{-9}X$	0.493	0.07
" phosphorus	$Y = 0.3452 + 0.4571X - 0.0357X^2$	2.117	0.41
" potassium	$Y = 5.83 \times 10^{-6} + 6.73 \times 10^{-7}X - 8.03 \times 10^{-8}X^2$	0.749	0.20
" calcium	$Y = 0.7170 - 0.0024X + 0.0059X^2$	10.175**	0.77
" Magnesium	$Y = 0.5788 - 0.0927X + 0.0133X^2$	14.923**	0.83
Soil organic carbon	$Y = 0.1443 - 0.0102X + 0.0021X^2$	3.420	0.53
Soil reaction (pH)	$Y = 0.2414 - 0.0188X + 0.0021X^2$	1.124	0.27
Girth	$Y = 0.6176 - 0.0217X + 0.0102X^2$	13.049	0.81

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX-II

Table 3.2a Regression equation of semi-variances of properties (Y) with lag distances (X) I- B plantations

Property	Regression equations	F	R^2
Plant nitrogen	$Y = 1.22x10^{-5} + 2.84x10^{-6}X + 5.95x10^{-9}X^2$	2.316	0.48
" phosphorus	$Y = 0.0103 + 0.0015X - 0.0002X^2$	0.637	0.20
" potassium	$Y = 0.0567 - 0.0064X$	11.941*	0.66
" calcium	$Y = 0.0999 - 0.0106X$	18.442**	0.75
" magnesium	$Y = 0.00420 + 0.00034X - 0.00010X^2$	10.566**	0.81
Soil available nitrogen	$Y = 0.0836 + 0.0123X$	27.604**	0.82
" phosphorus	$Y = 10004.11 - 2167.18X + 440.06X^2$	12.793*	0.84
" potassium	$Y = 8388.701 + 325.329X - 39.147X^2$	0.643	0.20
" calcium	$Y = 1.91x10^{-4} + 6.05x\ 10^{-5}X - 8.51x\ 10^{-6}X^2$	1.028	0.29
" magnesium	$Y = 7.28x10^{-4} - 4.31x\ 10^{-5}X - 3.57\ x\ 10^{-6}X^2$	2.037	0.44
Soil total nitrogen	$Y = 1.10x\ 10^{-7} - 3.52\ x\ 10^{-8}X + 6.92\ x\ 10^{-9}X^2$	43.409**	0.95
" phosphorus	$Y = 1.11\ x\ 10^{-6} - 3.87\ x\ 10^{-8}X + 8.93\ x\ 10^{-9}X^2$	1.629	0.39
" potassium	$Y = 1.39\ x\ 10^{-6} + 8.86\ x\ 10^{-7}X - 7.14\ x\ 10^{-8}X^2$	2.477	0.50
" calcium	$Y = 0.1764 + 0.0394X - 0.0058X^2$	5.492	0.69
" magnesium	$Y = 0.0739 + 0.00172X - 0.00076X^2$	6.956*	0.74
Soil organic carbon	$Y = 0.1132 + 0.0119X - 0.0019X^2$	2.757	0.52
Soil reaction (pH)	$Y = 0.1859 + 0.0341X - 0.0054X^2$	2.211	0.47
Girth	$Y = 0.5796 + 0.1742X - 0.0263X^2$	9.842*	0.80

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX- III

Table 3.3a Regression equations of semi-variances of properties (Y) with lag distances (X) II- A plantation

Property	Regression equation	F	R^2
Plant nitrogen	$Y = 3.60 \times 10^{-6} - 5.20 \times 10^{-7}X + 1.24 \times 10^{-7}X^2$	7.349*	0.75
" phosphorus	$Y = 0.0084 + 0.00038X - 0.00002\ X^2$	2.241	0.01
" potassium	$Y = 0.0134 + 7.14 \times 10^{-5}X + 1.67 \times 10^{-4}X2$	2.720	0.52
" calcium	$Y = 0.0414 + 0.0038X$	6.366*	0.51
" magnesium	$Y = 10.0072 - 1.5798X + 0.1226X^2$	0.741	0.23
Soil available nitrogen	$Y = 0.2020 + 0.0214X - 0.0058X^2$	10.051*	0.80
" phosphorus	$Y = 3898.82 + 4927.62X - 632.47X^2$	13.415**	0.84
" potassium	$Y = 5915.967 + 3240.933X - 280.694X^2$	1.331	0.35
" calcium	$Y = 3.97 \times 10^{-4} + 5.88x\ 10^{-5}X - 1.24 \times 10^{-5}X^2$	4.210	0.63
" magnesium	$Y = 2.1550 + 0.2110X - 0.0625X^2$	8.422*	0.77
Soil total nitrogen	$Y = 3.24 \times 10^{-8} + 4.89 \times 10^{-10}X - 5.10 \times 10^{-10}X^2$	12.173*	0.83
" phosphorus	$Y = 1.86 \times 10^{-6} - 2.64 \times 10^{-7}X + 4.52 \times 10^{-8}X^2$	22.398**	0.90
" potassium	$Y = 6.489 + 1.382X - 0.280X^2$	11.960*	0.83
" calcium	$Y = 37.179 - 3.762X$	6.591*	0.52
" magnesium	$Y = 0.5398 + 0.1468X - 0.0202X^2$	3.116	0.55
Soil organic carbon	$Y = 0.133 + 0.006X$	6.806	0.53
Soil reaction (pH)	$Y = 0.1275 + 0.0337X - 0.0054X^2$	4.346	0.63
Girth	$Y = 16.247 + 9.889X - 1.183X^2$	6.047*	0.71

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX -IV

Table 3.4a Regression equations of semi-variance of properties (Y) with lag distances (X) II-B plantation

Property	Regression equation	F	R^2
Plant nitrogen	$Y = 2.0 \times 10^{-5} + 6.6 \times 10^{-6}X - 3.0 \times 10^{-6}X^2$	0.750	0.60
" phosphorus	$Y = 0.0052 - 0.0008X + 0.00008X^2$	0.423	0.46
" potassium	$Y = 0.0275 + 0.0032X - 0.0020X^2$	68.646	0.99
" calcium	$Y = 0.0033 - 0.0024X - 0.0007X^2$	23.954	0.98
" magnesium	$Y = 0.00012 + 0.00002X + 0.00003X^2$	10.732	0.96
Soil available nitrogen	$Y = 0.00298 + 0.0380X - 0.0102X^2$	0.667	0.57
" phosphorus	$Y = 2896.09 + 3486.57^{*}X - 733.47X^2$	10.739	0.96
" potassium	$Y = 12049.2 - 1796.37X$	4.000	0.67
" Calcium	$Y = 0.00040 + 0.00330^{*}X - 0.00006X^2$	182.226	0.99
" magnesium	$Y = 5.02 \times 10^{-5} - 1.54 \times 10^{-5}X + 2.75 \times 10^{-6}X^2$	0.549	0.10
Soil total nitrogen	$Y = 4.8 \times 10^{-9} + 3.0 \times 10^{-9}X + 8.0 \times 10^{-10}X^2$	1.383	0.73
" phosphorus	$Y = 6.2 \times 10^{-7} - 1.9 \times 10^{-7}X - 6.0 \times 10^{-8}X^2$	1.305	0.72
" potassium	$Y = 1.9 \times 10^{-6} + 5.9 \times 10^{-7}X - 1.5 \times 10^{-7}X^2$	0.278	0.36
" calcium	$Y = 0.1050 + 0.0449X - 0.0150X^2$	5.399	0.92
" magnesium	$Y = 0.0142 + 0.0094X - 0.0033X^2$	57.204	0.99
Soil organic carbon	$Y = 0.0810-0.0407X + 0.0115X^2$	4.737	0.90
Soil reaction (pH)	$Y = 0.6332 - 0.2207X + 0.0292X^2$	1.089	0.69
Girth	$Y = 197.550 - 105.140X + 21.100X^2$	36.122	0.99

* Significant at 5 per cent level

APPENDIX-V

Table 3.5a Regression equations of semi-variances of properties (Y) with lag distances (X) III plantation

Property	Regression equation	F	R^2
Plant nitrogen	$Y = 1.5 \times 10^{-5} + 1.5 \times 10^{-6}X - 3.3 \times 10^{-7}X^2$	2.068	0.45
" phosphorus	$Y = 1.0161 + 0.0601X - 0.0137X^2$	2.257	0.47
" potassium	$Y = 0.0354 + 0.0179X - 0.0021X^2$	1.818	0.42
" calcium	$Y = 0.1289 - 0.0293X + 0.0045X^2$	4.439	0.64
" magnesium	$Y = 0.00957 - 0.00138X + 0.00048X^2$*	45.586**	0.95
Soil available nitrogen	$Y = 0.163 + 0.022X - 0.0024X^2$	0.255	0.10
phosphorus	$Y = 1057.712 + 652.0118X - 73.1697X^2$	1.462	0.37
potassium	$Y = 1996341 - 590912X + 149421.3X^2$*	123.687**	0.98
Calcium	$Y = 3.88 \times 10^{-6} + 4.86 \times 10^{-6}X - 6.13 \times 10^{-7}X^2$	11.449*	0.82
magnesium	$Y = 2.12 \times 10^{-4} - 1.49 \times 10^{-5}X + 1.73 \times 10^{-6}X^2$	0.147	0.06
Soil total nitrogen	$Y = 1.9 \times 10^{-7} + 4.8 \times 10^{-9}X - 4.2 \times 10^{-10}X^2$	0.020	0.01
phosphorus	$Y = 7268 + 0.9887X - 0.1113X^2$	5.170	0.67
potassium	$Y = 1.96 \times 10^{-7} + 2.30 \times 10^{-8}X - 4.30 \times 10^{-9}X^2$	32.840**	0.93
calcium	$Y = 4.5089 + 0.1494X + 0.0208X^2$	2.527	0.50
magnesium	$Y = 0.0782 + 0.0209X - 0.0033X^2$	29.787**	0.92
Soil organic carbon	$Y = 0.2221 + 0.1592X - 0.0180X^2$	1.727	0.41
Soil reaction (pH)	$Y = 0.2220 + 0.04460X - 0.00089X^2$	20.366**	0.89
Girth	$Y = 25.6884 + 2.0137X - 0.4734X^2$	2.179	0.47

* Significant at 5 per cent level
** Significant at 1 per cent level

NUTRIENT MANAGEMENT MODEL FOR COMPENSATING SPATIAL SOIL VARIABILITY IN RUBBER PLANTATIONS IN AMBOORI AREA

BY

ANILKUMAR J. R

ABSTRACT OF A THESIS

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ABSTRACT

A study of the soils of rubber plantations in Amboori area has been undertaken to investigate the spatial variability of soil properties in those plantations with a view to relating it with the girth of the trees prior to tapping and to work out compensating models for nutrient management.

Five plantations of three age groups viz. 1-2 years, 4-5 years and 6-7 years old but prior to the commencement of tapping were selected for this purpose. The plantations were having a slope of 20-30^{o} and were planted with the rubber variety RRII-105. Soil samples collected from these plantations, from the previously fixed grid points separated by a lag distance (h) of 8 m along the slope, were analysed for the chemical properties such as pH, organic carbon, total and available nutrients. The leaf samples also taken, were analysed to know the nutrient contents in plant. Analysis of variance of the data to establish the variability, correlation and regression studies to relate the girth with nutrient variations in soil and plant, and computation of semi-variance $\gamma(h)$ for different lag distances for each nutrient to work out nutrient management models were undertaken.

The study showed the existence of considerable spatial variability of soil properties in the plantations under study. Total nutrients such as total nitrogen, phosphorus and potassium were found to be spatially variable and significantly dependent on lag distances. However, three of the five plantations showed less impact of lag distances along the slope on the total nitrogen status of soil. While total calcium did not exhibit significant variations, total magnesium was found to possess spatial variation to some extent. A very significant spatial dependence characterised by an increase along the slope downwards with respect to available nitrogen, was an important observation of the study. Other available nutrients showed lesser degree of variations. Girth of trees when correlated with available nitrogen and organic carbon gave linear regression equations.

Nutrient management models in terms of semi-variance were obtained for major nutrients of soil for compensating spatial variability of the nutrients. The models can be helpful in obliterating the effects of spatial variability of nutrients on crop growth. The model will be tested in the field at the Amboori tribal area Research Centre where extensive rubber plantations have been laid out.