ASSESSMENT OF NITRIFICATION RATE OF KERALA SOILS AND AGRONOMIC FACTORS INFLUENCING IT

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
Vellanikkara - Trichur
Kerala

1989

DECLARATION

I hereby declare that the thesis entitled "Assessment of nitrification rate of Kerala soils and agronomic factors influencing it" 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 any other similar title, of any other University or Society.

Vellanikkara,
15-5-1989.

(MARYKUTTY ZACHARIAS)

CERTIFICATE

Certified that the thesis entitled "Assessment of nitrification rate of Kerala soils and agronomic factors influencing it" is a record of research work done by Smt.MARYKUTTY ZACHARIAS, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Dr.R. VIKRAMAN NAIR
Chairman,
Advisory Committee,
Professor of Agronomy,
College of Horticulture,
Vellanikkara, Trichur.

Vellanikkara,
- -1989.

CERTIFICATE

We, the undersigned, members of the Advisory Committee of Smt.MARYKUTTY ZACHARIAS, a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled "Assessment of nitrification rate of Kerala soils and agronomic factors influencing it" may be submitted by Smt.MARYKUTTY ZACHARIAS, in partial fulfilment of the requirement for the degree.

CHAIRMAN Dr.R. Vikraman Nair

MEMBERS Dr.C. Sreedharan

Dr.A.I. Jose

Dr.P.V. Nair

ACKNOWLEDGEMENTS

I deem it as a great pleasure to express my esteemed gratitude and unforgettable indebtedness to Dr.R. Vikraman Nair, Professor of Agronomy and the Chairman of my Advisory Committee for his expert guidance, critical suggestions, kind advice and constant encouragement throughout the course of this investigation and preparation of the manuscript.

I extent my cordial thanks and express my indebtedness to Dr.C. Sreedharan, Professor and Head, Department of Agronomy, Dr.A.I. Jose, Professor and Head, Department of Soil Science and Agricultural Science and Dr.P.V. Nair, Professor, Department of Plant Pathology; members of my Advisory Committee for the sustained interest they had shown in the study and the valuable guidance and suggestions rendered during the various stages of the work.

I express my sincere thanks to Dr.V.K. Venugopal, Assistant Professor, Soil Science and Agricultural Chemistry for his timely help at different periods of my study. My hearty thanks to Dr.Padmaja, Professor, Soil Science and Agricultural Chemistry for her constant encouragement and suggestions given during the various stages of the work.

I gratefully acknowledge the sincere help rendered to me by Sri.K. Madhavan Nair, Associate Professor, Instrumentation during the periods of this study.

It is with pleasure that I express my heartfelt thanks to one and all of the staff members of the Department of Agronomy for the whole hearted co-operation, guidance and encouragement extended to me throughout the period of this investigation.

I like to express my thanks to Sri.P.K. Velayudhan, Lab Assistant, Agronomy and P.B. Parshajan, Farm Assistant, Agronomy for their sincere help in collecting soil samples from various places.

I also place on record my thanks to all my friends and colleagues for their help and co-operation.

I express my gratitude to the Director, Department of Agriculture, Kerala for sanctioning my study for the P.G. programme on deputation.

A word of thanks to Mr.Joy for the neat typing and prompt service.

It is with gratitude I remember the warm blessings and constant encouragement of my husband Sri.K.C. George, parents, brothers and sisters.

Above all, I bow my head before God Almightly who blessed me with health and confidence to undertake the work successfully.

MARYKUTTY ZACHARIAS

To My Husband

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

INTRODUCTION

Nitrogen is the most important and widely applied fertilizer element. The fertilizer nitrogen applied to soil undergoes numerous physical, chemical and biological transformations which affect its loss and ultimate use efficiency for crop production. The study of fertilizer nitrogen transformations in soils is an important component of research for increasing the efficiency of nitrogen and undoubtedly better understanding of various mechanisms of nitrogen loss will help in devising techniques for reducing these losses. Amide and ammoniacal fertilizers that are commonly used as source of fertilizer nitrogen are converted to nitrate form in the soil by the action of nitrifying organisms. Nitrification results in the conversion of a relatively immobile cationic form, NH_4^+-N into a more mobile anionic form, NO_3^--N and it has a direct bearing upon crop nutrition as it alters the availability of the chief plant nutrient element obtained from the soil. The determination of the intensity of nitrification through which the soil content is maintained is very important in the assessment of soil fertility. If nitrate formed is not assimilated by the crop or immobilized by the microflora, it is susceptible to downward movement, and the nitrogen may thus in effect be lost to the plants following nitrification. Another way in which this element can be lost following nitrification is through denitrification. Prolonged use of ammonium fertilizers leads not only to the self-destruction of the nitrifying autotrophs but also to the appearance in soluble forms of a number of cations. Therefore, it is clear that nitrification is a mixed blessing and possibly a frequent evil.

Factors influencing the activity of the nitrifying bacteria have a pronounced effect on the amount of nitrates produced and consequently on the utilization of nitrogen by plants. The environmental factors favouring the growth of most upland agricultural plants also favour the activity of the nitrifying bacteria. The important factors affecting the nitrification pattern in soils are supply of ammonium ion, populations of nitrifying organisms, soil reaction, soil aeration, soil moisture and temperature.

Many of the soils of Kerala have pH values much lower then the reported optimum for nitrification and often lower than the ultimate limit. This factor was also considered to be responsible for the usually reported lack of response to the use of nitrification inhibitors in theso soils even though these are found to be advantageous in many of the soils of the country. In an earlier study (Mathew, 1986) conducted to screen materials for their potential nitrification inhibition properties using the laterite soil, it was indicated that nitrification did not practically occur within reasonable period of time in the soil. It was also observed that neutral to alkaline soils from Coimbatore recorded substantial rate of nitrification under identical experimental conditions. Following this observation, it is considered opportune to assess the nitrification rates of the other representative soils of this state and to assess the factors that are probably responsible for the low nitrification rate in some of our soils. A reconfirmation of the lack of significant rate of nitrification of laterite soil was also intended in the present study.

Attempts of amending the soil with the objective of enhancing the nitrification rate of soils of low nitrification rate are also envisaged. The details of the objectives are:

1. to assess the inherent population of nitrifying organisms in Kerala soils and the inherent rate of nitrification in these soils
2. to locate the chemical factors influencing nitrifier population and nitrification rate

3. to amend the factors and to study the effect of amendment on nitrification in soils of low nitrification
4. to study the effect of nitrification inhibitors on soils of low nitrification with and without amendment.

Review of literature

REVIEW OF LITERATURE

Nitrification, the biological oxidation of ammonium nitrogen to nitrate via nitrite is important in fertilizer use efficiency and nitrogen nutrition of crops. Nitrification results in conversion of a relatively immobile cationic form, NH_4^+-N into a more mobile anionic form, NO_3^--N. Nitrate formed is liable to losses by leaching and denitrification. It is therefore quite essential that attempts be made to check these losses by adopting proper soil and fertilizer management practices. Application of certain chemicals called nitrification inhibitors seems to be the easiest short term approach towards this problem (Goring, 1962).

Factors affecting nitrification

1. Nitrifier population

According to Alexander (1965), the numbers of *Nitrosomonas* and *Nitrobacter* per g of unfertilized soil are rarely more than a lakh and frequently less than 100, particularly if the soil is acid. If the concentration of substrate is increased, however, the numbers rise and may exceed one million per g. This variation of population with substrate is one of the reasons for supposing that *Nitrosomonas* and *Nitrobacter* are predominant among microorganisms involved in NH_4^+ oxidation.

Deshpande *et al.* (1971) found that lime and urea alone and together increased bacterial populations. Etchevers *et al.* (1978) reported that nitrification rate were positively correlated with the number of nitrifying bacteria. Sarathchandra (1978) observed that once the pH was lowered from 7.5 to 5.5 the nitrification rate decreased slowly with a corresponding decrease in the numbers of nitrifying bacteria. Laudelout and Lambert (1982) reported that bacterial population in a soil under permanent pasture reached maxima in spring and autumn.

Kreitinger *et al.* (1985) found that nitrification in acid forest soil is not the result of classical autotrophic nitrifiers, and a possible role for methylotroph type organism in nitrification is suggested. The nitrification in acid tea soils was through the activity of other nitrifying organisms since oxidation by autotrophic nitrifiers is doubtful due to the poor population (Bezbaruah and Baruah, 1985). Martikainen (1985) found that application of urea alone or together with apatite + biotite or with apatite + biotite + micronutrients, increased the numbers of NH_4^+ and NO_2^- oxidisers. Wood ash alone or with apatite, had a smaller stimulatory effect. Harmsen and Schreven (1985) reported that the salt tolerance of nitrifying bacteria was higher than that of most crop plants.

2. Soil reaction

Nitant (1974) found that both high pH and high salt content in sodic and saline soil, respectively, influenced the changes of NH_4^+, NO_2^- and NO_3^--N of applied urea fertilizer. Whereas hydrolysis of urea was delayed and nitrification rate was suppressed, there was enhancement in nitrite accumulation and persistence in saline sodic soils. Gandhi and Paliwal (1976) reported that salinity and pH were both correlated negatively with N mineralization and positively with the gaseous losses of NH_3 in salt affected soils. Nitrification was retarded, suppressed or inhibited completely by salinity, the effect depending on both the amount of salt and the type of amendment (Lawra, 1977; Shahawy and Masbhady, 1984).

Bandyopadhyay and Bandyopadhyay (1983) reported that the nitrification was considerably reduced by soil salinity of 10 dSm^{-1} at 25°C and above. Mc Clung and Frankeriberger (1985) reported the results of an experiment conducted to test the effects of sodium sulphate, sodium chloride and calcium chloride applied at rates that produced electrical conductivities of saturation extracts (ECe) of 5, 10, 15 and 20 dSm^{-1} on ammonia volatilization, amnonification of urea and nitrification in the diverse soils. The effect of salinity on ammonia volatilization and nitrification varied depending on the N source, the amounts and types of salts added and the soil used. The percentage of inhibition of nitrification ranged from 8 to 83. Sodium sulphate was less inhibitory to nitrification that the chloride salts. Inhibition of nitrification at ECe values of 20 dSm^{-1} (NaCl) was as high as 75 and 83% when ammonium sulphate and urea were applied to soils, respectively.

It was reported by Sahrawat (1982) that the amount of NO_3^--N formed is highly positively correlated with soil pH but was not correlated with organic C or total N contents. Nitrate formation was not significantly correlated with soil pH in soils of pH greater than 6.0. The range of reaction over which nitrification takes place has generally been given as pH 5.5 to about 10.0 with the optimum around 8.5 (Tisdal et al., 1985). Arora et al. (1986) found that pH had positive correlation with accumulation of NO_3^--N at the end of a 65 day incubation and also found that nitrification rate depended on lime rate.

3. Soil management

Stevanovic et al. (1982) found that deep tillage intensified nitrogen mineralization in soil under corn in various rotations. Rice and Smith (1983) reported that the ratios of NO_3^- to NH_4^+ were higher in ploughed soils except immediately after fertilization. According to Naumov (1983) ammonifying capacity was little affected by soil erosion, but accumulation of nitrates was greatly slowed down. Groffman (1985) reported that nitrification and denitrification activities were consistently higher in the top 5 cm of no tillage soil than in conventional tillage soil and a reverse pattern was observed at lower depths. Hadas et al. (1986) reported that the maximal rate of nitrification and delay period of surface soil samples were from 5 to 70mg kg^{-1} d^{-1} and from 0.2 to 8 d, respectively. The maximal rate of nitrification decreased and delay period increased with soil depth.

Plhak and Vicherkova (1970) observed that the rate of nitrification was usually lower in previously uncultivated than cultivated soils except in the case of pea, timothy grass and onion where increased rates were found. Vlassak (1970) found that relatively rapid mineralization and nitrification were found with soils from cultivated land and pastures, but soils under natural vegetative covers of conifers and hard woods were mostly ammonifying. Wheeler and Donaldson (1983) reported that nitrification was rapid in soil under herbaceous communities, followed by bush vegetation and was not detectable in soil under trees. Beck (1983) reported that different measures of soil management (pre-ceeding crops, application of sewage sludge, addition of heavy metals) had a fairly pronounced effect on the rate of N mineralization.

4. Soil moisture

Hulpoi (1970) reported that in soils having a high moisture content (26%), the nitrification depended on the amount of NH_4^+-N applied and on the degree of aeration. Schreven and Sieben (1972) found that water logging increased the amounts of N mineralized on subsequent incubation. Oxidation of nitrite to nitrate was delayed for the first week following waterlogging in a humic clay and the numbers of bacteria decreased as the period of waterlogging increased. More and Varade (1982) found that the maximum rate of nitrification was in the moisture range of -5 to -0.33 bar, since the process was highly aerobic and favoured by lower soil water potential.

5. Soil temperature

Harmsen and Schreven (1955) reported that the extreme temperature limits for nitrification in forest and peat soils proved to be 4° and 40°C with the optimum between 20° and 30°C;

this was about the same as in ordinary soils. Knop (1970) reported that the intensity of ammonification and nitrification was low at 0-3°C both in acid soil (pH 5.2) and alkaline soil (pH 7.8). Beck (1983) reported that the optimum temperature was 50°C for N mineralization and 26°C for nitrification. Mochoge et al. (1983) found that even at lower temperature, nitrification in agricultural soil was active though it occurred at a reduced rate while in forest soil, the nitrification rate was extremely low and appeared to be independent of temperature. Ahrens (1985) found that at 25°C maximum nitrate accumulation occurred after 15 days and at 30°C after 44 days incubation.

6. Organic matter

Mineralization and nitrification can be stimulated by mulching (Harmsen and Schreven, 1955). Rice and Pancholy (1972) found that leaves with low levels of N and P led to the production of higher polyphenol concentrations which retarded litter decay and increased the soil content of tannins and their derivatives. These latter compounds were responsible for the nitrification inhibition. Richard et al. (1983) reported that higher phenolic concentration inhibited nitrification in the forest floor. Nasser et al. (1983)

found that application of dry guava leaves in conjunction with peptone or ammonium sulphate on a clay loam soil reduced ammonium oxidising and nitrite oxidizing bacteria and nitrification process.

Mochoge and Beese (1983) reported that the forest soil had higher incorporation of N in the organic fraction than did the agricultural soil. Nitrification was low in the forest soil, but in the agricultural soil there was a fairly high nitrification even at 4°C. Mc Carty and Bremner (1986) found that phenolic acids and tannins did not significantly affect nitrification in soil even when the amounts applied greatly exceeded the amounts that have been reported to inhibit nitrification or to occur in soil. Tan and Falcon (1987) found that humic acid increased the delay period, and at the same time decreased the maximum rate of nitrification.

7. Fertilizers

Takahash (1964) reported that the nitrification of urea did not proceed indefinitely because nitric acid formed as a result of nitrification made the soil acid and thereby retarded nitrification. Kiehl and Netto (1974) reported that treating soil samples with anhydrous ammonia greatly reduced nitrification. It was reported by Bharagava and Ghosh (1976) that biuret did not get nitrified to more than 10% in five weeks time and it appeared that its low solubility and complex nature resisted nitrification. It was concluded that although biuret itself was definitely resistant to nitrification, it was not likely to inhibit the nitrification of urea to a noticeable extent at least in the concentration in which it was likely to be present in the commercial fertilizer grade urea. Sahrawat (1977) found that the biuret impurity in urea fertilizer enhanced nitrite toxicity. Potassic and phosphatic fertilizers reduced both the rate of decomposition of urea and the nitrification of ammonium N produced by the decomposition. Sulphate, chlorides and super phosphates all caused marked inhibition of nitrification (Vostal et al., 1976). Nitrifying potential in the acid soil was almost halved by the long term application of mineral fertilizers. Nitrification in the limed soil was not reduced (Lebedeva and Zagumennikov, 1977; Roy et al., 1985). Vostal et al. (1977) found that the rate of nitrification following the application of nitrogen fertilizers proceeded in the order urea > ammonium nitrate > ammonium sulphate. Potassium sulphate markedly reduced nitrification in soils amended with ammonium fertilizers but K fertilizers had little effect where urea was applied. Ivanov (1981) reported that temporary alkalification of acid soils caused more rapid and complete nitrification of NH_4^+-N from urea than from NH_4^+ salts.

Wetselaar et al. (1972) reported the effect of banding N fertilizers in soil on nitrification. Nitrification was completely inhibited if the osmotic potential of the soil solution was $>$ 10 bars, if the ammonium N concentration in the soil solution was $>$ 3000 ppm or if pH was $>$ 8. Darrah et al. (1986) found that nitrification was inhibited at the site of application of ammonium chloride due to increased osmotic pressure or chloride ion in the soil.

Oke (1970) found that nitrification was slightly increased with the addition of phosphate. It was also found that in the presence of sulphur, more nitrate was formed than in the soil alone or soil with phosphorus. Glambiazi and Kraljev (1973) reported that the contents of P and Ca were significantly correlated with nitrifying activity in A horizon, but in B horizon Ca was unrelated and P was related to only a small extent. Etchevers et al. (1978) noticed that nitrification rate was positively correlated with available P concentration. Hue and Adams (1984) reported that the organic P concentrations in soil solution above which NH_4

oxidizers would not respond to additional P were 0.59±0.24 μM for the minimum delay time and 0.6±0.28 μM for the maximum nitrification rate. Nitrite oxidizers required not more than 0.13 and 0.24±0.07 μM P for the minimum delay time and the maximum oxidation rate, respectively. Arora *et al.* (1986) found that nitrification rate in a coarse textured kaolinitic Ultisol was negatively correlated to exchangeable Ca.

8. Inhibitors

Goring (1962) found that N-Serve inhibited nitrification of ammonium and amide fertilizers at rates varying from 0.2 to 2% of N and that retardation of nitrification by N-Serve was brought about mainly due to toxicity to ammonium oxidizing autotrophs of genus *Nitrosomonas*. Manickam *et al.* (1976) reported that crushed neem seed treated urea was significantly superior to the mahua cake extract treated urea but was on par with the N-Serve treated urea and neem cake extract treated urea in inhibiting nitrification. Tetruashvili *et al.* (1980) observed that N-Serve was more effective with soil moisture content at 70% field capacity. Boratynski and Zietecka (1982) reported that the inhibitory effect of N-Serve depended on the soil. Liming accelerated the nitrification rate and decreased the effectiveness of nitrification inhibition by

N-Serve. Mukhopadhyay et al. (1985) found that the use of N-Serve resulted in an increase in the amount of exchangeable and fixed NH_4^+ in the soil under aerobic incubation (30 and 60% of WHC), but virtually no effect of N-Serve was observed on mineral nitrogen transformation in the soil incubated under waterlogged condition.

Warren et al. (1980) reported that nitrification inhibition could effectively reduce N losses without adversely affecting the uptake of other minerals or the mineral composition of maize leaf tissue. Iruthayaraj (1981) found that nitrification inhibitors increased the content of NH_4^+-N in soil, but had no effect on NO_3^--N content. Huber et al. (1982) observed that nitrification inhibitors had a good potential to improve N use efficiency and grain yield by reducing losses of applied NH_4^+-N in no till corn production system. Listanska (1982) noticed that the nitrification inhibitors had a more pronounced effect at temperature more favourable to nitrification. Walter et al. (1986) reported that the nitrification process was considerably delayed and the residual effect of the nitrificides prolonged at pH below 5.9.

9. Chemical factors

Quraishi and Cornfield (1971) reported that the addition of 100, 1000 and 10,000 ppm copper, as oxide, or hydrogen phosphate stimulated nitrogen mineralization and nitrification during incubation of a sandy loam (0.5% $CaCO_3$) treated with 200 ppm N as dried blood. Wilson (1977) found that nitrification was totally inhibited by 1000 μ g Zn g^{-1} of three different soils. Liang and Tabatabai (1978) observed that the relative effectiveness of the trace elements in inhibition of nitrification of NH_4^+-N added to soil depended on soil type. When the trace elements were compared using 5 M g^{-1} of soil, Ag (i), Hg (ii), Cd (ii), Ni (ii), As (iii), Cr (iii), B (ii), Al (iii), Se (iv), Mo (vi) were the most effective inhibitors (average inhibition $>$ 50%) and Mn (ii) and Pb (ii) the least effective (average inhibition $<$ 25%) inhibitors.

Etchevers et al. (1978) observed that nitrification rate was negatively correlated with Al concentration. Giashuddin and Cornfield (1978) found that with increasing Ni level, nitrification decreased to a greater extent than N and C mineralization. Nitrification and N and C mineralization decreased by 68-36 and 35%, respectively, with 1000 ppm Ni. Liang and Tabatabai (1978) investigated the inhibition of nitrification using 21 cationic metals and reported that Ag, Hg and Se strongly inhibited the nitrification process.

Rother *et al.* (1982) reported that nitrification was considerably more sensitive to heavy metals than ammonification. Chang and Broadbent (1982) found that nitrogen immobilization, mineralization and nitrification were inhibited to a greater extent by Cr (iii) added to a neutral soil. Among the six metals they studied the sequence in order of decreasing inhibition to all nitrogen transformation was Cr > Cd > Cu > Zn > Mn > Pb. Ueda (1988) reported that nitrification was prevented at the 10 ppm level by chromate and at the 1000 ppm level by chromium chloride.

An experiment was conducted by Ishaque and Bhuiyan (1984) to study the effects of the addition of Fe, Cu and Zn (50 or 100 ppm) and B, Co, Mo (20 or 50 ppm) to an alluvial soil of pH 7, under aerobic (50% maximum waterholding capacity) or anaerobic (133% maximum waterholding capacity) conditions with respect to nitrogen transformations after six and 12 weeks of incubation at 30°C. It was found that Mo at both levels consistently increased nitrogen mineralization and nitrification. During the six week period, the greatest effect of N mineralization was with 20 ppm Co under anaerobic conditions, followed in decreasing order by 50 ppm B and then by 50 ppm Zn both under aerobic conditions. Under aerobic conditions, 50 ppm of Fe or Cu, seemed to stimulate N mineralization and nitrification after both periods of incubation. Iron or Cu at 100 ppm appeared to inhibit these processes under aerobic conditions and to enhance them under anaerobic conditions.

Broberg (1984) found based on studies of fresh water residues that high levels of metals did not prevent ammonium and nitrite oxidation, the processes were only delayed for a certain time. This was taken to indicate that the nitrifying bacteria became adapted or acclimatised to the metal rich environment. He also found that the oxidation of nitrite was more affected by metal contamination than ammonium oxidation. Low concentrations of Cu and Pb had a stimulatory effect on the oxidation of ammonium. The depressing effect of the metals on the nitrification process followed the order $Cd > Zn > Cu > Pb$.

Olsen and Jacobsen (1985) reported that nitrification was depressed by the addition of $Hg\ Cl_2$ and methoxy ethyl mercury acetate to a sandy loam and a peat. They also found that addition of $Pb\ Cl_2$ could depress nitrification. Arora et al. (1986) found that in coarse textured kaolintic Ultisol the exchangeable Al was negatively correlated with the accumulation of NO_3^--N at the end of a 65 day incubation.

Based on the above review, the effects of the different factors may be summarised as follows. The important factors affecting nitrification were nitrifier population, soil reaction, soil management, soil moisture, soil temperature, organic matter, fertilizers, inhibitors and chemical factors in soil. The nitrifier population was reported to be generally substrate dependant. Decrease of pH in the range from 7.5 to 5.5 decreased the nitrification rate slowly with a corresponding decrease in the number of nitrifying bacteria. Tillage was found to adversely affect nitrification activity in the top 5 cm soil whereas the reverse was the trend at lower depths. Lower soil water potential generally favoured nitrification and the maximum rate of nitrification was in the moisture range of -5 to -0.33 bar. The optimum temperature for nitrification was between 20° and 30°C. Organic acids such as phenolic acid, humic acids etc. formed in the decomposition of organic matter retards nitrification. Nitrification rate was negatively correlated to aluminium concentration and positively correlated to calcium status. Nitrification was found to be sensitive to heavy metals and 5 μmoles of Al and Fe g^{-1} of soil were sufficient to inhibit nitrification. Nirtification inhibitors are widely reported to increase the content of NH_4^+-N in soil and improve N use efficiency in many situations.

Earlier work using laterite soils of Trichur had indicated that the inherent rate of mineralisation in these soils was low and that nitrification inhibitors did not have any effect either on nitrification rate of soil or on crop performance. Amelioration of soil acidity by liming these soils did not enhance nitrification.

Materials and Methods

MATERIALS AND METHODS

The present study was aimed to assess the nitrification rate of Kerala soils and agronomic factors influencing it.

The study comprised of two parts

A - Laboratory experiments

B - Pot experiment

The experiments were conducted during the period from June 1987 to November 1988 at the College of Horticulture, Vellanikkara, Trichur, which is situated at 10°32° N latitude and 76°10° E longitude at an altitude of 22.25 m above mean sea level.

The soils for the laboratory experiments included seven soil types, five from Kerala and two from Coimbatore. The soil types from Kerala were laterite, red, alluvial, forest and black and those from Coimbatore, black and red. Four samples of these soils were collected from different locations.

From the above seven soil types, four soils which were of low nitrification and one soil with high nitrification were used for the pot experiment. The list of the 22 soil samples selected for laboratory study is given in Table 1.

Table 1. Soil samples selected for laboratory study

S.No.	Soil type	Location
1	Laterite soil	Vellanikkara - crop museum
		Vellanikkara - vegetable plot
		Mulamkunnathukavu 1
		Mulamkunnathukavu 2
2	Red soil	Muttackad
		Keezhoor
		Pilicode - N_6 block
		Pilicode - New area
3	Alluvial soil	Manaloor 1
		Manaloor 2
		Manaloor 3
		Manaloor 4
4	Forest soil	Vazhachal
		Thiruvazhamkunnu
		Sholayar 1
		Sholayar 2
5	Black soil	Eruthiyampathi 1
		Eruthiyampathi 2
		Eruthiyampathi 3
		Eruthiyampathi 4
6	Coimbatore red soil	Coimbatore
7	Coimbatore black soil	Coimbatore

A - Laboratory experiments

Experiment No.1

A laboratory incubation study was undertaken to assess the nitrifier population in each soil by the method of most probable numbers (MPN) (Alexander, 1982).

Details of the incubation study

One ml of the ten-fold dilution series of soil upto 10^{-7} was added to liquid culture media for nitrite and nitrate oxidizers. The inoculated tubes were incubated for four weeks at room temperature and the growth in each tube was recorded as either positive or negative. From that count the numbers of *Nitrosomonas* and *Nitrobacter* in each soil sample were calculated using the table for most probable numbers (Cochran, 1950).

Experiment No.2

This experiment was aimed to assess the nitrification rate of soils after the addition of 100 ppm nitrogen as urea.

Details of the incubation study

One kg each of 2 mm sieved soil samples was taken in a plastic bucket with lid and mixed with urea to supply 100 ppm

N. Sufficient water was added to bring the moisture level to 60% of field capacity and this moisture level was maintained throughout the period of incubation by frequent replenishment of water lost. Samples were drawn at intervals of 5, 10, 20 and 30 days for determination of ammoniacal and nitrate nitrogen. Nitrite nitrogen was not detected in measurable amounts and hence its estimation was not carried out. Rate of nitrification was calculated as below.

$$\text{Rate of nitrification (\%)} = \frac{NO_2^- - N + NO_3^- - N \times 100}{NH_4^+ - N + NO_2^- - N + NO_3^- - N}$$

Soil analysis

Soil samples drawn were immediately extracted for 1 hour with 2 M neutral KCl solution and filtered through Whatman No.42 filter paper. The extract was used for analysis. Ammoniacal and nitrate nitrogen were determined by steam distillation method (Bremner, 1965).

Experiment No.3

The objective of this experiment was to relate the chemical properties of soil to nitrifier population and nitrification rate. For this, the soils were analysed for pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon. The pH of the soil was found using a pH meter. Free Iron oxide and Alumina were extracted using dithionite citrate bicarbonate extraction method (Mehra and Jackson, 1960). Exchangeable Ca was determined by versenate method (Hesse, 1971). Organic carbon in the soil was determined by Walkley and Black method (Jackson, 1958).

Experiment No.4

The objective of this study was to find the effect of soil amendment on nitrification. This study was conducted in four soils which were identified as having the lowest rates of nitrification and one with high nitrification. From Experiment No.3 it was found that pH had positive correlation with nitrification rate. Lime requirement of the soil was determined by incubating the soil at 60% field capacity with different quantities of CaO. Soil samples were drawn at 3 days interval till the pH of the soil stabilised. From the graph plotted with pH against different levels of CaO, the quantity of CaO required to reach pH 7 was found.

Sets of 250 g of each soil after passing the entire quantity through 0.5 mm sieve were taken in plastic buckets with lid and were mixed with different levels of CaO viz. 0, 25, 50, 75 and 100% of lime requirement. Sufficient water was added to bring the moisture level to 60% of field capacity and this moisture level was maintained throughout the period of incubation. Soil samples were drawn at 3 days intervals to find the pH. On the date of pH stabilisation, free Aluminium oxide, free Iron oxide and exchangeable Ca in the soils were determined and the soils were mixed with urea to supply 100 ppm N. From this, samples were drawn after 5, 10, 15, 20 and 30 days for determination of ammoniacal nitrogen and after 20 and 30 days for determination of nitrate nitrogen by steam distillation method. Treatments were replicated twice.

B - Pot experiment

A pot experiment was laid out to study the response to application of two standard nitrification inhibitors, N-serve and neem cake on a crop of fodder maize supplied with nitrogen at 100 ppm with and without amendments.

Soils

The soils selected for Experiment No.4 were selected for pot experiment.

Season and climate

The pot experiment was conducted during the period from 20th August 1988 to 19th October 1988. The meteorological data for the crop period are presented as weekly average in Appendix I. The maximum temperature during the crop period ranged between 29.6°C to 31.8°C and the range of minimum temperature was from 22.4°C to 24.6°C. Rainfall was almost distributed throughout the growth period of the crop and a total of 959.7 mm rainfall was received over a period of 49 days.

Layout

The experiment was laid out in completely randamised block design with three replications.

Treatments

T_1 Without nitrification inhibitor and without amendment (I_oA_o)

T_2 Without nitrification inhibitor and with amendment (I_oA)

T_3 With neem cake and without amendment (NC A_o)

T_4 With neem cake and with amendment (NC A)

T_5 With N-serve and without amendment (NS A_o)

T_6 With N-serve and with amendment (NS A)

Planting materials

Test crop	:	Fodder maize
Variety	:	Ganga-5

Pot culture

Sieved soil at the rate of 7.5 kg on oven dry basis was used for the pot experiment. The lime treated soil was maintained at 60% field capacity for over 9 days for pH stabilisation before planting. Cultural practices recommended in the Package of Practices (KAU, 1986) were followed. Seeds were dibbled at 5 cm depth and gap filling was done on seventh day. Watering was done as and when needed.

Fertilizer application

Nitrogen at the strength of 100 ppm in the form of urea was applied basally on the date of sowing.

After cultivation

Weeding, plant protection measures etc. were carried out. The pots were kept weed-free throughout the experimental period.

Observations

1. Growth characters

Plant height

Height was recorded at 15 days interval from the base of the plant to the tip of the longest leaf and the mean height was worked out.

Dry matter production

After harvesting, the plants were oven dried to constant weight at 70 $\pm$ 2°C and the total dry weight was expressed as g $plant^{-1}$.

2. Chemical analysis

The plant samples were ground and N contents were determined using micro-Kjeldahl method (Jackson, 1958).

Uptake of nitrogen

The nitrogen contents were multiplied with their dry matter production and uptake was expressed as mg $plant^{-1}$.

Statistical analysis

The data from the laboratory study were subjected to correlation and those from the experiment to analysis of variance technique (Panse and Sukhatme, 1967).

Results

RESULTS

The data from the laboratory experiments are presented first and these are followed by the results from the pot experiment.

A. Laboratory experiments

Experiment No.1

This laboratory experiment was to assess the nitrifier population in soil by the method of most probable numbers.

Nitrosomonas and nitrobacter population (Table 2)

The overall mean nitrifier population in 10 g of laterite soil was 70 and 384 of *Nitrosomonas* and *Nitrobacter*, respectively. The corresponding mean counts in red soil were 85 and 95, in alluvial soil 78 and 230, in forest soil 120 and 6203 and in black soil 17 and 345. *Nitrosomonas* populations in Coimbatore red and black soils were 5 and 20, respectively. The *Nitrobacter* population in red soil was 3300 and that of black soil, 2500.

Among the total of 18 samples assayed for populations of *Nitrosomonas* and *Nitrobacter*, there were indications of

Table 2. Most probable number of nitrifying bacteria in 10 g soil

S.No.	Type of soil and location	Nitrosomonas	Nitrobacter
1	Laterite soil		
	Vellanikkara - crop museum	0	330
	Vellanikkara - vegetable plot	0	790
	Mulamkunnathukavu	210	33
	Mean	70	384
2	Red soil		
	Muttackad	330	130
	Keezhoor	11	23
	Pilicode - N_6 block	0	220
	Pilicode - New area	0	8
	Mean	85	95
3	Alluvial soil		
	Maneloor 1	78	230
	Mean	78	230
4	Forest soil		
	Vezhachal	400	23000
	Thiruvazhamkunnu	78	280
	Sholayar 1	0	1300
	Sholayar 2	0	230
	Mean	120	6203
5	Black soil		
	Eruthiyampathi 1	45	220
	Eruthiyampathi 2	5	790
	Eruthiyampathi 3	0	330
	Eruthiyampathi 4	17	49
	Mean	17	345
6	Coimbatore red soil	5	3300
7	Coimbatore black soil	20	2500

the presence of Nitrosomonas only in 12 samples, whereas Nitrobacters were noted in all the samples. Comparing between mean populations of soil types, the lowest number of Nitrosomonas of 5 was noted in Coimbatore red soil and the highest number 120 in forest soil. In the case of Nitrobacter, the corresponding values were 95 in red soil and 6203 in forest soil.

Experiment No.2

The aim of this experiment was to assess the nitrification rate of soils after the addition of 100 ppm nitrogen as urea. Assessment was made through estimation of NH_4^+ and NO_3^--N contents.

Ammoniacal nitrogen (Table 3, Fig.1)

The NH_4^+-N in laterite, red and forest soils increased to 120.6 ppm, 103.8 ppm and 89 ppm, respectively on 30th day from 112.3 ppm, 95.4 ppm and 63.2 ppm on 5th day after incubation. In alluvial and black soils the NH_4^+-N decreased with incubation period. The values of NH_4^+-N in alluvial soil were 104.5 ppm on 5th day and 76.5 ppm on 30th day. The corresponding values in black soil were 57.7 ppm and 33.5 ppm. The Coimbatore red and black soils also showed a decrease in NH_4^+-N

Table 3. Content of ammoniacal nitrogen in soil after varying periods of incubation

S. No.	Soil type and location	Content of NH_4^+-N (ppm)			
		Days after incubation			
		5	10	20	30
1	Laterite soil				
	Vellanikkara crop museum	86.5	99.3	104.4	127.3
	Vellanikkara vegetable plot	127.3	122.1	98.7	122.1
	Mulamkunnathukavu 1	117.1	117.1	106.9	122.2
	Mulamkunnathukavu 2	118.3	105.4	108.0	110.6
	Mean	112.3	111.0	104.5	120.6
2	Red soil				
	Muttackad	106.9	106.9	114.5	91.6
	Keezhoor	78.9	78.9	127.3	104.4
	Pilicode - N_6 block	105.0	115.5	110.3	97.1
	Pilicode - New area	90.9	93.5	83.1	122.1
	Mean	95.4	98.7	108.8	103.8
3	Alluvial soil				
	Manaloor 1	101.8	106.9	84.0	104.4
	Manaloor 2	113.4	93.3	80.6	95.0
	Manaloor 3	101.8	89.1	58.5	71.3
	Manaloor 4	100.8	75.6	37.8	35.3
	Mean	104.5	91.2	65.2	76.5
4	Forest soil				
	Vazhachal	31.2	70.1	39.0	23.4
	Thiruvazhamkunnu	47.3	105.0	152.3	115.5
	Sholayar 1	88.5	93.8	99.2	115.3
	Sholayar 2	85.8	107.2	88.5	101.9
	Mean	63.2	94.0	94.8	89.0
5	Black soil				
	Eruthiyampathi 1	46.8	83.1	26.0	41.6
	Eruthiyampathi 2	49.9	42.0	2.7	0
	Eruthiyampathi 3	44.6	13.1	0	0
	Eruthiyampathi 4	89.6	89.6	106.5	92.4
	Mean	57.7	57.0	33.8	33.5
6	Coimbatore red soil	96.5	104.6	126.0	85.8
7	Coimbatore black soil	47.8	42.4	2.7	0

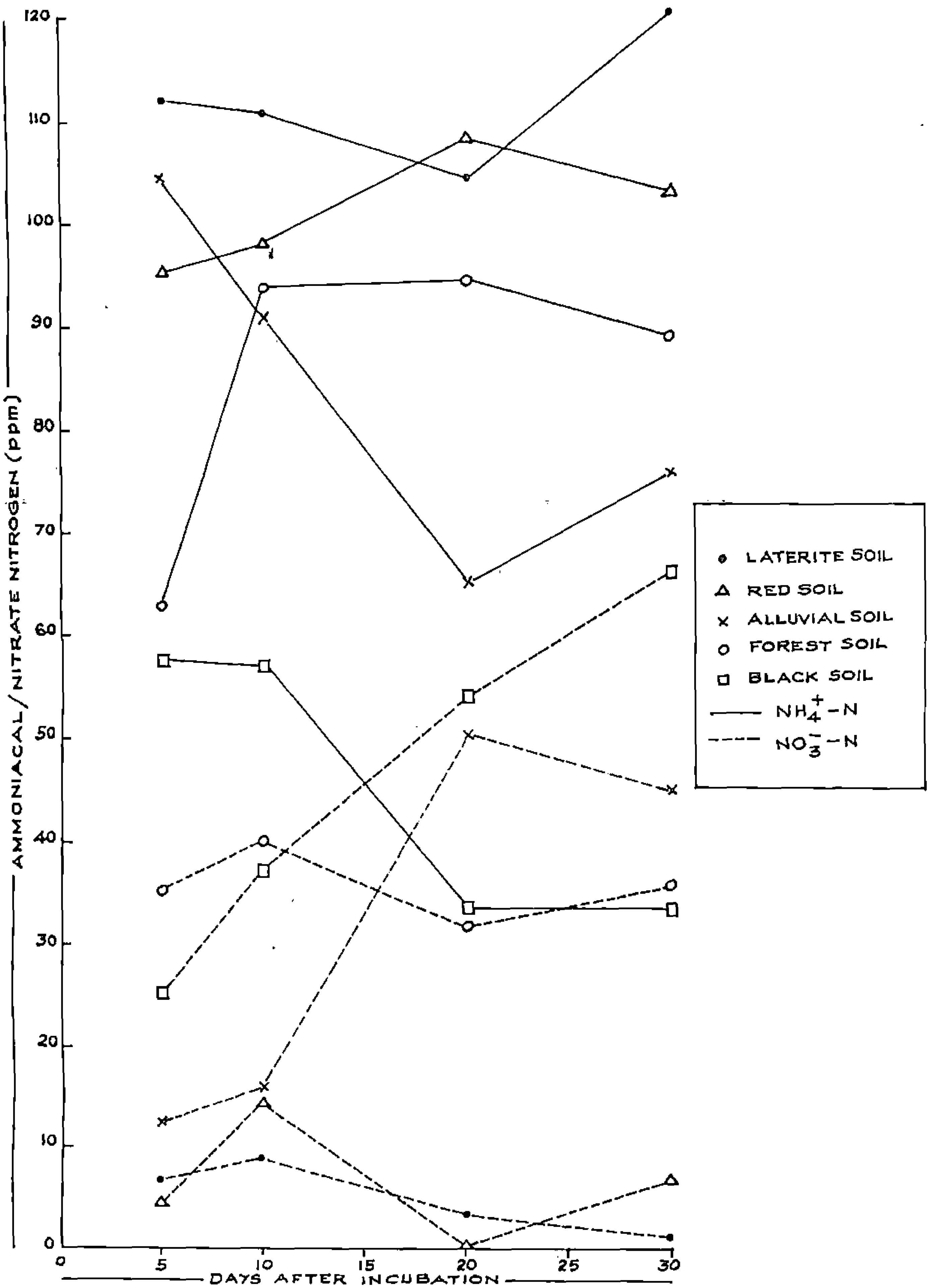

FIG. 1. CONTENT OF AMMONIACAL AND NITRATE NITROGEN IN SOIL AFTER VARYING PERIODS OF INCUBATION.

with incubation time. The values of NH_4^+-N in Coimbatore red soil were 96.5 ppm on 5th day and 85.8 ppm on 30th day. In the corresponding period, the values in Coimbatore black soil were 47.8 ppm and 0 ppm.

Among the Kerala soils, on 5th day after incubation the highest content of NH_4^+-N was noticed in laterite soil (112.3 ppm) and lowest in black soil (57.7 ppm). On 10th day, maximum ammonium content was in laterite soil (111 ppm) and minimum in black soil (57 ppm). On 20th day, the highest amount was in red soil (108.8 ppm) and lowest was in black soil (33.8 ppm). On 30th day, the corresponding figures were 120.6 ppm in laterite soil and 33.5 ppm in black soil.

In two of the five soil types in which samples from multiple locations were included in the study there was substantial decrease in NH_4^+-N content. These are the alluvial and black soils. In the laterite and red soils, there was no consistent trend of change over the period from 5 to 30 days. In forest soil, on the contrary, the trend was one of increase in content. In the case of the two lone samples from Coimbatore, there was substantial decrease in the black soil and lack of it in the red.

Another important feature of the results was that the NH_4^+-N content values were around 100 ppm at the first estimation five days after incubation in almost all the soils. There were, however, strong exceptions to this in the forest and black soils where the values were nearly half as much at this stage.

<u>Nitrate nitrogen</u> (Table 4, Fig. 1)

The mean values are presented in the table after deleting the abnormal values noticed (152.7 ppm in laterite soil, 462.4 ppm in red soil and 181.1 ppm in black soil).

The mean NO_3^--N in laterite soil decreased from 6.5 ppm on 5th day to 1.7 ppm on 30th day after incubation. In red, alluvial and black soils the NH_4^+-N content showed a trend though inconsistent, of increase with time. The values of NO_3^--N on 5th and 30th days after incubation in red, alluvial and black soils in ppm were 4.5 and 7.1, 12.7 and 45.4 and 25.6 and 66.5, respectively. In forest soil, the mean NO_3^--N content remained steady throughout at around 30-40 ppm.

Among the Kerala soils, on 5th and 10th days after incubation, the highest amount of NO_3^--N was observed in forest soil (35.8 ppm and 40 ppm, respectively) and lowest in red soil (4.5 ppm) on 5th day and on 10th day in laterite soil (9.3 ppm). On 20th day and 30th day the highest amount of NO_3^--N was noticed in black soil (54.1 ppm and 66.5 ppm,

Table 4. Content of nitrate nitrogen in soil after varying periods of incubation

S. No.	Soil type and location	Content of NO_3^--N (ppm)			
		Days after incubation			
		5	10	20	30
1	Laterite soil				
	Vellanikkara crop museum	0	15.3	0	152.7*
	Vellanikkara vegetable plot	0	7.8	5.2	0
	Mulamkunnathukavu 1	22.0	3.8	1.3	0
	Mulamkunnathukavu 2	3.9	10.3	7.7	5.1
	Mean	6.5	9.3	3.6	1.7
2	Red soil				
	Muttackad	7.6	1.3	0	16.6
	Keezhoor	10.2	54.7	0	3.8
	Pilicode - N_6 block	0	2.6	0	0
	Pilicode - New area	0	0	462.4*	7.9
	Mean	4.5	14.7	0	7.1
3	Alluvial soil				
	Manaloor 1	6.4	1.3	56.0	16.6
	Manaloor 2	0	7.5	13.9	62.5
	Manaloor 3	38.2	12.7	49.7	36.9
	Manaloor 4	6.3	44.1	82.2	65.5
	Mean	12.7	16.4	50.5	45.4
4	Forest soil				
	Vazhachal	59.7	14.3	110.4	126.0
	Thiruvazhamkunnu	57.8	78.8	0	0
	Sholayar 1	25.5	53.6	0	5.4
	Sholayar 2	0	13.4	18.8	12.1
	Mean	35.8	40.0	32.3	35.9
5	Black soil				
	Eruthiyampathi 1	50.7	14.3	71.4	55.9
	Eruthiyampathi 2	2.6	49.9	181.1*	118.1
	Eruthiyampathi 3	40.7	85.3	85.3	91.9
	Eruthiyampathi 4	8.4	1.4	5.5	0
	Mean	25.6	37.7	54.1	66.5
6	Coimbatore red soil	84.5	2.7	0	0
7	Coimbatore black soil	31.8	43.8	102.1	33.2

*Deleted abnormal values

respectively) and lowest in red soil (0 ppm) on 20th day and in laterite soil (1.7 ppm) on 30th day.

Among the five Kerala soils, there was more or less steady and substantial build up of NO_3^--N content in the alluvial and black soils with advancing period of incubation whereas there was no such trend in the red and laterite soils. In forest soil, the content remained at about 30-40 ppm throughout.

A comparison of the absolute values of these soils indicated that the mean values were relatively high for alluvial and black soils especially towards later stages of incubation and low for the red and laterite. The values of the forest soils were intermediate.

<u>Nitrification rate</u> (Table 5, Fig. 2)

The mean values are presented in the table after deleting the abnormal values noticed in laterite soil (54.5%) and in red soil (84.8%).

In laterite and forest soils, the rate of nitrification decreased with incubation period. Nitrification rate in laterite soil on 5th day was 4.8% and on 30th day, 1.5% and the corresponding values in forest soil were 35.8% and 22.2%.

Table 5. Nitrification rate in soil after varying periods of incubation

S. No.	Soil type and location	Nitrification rate % days after incubation 5	10	20	30
1	Laterite soil				
	Vellanikkara crop museum	0	13.4	0	54.5*
	Vellanikkara vegetable plot	0	6.0	5.0	0
	Mulamkunnathukavu 1	15.8	3.2	1.2	0
	Mulamkunnathukavu 2	3.2	8.9	6.7	4.4
	Mean	4.8	7.9	3.2	1.5
2	Red soil				
	Muttacked	6.6	1.2	0	15.3
	Keezhoor	11.5	40.8	0	3.5
	Pilicode - N_6 block	0	2.2	0	0
	Pilicode - New area	0	0	84.8*	6.1
	Mean	4.5	11.1	0	6.2
3	Alluvial soil				
	Manaloor 1	5.9	1.2	40.0	13.7
	Manaloor 2	0	7.4	14.7	39.7
	Manaloor 3	27.3	12.5	45.9	34.1
	Manaloor 4	5.9	36.8	68.5	65.0
	Mean	9.8	14.2	42.3	38.1
4	Forest soil				
	Vazhachal	65.7	16.9	73.9	84.3
	Thiruvazhamkunnu	55.0	42.9	0	0
	Sholayar 1	22.4	36.4	0	0
	Sholayar 2	0	11.1	0	4.5
	Mean	35.8	26.8	18.5	22.2
5	Black soil				
	Erutiyampathi 1	52.0	14.7	73.3	57.3
	Eruthiyampathi 2	5.0	54.3	98.5	100
	Eruthiyampathi 3	47.7	86.7	100	100
	Eruthiyampathi 4	8.6	1.5	4.9	0
	Mean	28.3	39.3	69.2	64.3
6	Coimbatore red soil	46.7	2.5	0	0
7	Coimbatore black soil	40.0	50.8	97.4	100

*Deleted abnormal values

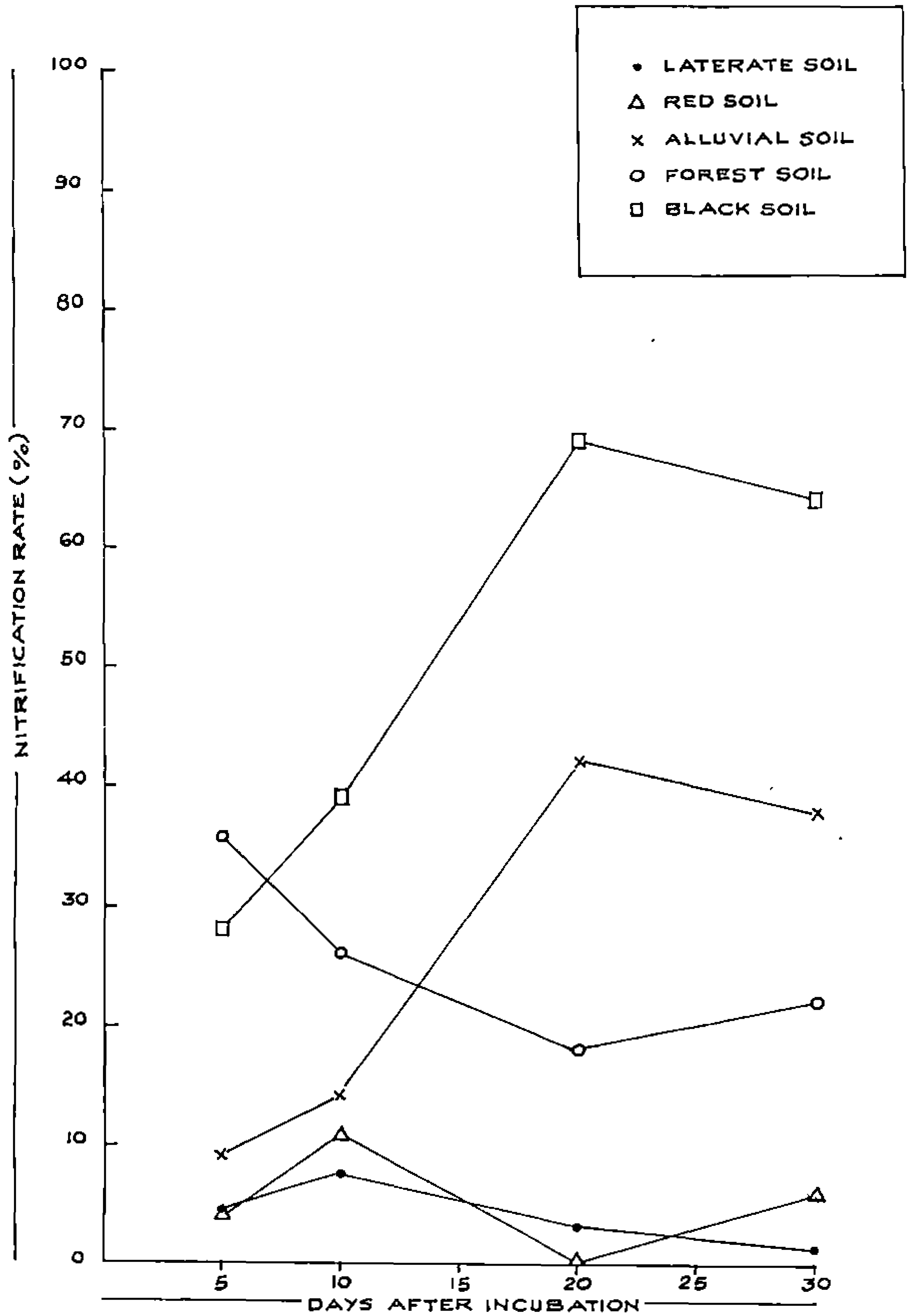

FIG. 2. NITRIFICATION RATE IN SOIL AFTER VARYING PERIODS OF INCUBATION.

In red, alluvial and black soils, the nitrification rate increased with incubation period. In red soil maximum nitrification was noticed on 10th day (11.1%) and in alluvial and black soils on 20th day after incubation (42.3% and 69.2%, respectively). In Coimbatore red soil the maximum nitrification was on 5th day (46.7%) and in black soil on 30th day (100%).

Among the Kerala soils, the maximum nitrification on fifth day was found in forest soil (35.8%) and minimum in red soil (4.5%). On 10th and 30th days, maximum nitrification was noticed in black soil (39.3% and 64.3%, respectively) and minimum in laterite soil (7.9% and 1.5%, respectively). On 20th day highest nitrification rate was noticed in black soil (69.2%) and there was no nitrification in red soil.

Among the five Kerala soils, the rate of nitrification increased with incubation period in alluvial and black soils. In laterite and red soils the nitrification rate increased slightly by 10th day of incubation and thereafter decreased whereas in forest soil the maximum nitrification was noticed on 5th day there being a more or less steady decrease afterwards.

A comparison of the absolute values of these soils indicated that the mean values were relatively high for alluvial and black soils especially towards the later stages of incubation and low for red and laterite. The values of the forest soils were intermediate.

Experiment No.3

The objective of this experiment was to relate the chemical properties of soil to nitrifier population and nitrification rate. For this the soils were analysed for pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon. Data are presented in Table 6.

Among the Kerala soils, black soil had the highest pH (8.1) and laterite soil had the lowest (5.65). The Coimbatore red soil had pH 8.15 and that of black soil, 8.2.

The free Aluminium oxide was highest in black soil (79 ppm) and lowest in forest soil (32 ppm). Free Aluminium oxide content in Kerala soils was in the order, forest soil (32 ppm) $<$ laterite soil (42 ppm) $<$ red soil and alluvial soil (68 ppm) and $<$ black soil (79 ppm). The Coimbatore red soil did not have measurable amounts of free Aluminium oxide. The content in black soil was 42 ppm.

The mean free Iron oxide was highest in laterite soil (16176 ppm) and lowest in black soil (2360 ppm). The free Iron oxide in Kerala soils was in the order black soil (2360 ppm)

Table 6. Chemical properties of soils selected for laboratory study

Sl. No.	Soil type and location	pH	Free Aluminimum oxide (ppm)	Free Iron oxide (ppm)	Exchangeable Ca (%)	Organic carbon (%)
1	Laterite soil					
	Vellanikkara crop museum	5.8	42	18191	0.05	1.2
	Vellanikkara vegetable plot	5.5	42	9901	0.05	1.3
	Mulamkunnathukavu 1	6.0	42	15000	0.06	0.8
	Mulamkunnathukavu 2	5.9	42	21612	0.05	0.8
	Mean	5.65	42	16176	0.05	1.0
2	Red soil					
	Muttackad	6.35	68	8553	0.08	0.9
	Keezhoor	6.1	68	16283	0.05	0.5
	Pilicode - N_6 block	5.7	68	18684	0.04	1.6
	Pilicode - New area	5.95	68	19803	0.04	1.4
	Mean	6.03	68	15831	0.05	1.1
3	Alluvial soil					
	Manaloor 1	6.4	68	1809	0.05	0.5
	Manaloor 2	6.3	68	1480	0.04	0.7
	Manaloor 3	6.4	68	4474	0.06	1.0
	Manaloor 4	6.45	68	4112	0.06	1.1
	Mean	6.39	68	2969	0.05	0.8
4	Forest soil					
	Vazhachal	6.1	42	9046	0.12	5.3
	Thiruvazhamkunnu	5.9	42	19803	0.13	2.7
	Sholayar 1	5.8	0	11414	0.13	3.6
	Sholayar 2	5.9	42	12401	0.13	3.1
	Mean	5.75	32	13166	0.13	3.7
5	Black soil					
	Eruthiyampathi 1	8.2	42	1809	0.47	0.4
	Eruthiyampathi 2	8.2	42	1809	0.36	0.5
	Eruthiyampathi 3	8.2	115	724	0.40	0.5
	Eruthiyampathi 4	7.8	115	5099	0.63	0.8
	Mean	8.1	79	2360	0.47	0.6
6	Coimbatore red soil	8.15	0	7270	0.53	0.3
7	Coimbatore black soil	8.2	42	2303	0.63	0.6

alluvial soil (2969 ppm) < forest soil (13166 ppm) < red soil (15831 ppm) and < laterite soil (16176 ppm). Among the Coimbatore soils, red soil contained lower quantity of free Iron oxide (2303 ppm) than black soil (7270 ppm).

Mean exchangeable Ca was highest in black soil (0.47%) and lowest in laterite, red and alluvial soils (0.05%). Forest soil contained 0.13% exchangeable Ca. The exchangeable Ca content in Coimbatore red soil was 0.53% and that of black soil, 0.63%.

The forest soil contained the highest organic carbon content of 3.7% and black soil contained the lowest (0.6%). The mean organic carbon content in the Kerala soils was in the order, black soil (0.6%) < Alluvial soil (0.8%) < laterite soil (1.0%) < red soil (1.1%) and < forest soil (3.7%). The organic carbon content in Coimbatore red soil (0.3%) was lower than that of black soil (0.6%).

Relation of chemical properties of soil with nitrifier population, contents of nitrogen fractions and nitrification rate

Simple correlation coefficients of chemical properties of soil (pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon) with nitrifier population (*Nitrosomonas* and *Nitrobacter*), contents of nitrogen fractions (NH_4^+-N, NO_3^--N) and nitrification rate were worked out. These are given in Table 7.

No significant correlation was obtained relating the nitrifier population with the chemical properties of soil such as pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon and also with the NH_4^+-N, NO_3^--N and nitrification rate.

Soil pH had significant negative and free Iron oxide significant positive correlation with NH_4^+-N at all periods except during the 5th day where the correlation between NH_4^+-N and free Iron oxide failed to attain the level of significance. Exchangeable Ca also registered significant negative correlation with NH_4^+-N on 5th, 10th and 30th days after incubation. It was also found that pH had significant positive correlation with NO_3^--N on 5th day and with nitrification rate on 5th, 20th and 30th days after incubation. Free Iron oxide had significant negative correlation with NO_3^--N and nitrification rate on 20th and 30th days after incubation. Exchangeable Ca had significant positive correlation with NO_3^--N content and nitrification rate only on 5th day after incubation. At other stages, the correlation was statistically not significant.

Table 7 - Correlation Coefficient (γ) between chemical properties of soil, nitrifier population, nitrogen fractions and nitrification rate

Factors	Nitrifier population		NH_4^+ - N				NO_3^- - N				Nitrification rate			
	Nitrosomonas	Nitrobacter	Days after incubation				Days after incubation				Days after incubation			
			5	10	20	30	5	10	20	30	5	10	20	30
Soil pH	0.2298	0.2899	-0.5149*	-0.6732**	-0.5918**	-0.7264**	0.4252*	0.2505	0.3577	0.4018	0.4358*	0.4198	0.4724*	0.6017**
Free Aluminium oxide	-0.0304	0.0367	-0.0133	-0.3212	-0.2005	-0.1889	-0.3366	0.0533	0.1953	0.1526	-0.1925	0.1428	0.2673	0.1773
Free Iron oxide	0.0954	-0.3032	0.2500	0.5385**	0.6845**	0.6803**	-0.1914	-0.0963	0.446*	-0.5719**	-0.2383	-0.2843	-0.4804*	-0.6497**
Exchangable Ca	0.1061	0.3773	-0.4987*	-0.5133*	-0.3993	-0.5583*	0.4532*	0.1729	0.1761	0.1588	0.4636*	0.3098	0.2589	0.3994
Organic Carbon	-0.2270	-0.2412	-0.2944	0.1136	0.0905	0.0696	0.1919	0.1006	0.1279	0.1754	0.2928	-0.0123	-0.0441	-0.0398
Nitrosomonas population			0.0848	0.2108	0.3106	0.2554	-0.1007	0.0039	-0.1708	-0.1907	-0.1207	-0.0880	-0.2582	-0.2653
Nitrobacter population			0.0582	0.1353	0.0403	0.0964	-0.2616	-0.1369	-0.0857	-0.0369	-0.2708	-0.1324	-0.1806	-0.0551

* Siginificant at 5% level

** Significant at 1% level.

Free Aluminium oxide and organic carbon contents of soil were found to have no significant relation with NH_4^+-N, NO_3^--N and nitrification rate.

Experiment No.4

The objective of this experiment was to study the effect of soil amendment on nitrification. This study was conducted in four soils which were identified as having the lowest rates of nitrification and one with high nitrification rate. The soils selected were laterite soil from Vellanikkara crop museum, red soils from Muttacked and Pilicode and forest soils from Vazhachal and Sholayar. From Experiment No.3, it was found that pH and pH-related factors had significant positive correlation with nitrification rate. The soils were therefore amended with different levels of lime requirement viz., 0, 25, 50, 75 and 100%. After pH stabilisation nine days after treatment, pH, free Aluminium oxide, free Iron oxide and exchangeable Ca were determined to correlate these with nitrification. The amended soils were then incubated after adding nitrogen at 100 ppm as urea and contents of NH_4^+ and NO_3^- nitrogen estimated at varying intervals.

pH (Table 8)

In all the five soils, the pH increased steadily with increasing addition of lime. With 100% lime requirement, the soil pH rose to 7 in laterite and Sholayar soils, to 6.9 in red soils and to 6.7 in Vazhachal soil.

Free Aluminium oxide (Table 8)

Free Aluminium oxide content showed no consistent trend of variation in any of the soils. In Vellanikkara soil it ranged from 23 to 57 ppm, in Muttackad soil 18 to 43 ppm (the abnormal values of 489 and 208 ppm deleted), in Pilicode soil 4 to 32 ppm, in Vazhachal soil 14 to 78 ppm and in Sholayar soil 27 to 43 ppm.

Free Iron oxide (Table 8)

Free Iron oxide content also did not show consistent trend in any of the soils tested. In Vellanikkara soil the free Iron oxide content ranged from 14167 to 25000 ppm, in Muttackad soil 7639 to 15000 ppm, in Pilicode soil 7639 to 17361 ppm, in Vazhachal soil 3056 to 8334 ppm and in Sholayar soil 9722 to 11944 ppm.

Table 8. Chemical properties of soil after liming

S. No.	Soil type and location	Level of lime requirement (%)	pH	Free Aluminium oxide (ppm)	Free Iron oxide (ppm)	Exchangeable Ca (%)
1	Laterite soil					
	Vellanikkara crop museum	0	6.4	23	14167	0.06
		25	6.6	43	24167	0.12
		50	6.8	43	15694	0.12
		75	6.9	57	25000	0.14
		100	7.0	23	15694	0.18
2	Red soil					
	Muttackad	0	5.5	23	15000	0.07
		25	6.0	18	11944	0.08
		50	6.5	469*	11111	0.11
		75	6.5	208*	7639	0.14
		100	6.9	43	7639	0.16
3	Red soil					
	Pilicode N_6 block	0	5.5	29	17361	0.02
		25	5.8	4	7639	0.04
		50	6.3	32	8333	0.09
		75	6.7	27	11944	0.13
		100	6.9	4	8333	0.18
4	Forest soil					
	Vazhachal	0	5.45	14	5000	0.05
		25	5.9	38	6944	0.12
		50	6.2	78	8334	0.18
		75	6.6	43	3056	0.26
		100	6.7	47	3611	0.34
5	Forest soil					
	Sholayar 1	0	6.3	43	10417	0.10
		25	6.5	38	8722	0.18
		50	6.7	27	11111	0.18
		75	6.8	32	11944	0.20
		100	7.0	38	10417	0.22

*Deleted abnormal values

Exchangeable Ca (Table 8)

Exchangeable Ca in the five soils tested steadily increased with addition of lime. With 100% lime requirement the exchangeable Ca increased in Vellanikkara soil from 0.06% to 0.18%, in Muttackad soil 0.07% to 0.16%, in Pilicode soil 0.02% to 0.18%, in Vazhachal soil 0.05% to 0.34% and in Sholayar soil 0.1% to 0.22%.

Ammoniacal nitrogen (Table 9, Fig. 3)

The NH_4^+-N content was determined 5, 10, 15, 20 and 30 days after incubation. On 5th day after incubation, NH_4^+-N content increased in all the five soil samples with increased levels of lime. On 10th, 15th, 20th and 30th days after incubation, the NH_4^+-N content increased with increasing levels of lime only in Vellanikkara and Pilicode soils. Throughout the experimental period, the trend of change in NH_4^+-N content in all soils was not consistent except in Vazhachal soil where there was a steady decrease in content with increasing levels of lime. The range of NH_4^+-N was from 43.4 ppm to 71.4 ppm in laterite soil, 58.1 ppm to 79.8 ppm in Muttackad soil, 70 ppm to 118.3 ppm in Pilicode soil, 4.9 ppm to 49 ppm in Vazhachal soil and 82.6 ppm to 124.6 ppm in Sholayar soil.

Table 9. Content of ammoniacal nitrogen, nitrate nitrogen and nitrification rate after various periods of incubation in soil after liming

S. No.	Soil type and location	Levels of lime requirement (%)	NH_4^+-N (ppm) Days after incubation					NO_3^--N (ppm) Days after incubation		Nitrification Rate (%) Days after incubation	
			5	10	15	20	30	20	30	20	30
1	2	3	4	5	6	7	8	9	10	11	12
1	Laterite soil										
	Vellanikkara crop museum	0	51.1	61.6	43.4	52.5	44.1	24.5	74.9	31.8	62.9
		25	55.3	58.8	48.3	71.4	64.4	17.9	19.6	20.0	23.3
		50	57.4	63.0	56.0	67.2	59.5	37.8	28.0	36.0	32.0
		75	51.1	63.0	52.5	65.1	56.0	48.7	23.8	42.8	29.8
		100	61.6	58.8	53.2	65.1	60.9	60.9	23.1	48.3	27.5
2	Red soil										
	Muttackad	0	64.4	79.8	80.5	78.4	76.3	9.1	2.7	10.4	3.4
		25	67.9	73.5	77.0	74.2	71.4	0	3.6	0	4.8
		50	83.3	60.2	71.4	74.2	68.6	8.1	8.4	9.8	10.9
		75	73.5	63.0	68.6	77.0	69.3	36.8	9.7	32.3	12.3
		100	65.1	58.1	60.9	69.3	63.0	44.5	7.0	39.0	10.0

Contd.

Table 9. Continued

1	2	3	4	5	6	7	8	9	10	11	12
3	Red soil										
	Pilicode - N_6 block	0	73.5	72.8	71.4	81.9	70.7	30.1	2.1	26.9	2.9
		25	74.9	86.1	72.8	79.8	70.0	13.0	10.5	14.0	13.0
		50	82.6	79.8	77.0	84.0	78.4	28.0	9.1	25.0	10.4
		75	75.6	100.8	82.6	91.0	90.3	21.0	16.5	18.8	15.5
		100	77.0	118.3	88.2	95.2	102.2	16.8	0	15.0	0
4	Forest soil										
	Vazhachal	0	46.2	32.2	23.1	28.9	16.1	70.9	74.9	71.0	82.3
		25	47.6	22.4	10.5	10.5	14.7	87.5	74.6	89.3	83.5
		50	41.3	20.3	8.4	8.4	7.7	96.6	100.8	92.0	92.9
		75	49.0	13.8	5.6	10.5	7.0	101.5	94.5	90.6	93.1
		100	49.0	16.8	4.9	9.8	9.1	100.5	83.7	91.1	90.2
5	Forest soil										
	Sholayar 1	0	82.6	120.4	103.8	124.6	101.5	32.9	29.8	20.9	22.7
		25	116.9	106.4	114.8	118.7	107.1	55.3	27.7	31.6	20.6
		50	107.8	98.0	102.2	107.1	89.6	55.7	60.9	34.2	40.5
		75	107.8	106.4	101.5	109.9	91.7	75.6	37.8	40.8	29.2
		100	109.2	110.6	107.1	123.9	90.3	42.8	63.7	25.7	41.4

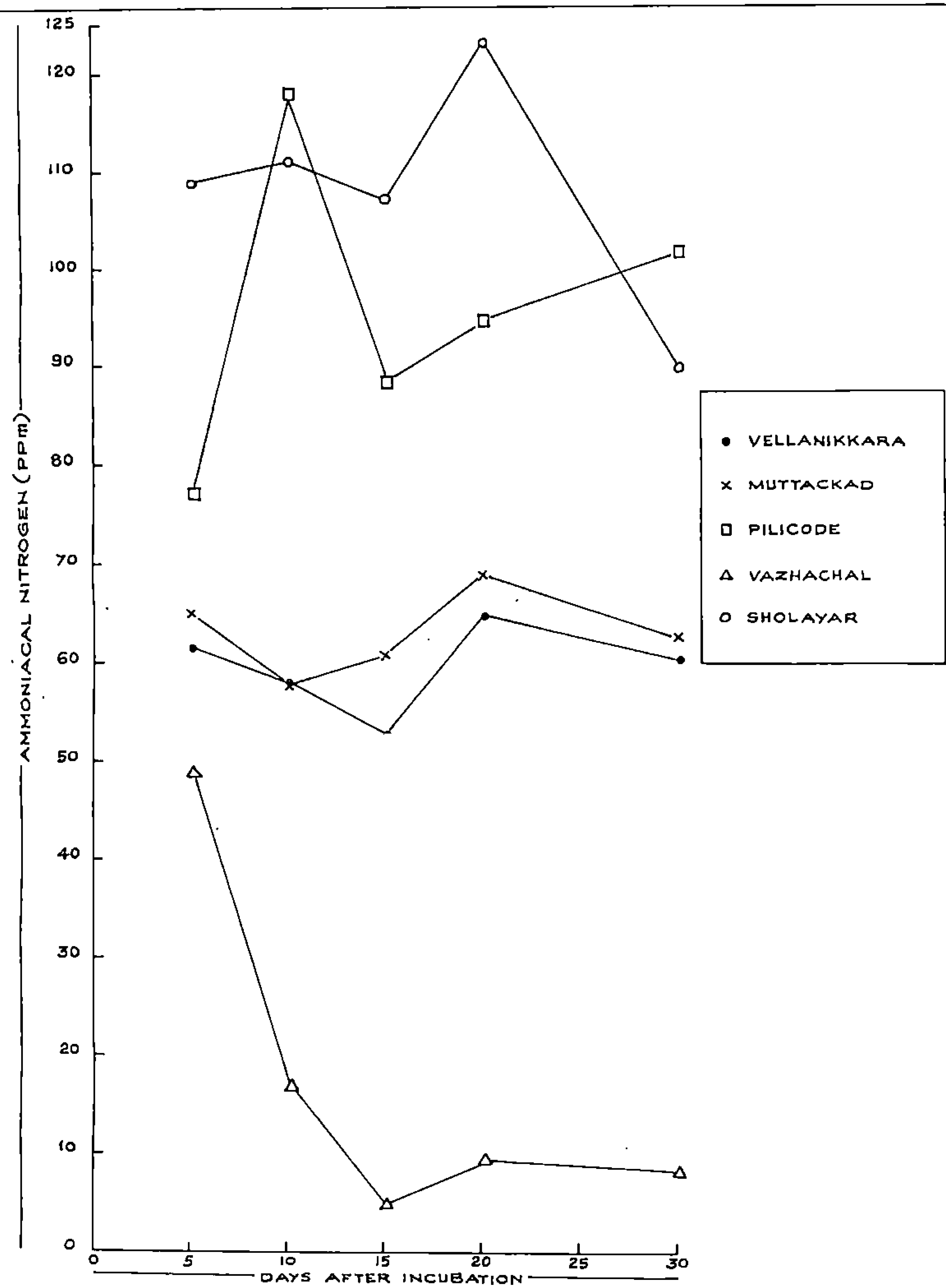

FIG.3. CONTENT OF AMMONIACAL NITROGEN IN SOIL AFTER LIMING AT 100% LIME REQUIREMENT.

On comparing the NH_4^+-N in different soils with different levels of lime requirement and incubation time, it was noticed that the values were lower in Vazhachal soil and substantially higher in all the others.

Nitrate nitrogen (Table 9)

The NO_3^--N content was determined 20 and 30 days after incubation. In this case also the data obtained were not consistent for the effect of liming. Comparing between soil types there was substantial accumulation of NO_3^--N only in Vazhachal soil. The ranges in values for the different soils were from 17.9 ppm to 74.9 ppm in laterite soil, 0 ppm to 44.5 ppm in Muttackad soil, 0 ppm to 30.1 ppm in Pilicode soil, 70.9 ppm to 101.5 ppm in Vazhachal soil and 27.7 ppm to 75.6 ppm in Sholayar soil.

Nitrification rate (Table 9)

The nitrification rate was determined on 20 and 30 days after incubation. Only in Vazhachal forest soil did nitrification rate increase with increasing levels of lime. Maximum nitrification was noticed on 30th day after incubation in this soil when treated with lime at 75% requirement (93.1%). In other soils the data obtained were not consistent. The range in values for the different soils were from 20 to

62.9% in laterite soil, 0 to 39% in Muttackad soil, 0 to 26.9% in Pilicode soil, 71 to 93.1% in Vazhachal soil and 20.6 to 41.4% in Sholayar soil.

It is to be concluded that consistent variation in contents of NH_4^+-N and NO_3^--N was not observed in any of the soil samples except Vazhachal forest soil, where a substantial decrease in NH_4^+-N and increase in NO_3^--N with high levels of lime were noticed. Liming, thus, appeared to have beneficial effects on nitrification only in Vazhachal forest soil.

Relation between chemical properties of amended soil and content of nitrogen fractions and nitrification rate

Simple correlation coefficients between chemical properties of amended soil (pH, free Aluminium oxide, free Iron oxide and exchangeable Ca) and nitrogen fractions (NH_4^+-N, NO_3^--N) and nitrification rate were worked out. These are given in Table 10.

Free Aluminium oxide, free Iron oxide, exchangeable Ca and pH had no significant correlation with NH_4^+-N content. It was also found that pH and free Aluminium oxide had no significant correlation with NO_3^--N content and nitrification rate of the soils tested. On 20th and 30th days after

Table 10. Correlation coefficient (r) between chemical properties of amended soil, nitrogen fractions and nitrification rate

Chemical properties	NH_4^+-N					NO_3^--N		Nitrification rate	
	Days after incubation					Days after incubation		Days after incubation	
	5	10	15	20	30	20	30	20	30
Soil pH	0.2517	0.2068	0.1750	0.2374	0.2369	0.1439	0.0241	0.0062	-0.0427
Free Aluminium oxide	0.0819	-0.1404	0.0005	-0.0220	-0.0119	-0.1706	-0.1525	-0.1355	-0.1288
Free Iron oxide	-0.0356	0.2212	0.2162	0.2864	0.2948	-0.4261*	-0.4016*	-0.4285*	-0.4089*
Exchangeable Ca	0.0920	-0.1824	-0.1881	-0.1765	-0.1970	0.6462**	0.4641*	0.5154**	0.4336*

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

incubation the NO_3^--N content in the soil and nitrification rate had significant negative correlation with free Iron oxide and positive correlation with exchangeable Ca.

Pot experiment

The results from the pot experiment that was laid out to study the response to application of two standard nitrification inhibitors, N-serve and neemcake on a crop of fodder maize supplied with nitrogen at 100 ppm with and without amendment are furnished in this section.

Plant height (Table 11, Appendix II)

No significant difference was noticed between treatments in respect of plant height on 15th, 30th, 45th and 60th days after sowing. Between soils, no significant difference was observed on 15th and 30th days after sowing. On 45th day the plants grown in Sholayar (94.6 cm) and Vazhachal (87.6 cm) soils were significantly taller than those in laterite soil (78.9 cm). The plants grown in Sholayar (94.6 cm) were also significantly taller than those in Muttackad (85.4 cm) and Pilicode (82.2 cm) soils. On 60th day also the plants grown in forest soils were significantly taller than those in laterite and red soils. The mean height of the plants in

Table 11. Effect of nitrification inhibitors and liming on plant height, dry weight, nitrogen content and nitrogen uptake of maize grown in different soils

	Plant height(cm) Days after sowing 15	30	45	60	Dry weight (g plant^{-1}) at harvest	Nitrogen content (%) at harvest	Nitrogen uptake (mg plant^{-1}) at harvest
Treatments							
T_1 (IoAo)	35.8	64.6	83.9	91.3	15.8	0.74	122.6
T_2 (IoA)	33.4	63.6	88.8	98.3	17.9	0.78	148.5
T_3 (NCAo)	36.1	63.5	81.2	86.7	16.2	0.78	125.7
T_4 (NC A)	33.1	63.1	85.4	93.7	17.1	0.76	145.7
T_5 (NS Ao)	36.1	69.9	86.5	94.2	17.1	0.76	129.7
T_6 (NS A)	35.9	66.2	88.8	98.3	20.5	0.83	172.7
SEm±	1.81	3.00	3.02	3.50	1.82	0.05	20.08
CD (0.06)	NS	NS	NS	NS	NS	NS	NS
Soils							
Laterite - Vellanikkara crop museum	35.1	64.0	78.9	83.1	11.9	0.74	87.8
Red - Muttackad	38.5	71.3	85.4	89.8	16.6	0.62	96.8
Red - Pilicode	33.6	60.6	82.2	88.3	13.3	0.70	99.7
Forest - Vazhachal	35.1	64.0	87.6	101.2	21.1	0.92	203.9
Forest - Sholayar 1	33.2	65.8	94.6	106.4	24.3	0.89	215.8
SEm±	2.65	2.74	2.76	3.19	1.66	0.05	18.33
CD (0.05)	NS	NS	7.64	8.85	4.59	0.13	50.78

Io - Without inhibitor
NC - With neem cake
NS - With N-serve

Ao - Without amendment
A - With amendment

different soils tested in the decreasing order were Sholayar (106.4 cm), Vazhachal (101.2 cm), Muttackad (89.8 cm), Pilicode (88.3 cm) and Vellanikkara (83.1 cm).

In general, the forest soils especially Sholayar soil favoured better plant growth as measured through plant height. Between treatments, there was no significant difference.

<u>Dry matter production</u> (Table 11, Fig. 4, Appendix II)

In respect of dry matter production, the treatments did not differ significantly from one another. The highest mean dry matter production of 20.5 g plant^{-1} was in T_6 (with N-serve and with amendment) and lowest (15.8 g plant^{-1}) in T_1 (without inhibitor and without amendment). Between soils, significant differences were noticed. Forest soils gave significantly higher values than Vellanikkara and Pilicode soils. Also, a significant difference was observed between Vellanikkara and Muttackad soils, the latter being superior. The highest dry matter production was in Sholayar soil (24.3 g plant^{-1}) and lowest in Vellanikkara soil (11.9 g plant^{-1}). The dry matter production in other soils were Vazhachal, 21.1 g plant^{-1}, Muttackad, 16.6 g plant^{-1} and Pilicode 13.3 g plant^{-1}.

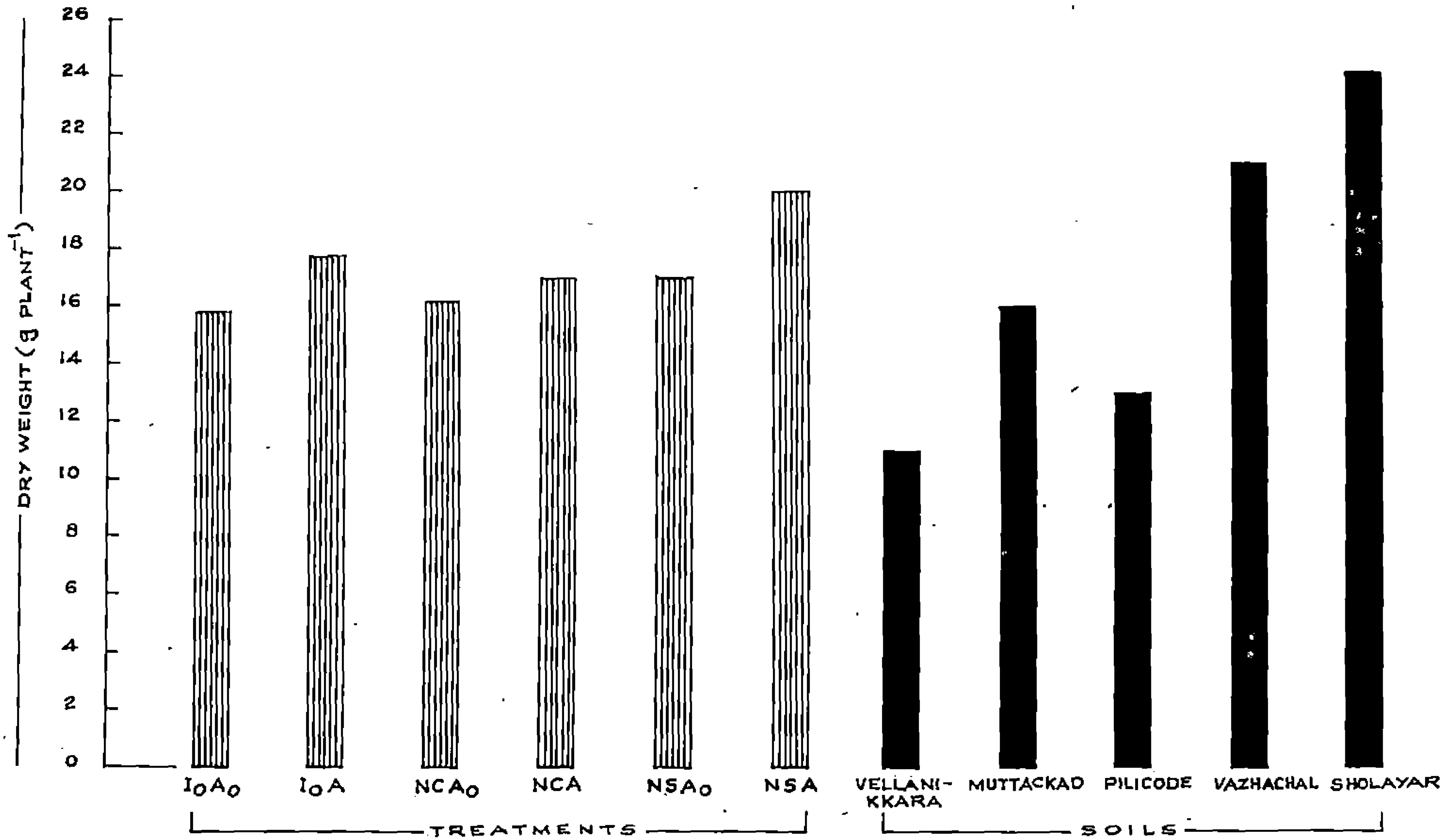

FIG. 4. EFFECT OF NITRIFICATION INHIBITORS AND LIMING ON DRY WEIGHT OF MAIZE GROWN IN DIFFERENT SOILS.

Nitrogen content (Table 11, Appendix II)

The treatments did not differ significantly from one another. The highest mean nitrogen content (0.83%) was observed in T_6 (with N-serve and with amendment) and lowest (0.74%) in T_1 (without inhibitor and without amendment). Between soils, significant difference was noticed. The forest soils were significantly different from laterite and red soils, the values of the former two being higher. The highest mean nitrogen content was found in plants grown in Vazhachal soil (0.92%) and lowest in Muttackad (0.62%). Nitrogen contents in plants grown in other soils were Sholayar 0.89%, Vellanikkara 0.74% and Pilicode 0.70%.

Nitrogen uptake (Table 11, Fig. 5, Appendix II)

The treatments did not differ significantly from one another. The highest mean nitrogen uptake (172.7 mg plant^{-1}) was in treatment T_6 (with N-serve and with amendment) and lowest (122.6 mg plant^{-1}) in T_1 (without inhibitor and without amendment). The forest soils were significantly different from laterite and red soils, the values of the former two being higher. The highest mean nitrogen uptake was found in plants grown in Sholayar soil (215.8 mg plant^{-1}) and lowest in Vellanikkara soil (87.8 mg plant^{-1}). Nitrogen uptake in

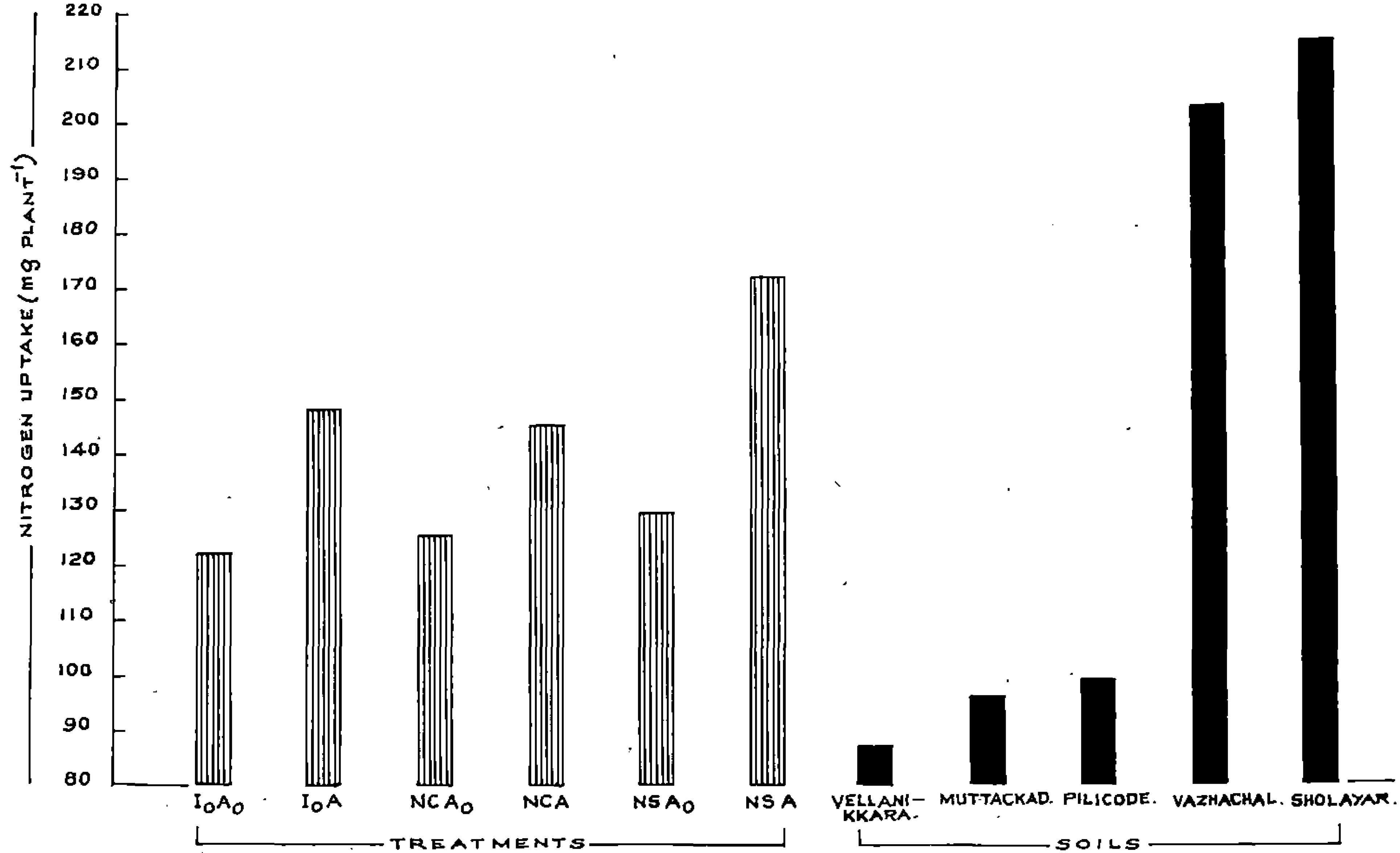

FIG. 5. EFFECT OF NITRIFICATION INHIBITORS AND LIMING ON NITROGEN UPTAKE OF MAIZE GROWN IN DIFFERENT SOILS.

plants grown in other soils was Vazhachal 203.9 mg plant^{-1}, Pilicode 99.7 mg plant^{-1} and Muttackad 96.8 mg plant^{-1}.

In general, forest soils were found superior to other soils in respect of dry matter production, nitrogen content and nitrogen uptake at harvest. Dry matter production and nitrogen uptake were highest in plants grown in Sholayar soils whereas nitrogen content was high in Vazhachal soil.

Discussion

DISCUSSION

The present study was aimed at assessing the nitrification rate of Kerala soils and agronomic factors influencing it. The assessment was done using laboratory incubation studies and a pot experiment. A total of 22 soil samples including 20 samples drawn from five soil types of Kerala and two from Coimbatore was used for the laboratory incubation study and five were selected for the pot experiment.

As the first part of this study, the nitrifier population of the soil samples was assessed by the method of most probable number (MPN) (Alexander, 1982). The results of the study showed positive indications of the presence of Nitrosomonas in 11 samples whereas Nitrobacters were noted in all the samples (Table 2). Comparing between mean population of soil types, the lowest number of Nitrosomonas of 5 was noted in Coimbatore red soil and the highest number of 120, in forest soil. In the case of Nitrobacter, the corresponding values were 95 in red soil and 6203 in forest soil. A perusal of the data on nitrifier population of different soils (Table 2) would indicate that there had been wide variations between soils in the population of nitrifiers and even between samples of the same type. Because of these large variations, it is difficult to depend on these data as an indicator of the relative nitrifying abilities of soil. The only conclusion that can be drawn from the data is that these organisms occur in all the soils tested.

Direct assessment of the nitrification rate of the different soils was made by incubating soil at 60% field capacity with addition of 100 ppm N as urea for a period of one month. The soil samples were drawn at intervals of 5, 10, 20 and 30 days for estimations of NH_4^+-N and NO_3^--N.

Data on the NH_4^+-N content showed that the content of this nitrogen fraction decreased substantially with advancing time in alluvial and black soils of Kerala and black soil of Coimbatore from initial high values indicating high rates of nitrification. In the laterite and red soils of Kerala and red soil of Coimbatore, there was no consistent trend of change over the period from 5 to 30 days and the values remained high throughout. Lack of a substantial conversion of NH_4^+-N produced from ammonification of added urea appears to be the reason for this. In forest soil, the trend was one of increase in content of NH_4^+-N. Continued ammonification of organic nitrogen in this organic rich soil is the probable reason for such an increase. The mean NH_4^+-N content values were around 100 ppm at the first estimation five days after incubation in almost all the soils except forest and black soils where the values were nearly half as much. Substantial conversion of NH_4^+-N even at the first stage five days after incubation in these two soils was perhaps responsible for the low content in these two soils.

The content of NO_3^--N followed as more or less predictable trend with substantial build up of this fraction in the alluvial and black soils and meagre levels of it in the laterite and red soils. It may be recalled that in the soils in which NO_3^- accumulation was low, the NH_4^+-N content remained high. It is to be noted, however, that there were large variations in the estimated values of NO_3^--N content between samples even within the same soil type. Even in the soil from the same location, substantial fluctuations were noticed between stages. The reason for such inconsistency in values probably lies in the fact that NO_3^- estimations in the soil were done by the substraction method which is prone to errors. In forest soil, the overall mean NO_3^--N content came in between the above two groups of soil with mean content fluctuating around 30-40 ppm. There was apparently some degree of nitrification inhibition in forest soils also. Evidences for lack of brisk nitrification in forest soils were reported earlier by Vlassak (1970) who observed that soils under natural vegetative covers of conifers and hardwoods were mostly ammonifying. Wheeler and Donaldson (1983) observed that nitrification was rapid in soil under herbaceous communities, followed by bush and that it was not detectable in soil under trees.

The calculated values of nitrification rate also showed large variations as in the case of NO_3^--N content. Still there was a more or less distinct trend of rates being high for the alluvial and black soils and low for the red and laterite with the forest soil coming in between.

Based on the above results of this part of the laboratory study, the overall conclusion may be drawn as follows.

1. Nitrifiers occur in all the soils tested though their abundance was generally low and highly variable.
2. There is rapid ammonification of nitrogen applied as urea in all the soils but nitrification rate is substantial only in the alluvial and black soils. The speed of nitrification measured in terms of contents of NH_4^+-N and NO_3^--N and nitrification rate was very low in red and laterite soils. Forest soils were intermediate.
3. Whereas in most of the soils tested accumulation of NH_4^+-N reached its peak by about 5th day of incubation, there was continued ammonification in forest soils either

because of mineralization of organic nitrogen or because of an early immobilization followed by a subsequent mineralization.

The next part of the laboratory study was aimed at locating the factors responsible for the low rates of nitrification in some of the soil types. The suspected factors and reasons for this were the following.

1. The pH values of these soils are low. The mean values of pH of the laterite, red and forest soils were 5.65, 6.03 and 5.75, respectively. Such a low pH may be unfavourable for the growth and activity of nitrifiers. If has been reported that once the pH was lowered from 7.5 to 5.5, the nitrification rate decreased slowly with a corresponding decrease in the numbers of nitrifying bacteria (Sarathchandra, 1978). According to Tisdale et al. (1985) the optimum pH for nitrification is 8.5.
2. The free Aluminium oxide in these soils are high. Etchervers et al. (1978) and Arora et al. (1986) observed that nitrification rate was negatively correlated with extractable Al concentration. Liang and Tabatabai (1978) found that 5 μmoles of Al g^{-1} of soil was sufficient to inhibit nitrification.

3. The free Iron oxide in these soils are high. Liang and Tabatabai (1978) found that 5 μ moles of Fe g^{-1} of soil could inhibit nitrification. Ishaque and Bhuiyan (1984) observed that 50 ppm of Fe stimulated N mineralization and nitrification after six and 12 weeks of incubation at 30°C, whereas 100 ppm Fe appeared to inhibit these processes under aerobic conditions and to enhance them under anaerobic conditions.

4. The exchangeable Ca in these soils are low. According to Glambiazi and Kraljev (1973), Ca content is significantly correlated with nitrifying activity in A horizon. Arora et al. (1986) found that exchangeable Ca had positive correlation with the accumulation of NO_3^--N at the end of a 65 day incubation in a coarse textured kaolinitic ultisol.

5. Organic carbon in some of these soils are high. Mochoge and Beese (1983) reported that the forest soil had higher incorporation of N in the organic fraction than did the agricultural soil. Nitrification was low in the forest soil, but in the agricultural soil there was a fairly high nitrification even at 4°C.

To assess the influence of above factors on nitrifier population, contents of NH_4^+ and NO_3^--N and on nitrification rate, a separate study was conducted. For this, all the soils used for the first laboratory incubation study were analysed for pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon.

The mean pH of Kerala soils ranged from 5.65 for laterite to 8.1 in black soil, the mean free Aluminium oxide from 32 ppm in forest to 79 ppm in black soil, the mean free Iron oxide from 2360 ppm in black soil to 16176 ppm in laterite, exchangeable Ca from 0.05% in red, laterite and alluvial soil to 0.47% in black soil and organic carbon from 0.54% in black soil to 3.7% in forest soil. Simple correlation worked out between the various parameters showed that NH_4^+-N content had significant negative relation in most of the instances with pH and exchangeable Ca. The relation with free Iron oxide was significant and positive. Nitrate nitrogen, on the contrary, gave the expected significant positive relation with pH and exchangeable Ca and negative relation with free Iron oxide in most of the instances. In the case of nitrification rate the type of relation was similar to that of NO_3^--N, there being larger number of occassions where the relations were significant. Free Aluminium oxide and organic carbon contents failed to register significant relations either with the nitrogen fractions or with nitrification rate. From the above trend of results, it can be concluded that acidic soils of Kerala with low pH values tended to inhibit nitrification. Such soils also had higher free Iron oxide contents and hence a negative relation between this fraction of Fe and nitrification was obtained. In as much as high Ca content and low free Iron oxide content are strongly linked with pH of the soil this character was isolated and identified as the probable factor which was to be amended if nitrification in these soils is to be enhanced.

Another ancillary observation that is to be made from the correlation values is that estimation of nitrifier population by the method of most probable numbers may not reflect the nitrifying ability of a soil. It is also to be noted that nitrifier number did not show significant relation with any of the soil characters studied.

In the next part of the laboratory study, an attempt was made to bring the soil to near neutrality by liming so that the suspected factors could be amended to a level more suitable for nitrification. The levels of liming were 0, 25, 50, 75 and 100% of lime requirement. For this study, a total of five soils from among the 22 were selected. All the selected soils excepting the Vazhachal forest soil had recorded very low rates of nitrification in the previous studies. After a period of nine days given for pH stabilisation, samples of soil were analysed for pH, free Aluminium oxide, free Iron oxide and exchangeable Ca. The amended soils were also incubated with nitrogen at 100 ppm as urea and estimations of NH_4^+ and NO_3^--N carried out at varying intervals.

Because of liming, the pH of all the soils was brought to near neutrality. The range of final pH values was from 6.7 to 7. This treatment also resulted in consistent increase in Ca content in all the soils. The trends of change in free Aluminium oxide and free Iron oxide content were inconsistent, there being increase in some instances and decrease in some others.

Incubation studies with amended soil showed no consistent advantage due to amendment of the soil with lime on nitrification as judged by contents of NH_4^+ and NO_3^--N. Correlation coefficients also showed total lack of significant relation between NH_4^+-N and any of the chemical factors studied. In the case of NO_3^--N content and nitrification rate whose values were less consistent, there were significant relations noticed with free Iron oxide and exchangeable Ca on 20th and 30th days after incubation. Neglecting these two isolated instances of statistical significance as incidental, the overall conclusion should be that modifications in chemical characters of soils of low nitrification could not result in a substantial increase in nitrification rate. The only exception to this appears to be in Vazhachal forest soil which was included in the study to represent a soil with high rate of nitrification. In an earlier study involving a laterite soil with low inherent nitrification ability, Mathew (1986) reported that amelioration of soil acidity by liming did not enhance nitrification. It may be recalled that in the laboratory study conducted to relate the chemical properties of different soils there was significant relation between nitrification and pH, exchangeable Ca and free Iron oxide. The relation must be treated as only incidental and the conclusion should be that soils with low nitrification rate generally have low pH, low exchangeable Ca and high free Iron oxide. The noted significant correlations in the first part of laboratory study was in all probability indirect.

The pot experiment was conducted to study the response to application of two standard nitrification inhibitors, N-serve and neemcake on crop of fodder maize supplied with nitrogen at 100 ppm with and without amendment. This replicated pot experiment with maize was conducted with a total of six treatments and five soils, viz., laterite soil from Vellanikkara, red soils from Muttackad and Pilicode and forest soils from Vazhachal and Sholayar. The nitrification inhibitors were applied at the standard rates. Fodder maize was grown for a period of 60 days and observations on plant height at 15 days intervals, dry matter production, N content and N uptake at harvest were recorded.

Data on the growth characters including plant height and dry matter production showed no significant difference between treatments (Table 11). The results of chemical analysis also showed no significant difference between treatments. Even though it was expected that there would be advantage due to the use of inhibitors at least in soils with high nitrification rates under conditions favouring heavy leaching, there was no such trend noted in the results of the present study. The apparent reason for this is that the rainfall pattern during the experimental period did not favour very heavy leaching. The total rainfall received in 49 rainy days during the crop period was 959.7 mm. Assuming that rainfall of over 1 cm in a day favoured significant leaching, there were conditions favouring substantial leaching only on 23 days. One ancillary advantage of the use of organic nitrification inhibitors like neemcake is the supply from them of growth promotors of the hormonal nature. Such an advantage also was not apparent in the present study.

A conspicuous and significant result from this experiment was that the soils showed significant difference in respect of plant height on 45th and 60th days and dry matter production, nitrogen content and nitrogen uptake at harvest (Table 11). Forest soils favoured better growth at nearly all stages and higher accumulation of nitrogen at harvest. The high content of organic matter in these soils and the accompanying improvement of physical, chemical and biological conditions are the attributable factors for this.

As had been indicated in the list of objectives, the main purpose of the study was to assess the nitrification rate of Kerala soils and agronomic factors influencing it. Among the Kerala soils the nitrification rate in alluvial and black soils were high, it was low for the red and laterite soils and the forest soil came in between. The nitrifier population estimated by the method of most probable number (MPN) did not show significant relation with any of the soil characters. It also did not reflect the nitrifying ability of a soil. Soils with low nitrification rate generally had low pH, low exchangeable Ca and high free Iron oxide. Modification on chemical characters of soils of low nitrification through liming to near neutral levels, however could not lead to an increase in nitrification rate.

Summary

SUMMARY

A study was conducted during the period from June 1987 to November 1988 at the College of Horticulture, Vellanikkara, Trichur to assess the nitrification rate of Kerala soils and agronomic factors influencing it. A series of laboratory incubation studies were conducted using a total of 22 soil samples including 20 samples drawn from five soil types (laterite, red, alluvial, forest and black soil) of Kerala and two from Coimbatore (red and black). The first laboratory study was to assess the nitrifier population in each soil by the method of most probable numbers (MPN).

The next laboratory study was aimed to assess the nitrification rate of soils after the addition of 100 ppm nitrogen as urea. All the above 22 soils were used for this. Samples were drawn at intervals of 5, 10, 20 and 30 days for determination of NH_4^+ and NO_3^--N. Another experiment was done to relate the chemical properties of soil to nitrifier population and nitrification rate. For this, the soils were analysed for pH, free Aluminium oxide, free Iron oxide, exchangeable Ca and organic carbon. Simple correlation was worked out to find the relation between chemical properties of soil, nitrifier population and content of nitrogen fractions and nitrification rate.

On relating the above factors with nitrification rate, it was found that pH had significant positive correlation with nitrification rate. Other chemical constituents like free Iron oxide and exchangeable Ca whose availabilities are related to pH were also found to be associated. Hence, an attempt was made to find the effect of amending the pH of soils of low nitrification through liming on nitrification. This study was conducted in four soils which were identified as having the lowest rates of nitrification. These soils were the laterite soil from Vellanikkara, red soils from Muttackad and Pilicode and forest soil from Sholayar. One soil with high nitrification (forest soil from Vazhachal) was also included in this study. Liming was done to levels of 0, 25, 50, 75 and 100% of estimated lime requirement values. Estimation of free Aluminium oxide, free Iron oxide, exchangeable Ca and pH were made after allowing a period of nine days for stabilisation of pH. These soils amended to various levels were used for estimating the contents of NH_4^+-N after 5, 10, 15, 20 and 30 days and NO_3^--N after 20 and 30 days of incubation to assess the effect of amendment on nitrification. Simple correlation was worked out to relate the chemical properties of amended soil with the contents of nitrogen fractions and nitrification rate.

The pot experiment was laid out to study the response to application of two standard nitrification inhibitors, N-serve and neemcake on a crop of fodder maize supplied with nitrogen at 100 ppm with and without amendment. The five soils selected for the laboratory incubation study on use of amendment were used for the pot experiment. The pot experiment was conducted during the period from 20-8-1988 to 19-10-1988 using fodder maize as test crop. Growth performance of the crop was assessed through observations on height and drymatter production. Assessment of nitrogen availability in soil was made through estimates of nitrogen content of plant tissue and total nitrogen uptake.

The results of study are summarised below:

1. The presence of Nitrosomonas was noticed in 11 soil samples and Nitrobacter in all the soils tested. Highest nitrifier population was in forest soil. The estimated number of these organisms in all the soils was comparatively low.
2. There was substantial decrease in NH_4^+-N content following incubation at 100 ppm N as urea in alluvial and black soils over a period of 30 days. There was no consistent decrease in laterite and red soils. An increasing trend was apparent in forest soils.

3. The NH_4^+-N content was around 100 ppm at the first estimation five days after incubation in almost all the soils except the forest and black soils where the values were nearly half as much at this stage.

4. There was more or less steady and substantial build up of NO_3^--N content in the alluvial and black soils with advancing period of incubation. There was no such trend in the red and laterite soils. In forest soil, the content remained at about 30-40 ppm throughout.

5. The rate of nitrification increased with incubation period in alluvial and black soils. In laterite and red soils the nitrification rate increased slightly by 10th day of incubation and thereafter decreased. In forest soil, the maximum nitrification was noticed on 5th day and thereafter it decreased more or less steadily.

6. The black soil had the highest pH and exchangeable Ca content and lowest of these were in laterite soil. The free Aluminium oxide was highest in black soil and lowest in forest soil. The mean free Iron oxide was highest in laterite soil and lowest in black soil. The organic carbon content was highest in forest soil and lowest in black soil.

7. No significant correlation was obtained relating the nitrifier population with chemical properties of soil, nitrogen fractions and nitrification rate.

8. Soil pH had significant negative correlation with NH_4^+-N at all periods and positive correlation with NO_3^--N on 5th day and nitrification rate on 5th, 20th and 30th days after incubation.

9. Free Iron oxide had significant positive correlation with NH_4^+-N on 10th, 20th and 30th days after incubation and negative correlation with NO_3^--N and nitrification rate on 20th and 30th days.

10. Exchangeable Ca had significant negative correlation with NH_4^+-N on 5th, 10th and 30th days after incubation and positive correlation with NO_3^--N and nitrification rate on 5th day.

11. Free Aluminium oxide and organic carbon contents of soil were found to have no significant relation with NH_4^--N, NO_3^--N and nitrification rate.

12. In all the five soils, pH increased steadily with increasing additions of lime. With 100% lime requirement, the soil pH rose to 7 in laterite and Sholayar soils, to 6.9 in red soils and to 6.7 in Vazhachal soil.

13. Liming led to no consistent change in contents of free Al and Fe oxide.

14. The exchangeable Ca in the five soils tested steadily increased with addition of lime.

15. On comparing the NH_4^+-N in different soils with different levels of lime and incubation time, it was noticed that the values were lower in Vazhachal soil and substantially higher in all the others.

16. In the case of NO_3^--N, the data obtained were not consistent on the effect of liming. There was substantial accumulation of NO_3^--N only in Vazhachal soil.

17. Only in Vazhachal forest soil did the nitrification rate increase with increased levels of lime. In other soils, the data obtained were not consistent.

18. Free Aluminium oxide, free Iron oxide, exchangeable Ca and pH gave no significant correlation with NH_4^+-N content in this study involving amendment of five selected soils.

19. The free Aluminium oxide and pH had no significant correlation with NO_3^--N content and nitrification rate of soil tested.

20. On 20th and 30th days after incubation the NO_3^--N content in the soil and nitrification rate had significant negative correlation with free Iron oxide and positive correlation with exchangeable Ca.

21. In the pot experiment, no significant difference was noticed between treatments in respect of plant height on 15th, 30th, 45th and 60th days after sowing. The forest soil especially Sholayar soil favoured better plant growth as measured through plant height.

22. In respect of drymatter production, the treatments did not differ significantly from one another. Between soils, the drymatter production of plants grown in forest soils was significantly higher than Vellanikkara and Pilicode soils. Also a significant difference was observed between Vellanikkara and Muttackad soil, the latter being superior. The highest mean drymatter production was found in Sholayar soil and lowest in Vellanikkara soil.

23. In the case of nitrogen content in plants, the treatments did not differ significantly from one another. Between soils, the forest soils were significantly different from laterite and red soils, the values of the former two being higher. The highest mean nitrogen content was found in Vazhachal soil and lowest in Muttackad soil.

24. The treatments did not differ significantly from one another for nitrogen uptake values. Between soils, the forest soils were significantly different from laterite and red soils, the values of the former two being higher. The highest mean nitrogen uptake was found in plants grown in Sholayar soil and lowest in Vellanikkara soil.

References

REFERENCES

*Ahrens, E. 1985. Progress of nitrogen - mineralization in the soil in relation to temperature and time. Zentralblatt fur Mikrobiologie. 140(3):175-181.

Alexander, M. 1965. Nitrification. In Bartholomew, W.V. and Clark, F.E. (Ed) Soil Nitrogen. Am. Soc. Agron. Madison, Wisconsin. pp.307-343.

Alexander, M. 1982. Most probable number method for microbial populations. In Page, A.L. (Ed) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd ed. Am. Soc. Agron. Madison Wisconsin, pp.1159.

Arora, Y., Mulongoy, K. and Juo, A.S.R. 1986. Nitrification and mineralization potential in a limed Ultisol in the humid tropics. Pl. Soil. 92:153-157.

Bandyopadhyay, B.K. and Bandyopadhyay, A.K. 1983. Effect of salinity on mineralization and immobilization of nitrogen in a coastal saline soil of West Bengal. Indian Agrist 27(1):41-50.

*Beck, T. 1983. N mineralization in soils under laboratory incubation conditions. Zeitschrift fur Pflanzenernahrung und Bodenkunde. 146(2):243-252.

Bezbaruah, B. and Baruah, G. 1985. Transformation of urea, ammonium sulfate and potassium nitrate in acid tea soils. Indian J. agric. Sci. 55:742-747.

Bharagava, B.S. and Ghosh, A.B. 1976. Effect of biuret content in urea on its nitrification in soil. Indian J. Agron. 21:76.

*Boratynski, K. and Zictecka, M. 1982. The effect of N-Serve on nitrification in soil, and the yields and chemical composition of plants. Part I. Intensity of nitrification inhibition in relation to some soil properties. Polish J. Soil Sci. 15(1): 75-80.

Bremner, J.M. 1965. Nitrogen availability indexes. In Black, C.A. (Ed). Methods of Soil Analysis. Am. Soc. Agron. Madison, Wisconsin, pp.1324-1345.

Broberg, A. 1984. Effect of heavy metals on nitrification in laboratory experiments with fresh water sediments. Ecological Bulletins 36:135-142.

Chang, F.H. and Broadbent, F.E. 1982. Influence of trace elements on some soil nitrogen transformations. J. environ. Quality 11(1):1-4.

*Cochran, W.G. 1950. Estimation of bacterial densities by means of the "most probable number". Biometrics 6:105-116.

Darrah, P.R., White, R.E. and Nye, P.H. 1986. Simultaneous nitrification and diffusion in soil 2. The effects at levels of ammonium chloride which inhibit nitrification. J. Soil Sci. 37:41-52.

Deshpande, R.S., Kulkarni, D.S. and Viswanath, S. 1971. Influence of lime and nitrogeneous fertilizers on soil biology. Mysore J. agric. Sci. 5(1):

*Etchevers, B.J., Longeri, S.L. and Venegas, M.J. 1978. Nitrification in soils of Nuble, Concepcion and Biobio. Agricultura Tecnica. 38(3):89-93.

Gandhi, A.P. and Paliwal, K.V. 1976. Mineralization and gaseous losses of nitrogen from urea and ammonium sulfate in salt affected soils. Pl. Soil. 45:247-255.

Giashuddin, M. and Cornfield, A.H. 1978. Incubation study on effects of adding varying levels of nickel (as sulphate) on nitrogen and carbon mineralisation in soil. Environmental Pollution. 15(3): 231-234.

*Glambiazi, N. and Kraljev, L.B. 1973. Nitrifying activity of different horizons in profiles of Florencio Varela (Buenos Aires Province) : Its causes. Revista de Investigaciones Agropecuariar. 10(7): 223-236.

Goring, C.A. 1962. Control of nitrification by 2-chloro-6 trichloromethyl pyridine. Soil Sci. 93:211-218.

Groffman, P.M. 1985. Nitrification and denitrification in conventional and no tillage soils. Soil Sci. Soc. Am. J. 49:329-334.

Hadas, A., Feigenbaum, S., Feigine, A. and Portnoy, R. 1986. Nitrification rates in differently managed soil types. Soil Sci. Soc. Am. J. 50:633-639.

Harmsen, G.W. and Schreven, D.A. Van. 1955. Mineralization of organic nitrogen in soil. Adv. Agron. 7: 300-383.

Hesse, P.R. 1971. A Text Book of Soil Chemical Analysis. William Clowes and Sons Ltd., London, pp.520.

Huber, D.M., Warren, H.L., Nelson, D.W., Tsai, C.Y., Ross, M.A. and Mengel, D. 1982. Evaluation of nitrification inhibitors for no till corn. Soil Sci. 134: 388-394.

Hue, N.U. and Adams, F. 1984. Effect of phosphorus level on nitrification rates in three low phosphorus Ultisols. Soil Sci. 137:324-331.

Hulpoi, N., Dakesian, S., Eliade, G.H. and Ghinea, L. 1970. The effect of soil physical conditions on the nitrification of NH_4. Pl. Soil. 32. 468-477.

Iruthayaraj, M.R. 1981. Effect of nitrification inhibitors on soil nitrogen. Agric. Sci. Digest. 1(4): 239-443.

Ishaque, M. and Bhuiyan, M.R.H. 1984. Effect of some mineral elements on the biodynamics of nitrogen during incubation of an alluvial soil. Indian J. agric. Chem. 17:47-52.

Iuraish, M.S.I. and Cornfield, A.H. 1971. Effects of addition of varying levels of copper, as oxide or phosphate on nitrogen mineralization and nitrification during incubation of a lightly calcareous soil receiving dried blood. Pl. Soil. 35:51-55.

*Ivanov, P. 1981. Hydrolysis and nitrification of urea in chernozem and gray forest soils. Pochvoznanie i Agrokhimiya. 16(1):80-88.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc., USA., pp.498.

*Jacobson, S. and Olsen, A.R.S. 1985. Influence of heavy metal pollution on nitrogen mineralization in soils. I. Effects of lead salts. Meldinger fra Norges Landbruskshogskole. 64(8):10.

KAU, 1986. Package of Practices Recommendations, Kerala Agricultural University, Vellanikkara. pp.225-226.

Kiehl, J. De C. and Netto, A.C. 1974. The inhibitory effect of anhydrous ammonia on nitrification. Solo. 66(2):7-13.

*Knop, K. 1970. Effect of temperature and soil reaction on the mineralization of nitrogen in some urea form compounds and in urea. Sbornike Vysoke Skoly Zemedelske V. Praze. 14 A:61-76.

Kreitinger, J.P., Klein, T.M., Novick, N.J. and Alexander, M. 1985. Nitrification and nitrifying micro-organisms in an acid forest soil. Soil Sci. Soc. Am. J. 49:1407-1410.

*Landelout, H. and Lambert, R. 1982. Seasonal variation in the soil microbial population. 2. Effect on nitrogen mineralization in soil. Revue d' Ecologie et de Biologic du sol. 19(1):1-15.

Laura, R.D. 1977. Salinity and nitrogen mineralization in soil. Soil Biol. Biochem. 9:333-336.

*Lebedeva, L.A. and Zagumennikov, V.G. 1977. Influence of long term and single application of mineral fertilizers on the nitrifying capacity of soddy podzolic soil. Moscow Univ. Soil Sci. Bull. 32(1):70-73.

Liang, C.N. and Tabatabai, M.A. 1978. Effects of trace elements on nitrification in soils. J. environ. Quality. 7(2):291-293.

*Listanska, J. 1982. Effect of nitrification inhibitors on nitrogen conversion in the soil at different temperatures. Rostlinna Vyroba. 28:1177-1185.

Manickam, T.S., Selvasselan, D.A. and Krishnamoorthy, K.K. 1976. Nitrification of urea treated with nitrification inhibitors coated fertilizers and slow acting fertilizers in soils. Fert. News 21(9):64-65.

Martikainen, P.J. 1985. Numbers of autotrophic nitrifiers and nitrification in fertilized forest soils. Soil Biol. Biochem. 17:245-248.

Mathew, G. 1986. Screening plant materials for nitrification inhibition properties and testing the field performance of promising materials. M.Sc. (Ag) thesis. Kerala Agricultural University, Vellanikkara, Trichur, Kerala.

Mc Carty, G.W. and Bremner, J.M. 1986. Effects of phenolic compounds on nitrification in soil. Soil Sci. Soc. Am. J. 50:920-923.

Mc Clung, G. and Frankenberger, W.T. Jr. 1985. Soil nitrogen transformations as effected by salinity. Soil Sci. 139:405-411.

Mehra, O.P. and Jackson, M.L. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Proceedings of the 7th National Conference on Clays and Clay Minerals, Permagon Press, New York. pp.317-327.

*Mochoge, B. and Beese, F. 1983. The behaviour of nitrogen fertilizers in neutral and acid loess soils. 2. Distribution and balances of N^{15} tagged nitrogen. Zeitschrift fur Pflanzenernahrung und Bodenkunde. 146(4):504-515.

*Mochoge, B. and Beese, F. 1983. The behaviour of nitrogen fertilizers in neutral and acid loess soils. 1. Transport and transformation of nitrogen. Zeitschrift fur Pflanzenernahrung und Bodenkunde. 146(1):89-100.

More, S.D. and Varade, S.B. 1982. Effect of soil water potential on transformations of added nitrogen in a vertisol. J. Indian Soc. Soil Sci. 30: 531-533.

Mukhopadhyay, A.K., Ghosh, R. and Saha, D. 1985. Influence of nitrification inhibitor N-Serve and soil moisture on transformation of mineral nitrogen. J. Indian Soc. Soil Sci. 33:902-904.

*Nasser, A.M., Safwat, M.S.A. and Ali, M.Z.H. 1983. The effect of dry guava leaves on nitrogen transformation in soil. Zincralblattfur Mikrobiologie. 138(2):115-122.

*Naumov, N.S. 1983. Peculiarities of ammonification and nitrification in eroded soils. Agrokhimiya. (5):10-14.

Nitant, H.C. 1974. Urea transformations in salt affected and normal soils. J. Indian Soc. Soil Sci. 22:234-239.

Oke, O.L. 1970. Mineralization of soil nitrogen. J. Indian Soc. Soil Sci. 18:297-301.

*Olsen, A.R.S. and Jacobsen, S. 1975. Influence of heavy metal pollution on nitrogen mineralization in soils. II. Effect of mercury. Meldinger fra Norges Landbrukshogskole. 64(9):7.

Panse, V.G. and Sukhatme, P.V. 1967. Statistical Methods for Agricultural Workers. 2nd ed. I.C.A.R., New Delhi, pp.347.

Plhak, F. and Vicherkova, M. 1970. The influence of previous plant cultivation on soil nitrification. Pl. Soil. 32:50-56.

Quraishi, M.S.I. and Cornfield, A.H. 1971. Effects of addition of varying levels of copper, as oxide or phosphate on nitrogen mineralisation and nitrification during incubation of slightly calcarious soil receiving dried blood. Pl. Soil. 35:51-55.

Rice, C.W. and Smith, M.S. 1983. Nitrification of fertilizer and mineralized ammonium in no till and plowed soil. Soil Sci. Soc. Am. J. 47:1125-1129.

Richard, K. Olson and William, A. Reiners. 1983. Nitrification in Subalpine balsam fir soils. Tests for inhibitory factors. Soil Biol. Biochem. 15:413-418.

Rother, J.A., Millbank, J.W. and Thornton, I. 1982. Effects of heavy metal additions on ammonification and nitrification in soils contaminated with cadmium, lead and zinc. Pl. Soil. 69:239-258.

Roy, A.B., Pal, H., Chakrabortry, S.C. and Mandal,A.K. 1985. Effect of intensive cropping of jute-rice-wheat on ammonification nitrification and nitrogen fixation in soil. J. Indian Soc. Soil Sci. 33: 905-907.

Sahrawat, K.L. 1977. Effect of biuret content on transformation of urea nitrogen in soil. Soil Biol. Biochem. 9:173-175.

Sahrawat, K.L. 1982. Nitrification in some tropical soils. Pl. Soil. 65:281-286.

Sarathchandra, S.U. 1978. Nitrification activities and the changes in the population of nitrifying bacteria in soil perfused at two different H-ion concentrations. Pl. Soil. 50(2):99-111.

Schreven, D.A. Van and Sieben, W.H. 1972. The effect of storage of soils under water logged conditions upon subsequent mineralization of nitrogen, nitrification and fixation of ammonia. Pl. Soil. 37:245-253.

*Shahawy, R.M. El. and Masbhady, A.S. 1984. Nitrification of ammonium sulfate and urea fertilizers under saline conditions. Zentralblatt fur Mikrobiologic. 139(5):343-347.

Stevanovic, M., Belic, B., Molnar, I. and Bzilitov, S. 1982. Effect of tillage depth, intensity of fertilization, and crop rotation on the dynamics of mineral nitrogen in slightly calcareous chernozem soil. Proc. 9th Conf. Soil Tillage Research Organization. pp.545-550.

Tan, K.H. and Falcon, R.A.L. 1987. Effect of fulvic and humic acids on nitrification. Part 1. In vitro production of nitrite and nitrate. Commun. Soil Sci. Pl. Anal. 18(8):835-853.

Tetruashvili, V.G., Ioseliani, G.I. and Aladashvili, N.Z. 1980. Effect of the inhibitor N-Serve on yield of maize and fodder beet. Agrokhimiya 8:27-29.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. 1985. Soil Fertility and fertilizers. 4th ed. Macmillan Publishing Company, New York, pp.754.

Ueda, K., Kobayashi, M. and Takahashi, E. 1988. Effect of an ionic heavy metals on ammonification and nitrification in soil. Soil Sci. Pl. Nutr. 34:139-146.

Vlassak, K. 1970. Total soil nitrogen and nitrogen mineralization. Pl. Soil. 32:27-32.

*Vostal, J., Knoop, K. and Vanek, V. 1976. Effect of fertilizers on the transformation of urea in soil. Sbornite Vysoke Skoly Zemedelskc V Praze Fakulta-Agronomicka. 1:121-137.

*Vostal, J., Knoop, K. and Vanek, V. 1977. Effects of K_2HPO_4, KCl and K_2SO_4 on N fertilizers transformations in soil and plant drymatter production. Agronomicka. 1:97-105.

*Walter, R., Hartbrich, H.J., Lang, S. and Gunther, K. 1986. The effect of 1-carbomoyl-3(5) methyl pyrazole (CMP) and 2-chloro-6-trichloromethyl-pyridine (nitrapyrin) as influenced by carbon content, CEC and pH value. Archiv fur Ackerund Pflanzenbau und Bodenkunde. 30(3):139-147.

Warren, H.L., Huber, D.M., Tsai, C.Y. and Nelson, D.W. 1980. Effect of nitrapyrin and N fertilizer on yield and mineral composition of corn. Agron. J. 72:729-732.

Wetselaar, R., Passiour, J.B. and Singh, B.R. 1972. Consequence of banding nitrogen fertilizer in soil. 1. Effects on nitrification. Pl. Soil. 36:159-175.

Wheeler, G.L. and Donaldson, J.M. 1983. Nitrification in upland forest sere. Soil Biol. Biochem. 15: 119-121.

Wilson, D.O. 1977. Nitrification in three soils amended with zinc sulphate. Soil Biol. Biochem. 9: 276-280.

*Originals not seen

Appendices

Appendix I. Weather data (weekly average) for the crop period (August 1988 to October 1988)

Week No.	Month and date	Rainfall (mm)	Temperature Maximum (°C)	Temperature Minimum (°C)	Relative humidity Forenoon	Relative humidity Afternoon	Sunshine hours
34	August 20-26	72.1	29.7	24.6	93	74	5.1
35	August 27-2 Sept.	200.8	29.6	23.6	94	74	3.5
36	September 3-9	153.7	29.6	23.6	91	78	4.9
37	September 10-16	113.7	30.5	23.4	92	78	6.1
38	September 17-23	240.0	29.6	23.4	93	78	4.5
39	September 24-30	123.2	29.7	22.4	94	76	4.4
40	October 1-7	29.8	30.4	23.4	92	72	6.5
41	October 8-14	19.6	31.8	23.2	88	68	7.7
42	October 15-21	6.8	31.8	24.0	92	65	7.6

Source : Meteorological Observatory, Vellanikkara.

Appendix II. Analysis of variance for the effect of nitrification inhibitors and liming on plant height, dry weight, nitrogen content and nitrogen uptake of maize grown in different soils

Source	df	Mean squares						
		Mean weight (cm)				Dry weight (g plant^{-1}) at harvest	Nitrogen content (%) at harvest	Nitrogen uptake (mg plant^{-1}) at harvest
		15 DAS	30 DAS	45 DAS	60 DAS			
Total	89	-	-	-	-	-	-	-
Soil	4	77.78	273.59	636.78**	1692.69**	492.17**	0.30**	72188.94**
Treatments	5	30.05	99.18	128.96	291.46	41.03	0.01	5340.33
Interaction	20	53.13	114.10	216.89	398.48**	80.43	0.05	9410.73
Error	60	46.86	129.81	131.22	176.11	47.41	0.04	5801.76

DAS - Days after sowing
* Significant at 5% level
** Significant at 1% level

ASSESSMENT OF NITRIFICATION RATE OF KERALA SOILS AND AGRONOMIC FACTORS INFLUENCING IT

By

MARYKUTTY ZACHARIAS

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
Vellanikkara - Trichur
Kerala

1989

ABSTRACT

The present study 'assessment of nitrification rate of Kerala soils and agronomic factors influencing it' was conducted during June 1987 to November 1988 at the College of Horticulture, Vellanikkara, Trichur. A series of laboratory incubation studies were conducted using a total of 22 soil samples including 20 samples drawn from five soil types (laterite red, alluvial, forest and black soils) of Kerala and two from Coimbatore (red and black). The presence of Nitrosomonas was observed in 11 soil samples and that of Nitrobacters in all soils tested. The nitrification rate was high for alluvial and black soils and low for the red and laterite soils. The forest soils came in between. No correlation was obtained relating the nitrifier population of the 22 soils with chemical properties of soil, nitrogen fractions and nitrification rate. Exchangeable Ca and pH had significant negative correlation with NH_4^+-N and positive relation with NO_3^--N and nitrification rate at nearly all the stages of estimation. Free Iron oxide had significant positive correlation with NH_4^+-N and negative relation with NO_3^--N and nitrification rate. Free Aluminium oxide and organic carbon had no significant relation with NH_4^+-N, NO_3^--N and nitrification rate. Amending the soils of low nitrification rate with lime could increase the soil pH and exchangeable

Ca but not the free Aluminium oxide and free Iron oxide contents. Liming was not beneficial in increasing nitrification in any of the soils tested except Vazhachal soil which had a high inherent nitrifying ability. The chemical properties of the amended soil showed no significant correlation with N fractions in soil and nitrification rate except in the case of free Iron oxide and exchangeable Ca with NO_3^--N and nitrification rate.

In the pot experiment, the treatments did not differ significantly from one another in respect of plant height, dry matter production, nitrogen content and nitrogen uptake. Between soils, significant difference was noticed. Forest soils were found superior to other soils in favouring better plant growth and nitrogen accumulation.