SCREENING PLANT MATERIALS FOR NITRIFICATION INHIBITION PROPERTIES AND TESTING THE FIELD PERFORMANCE OF PROMISING MATERIALS

By

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THESIS

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the requirement for the degree of

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COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that this thesis entitled "Screening plant materials for nitrification inhibition properties and testing the field performance of promising materials" 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.

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CERTIFICATE

Certified that the thesis entitled "Screening plant materials for nitrification inhibition properties and testing the field performance of promising materials" is a record of research work done by Kum. GRACY MATHEW, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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CERTIFICATE

We, the undersigned, members of the Advisory Committee of Kum. GRACY MATHEW, a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled "Screening plant materials for nitrification inhibition properties and testing the field performance of promising materials" may be submitted by Kum. GRACY MATHEW, in partial fulfilment of the requirement for the degree.

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GRACY MATHEW

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INTRODUCTION

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Nitrogen is commonly the most important fertiliser element applied to soil, its effects being manifested quickly on plant growth and ultimately on crop yields. It is one of the costliest inputs in agricultural production and its efficient use has been the subject of study since the very dawn of scientific agriculture. It is now well recognised that in the tropics only 25 to 40 per cent of nitrogen applied in the form of fertilisers is utilised by plants. Amide and ammoniacal fertilisers that are commonly used as sources of fertilizer nitrogen are converted to nitrate form in the soil by the action of nitrifying organisms. Compared to ammoniacal form, nitrates are less sorbed on clay surfaces and hence it is easily leached down in rain or irrigation water and thus lost from the rootzone. Besides, nitrates under anaerobic or waterlogged conditions are subject to biological reduction to gaseous form which escapes into the atmosphere. Thus crops make inefficient use of the fertiliser. It is therefore quite essential that attempts be made to check these losses by adopting proper soil and fertiliser management practices. Application of certain chemicals called nitrification inhibitors seems to be the easiest short term approach towards this problem (Goring, 1962).

Nitrification inhibitors specifically retard the activity of nitrifying bacteria and as a result, nitrogen mineralisation stops with the formation of ammoniacal nitrogen which gets adsorbed on clay lattice without being easily lost. Since the ammoniacal form of nitrogen thus retained becomes available to the crop for a longer period of time, number of split applications can also be reduced. Nitrification inhibitors also minimize nitrate pollution of ground and surface waters; also keep nitrate contents in vegetables and forage crops at low levels.

Several synthetic chemicals with commercial names of N-Serve, AM etc. are established as potential nitrification inhibitors, but their use is restricted because of the high cost. Vegetable tannins and waste tea are also of use, but only in the areas of origin as the amounts to be used are appreciable and the products are not easy to handle and transport. Several plant products such as non-edible oilseed cakes and their isolates have been identified to have nitrification inhibition properties. There is an obvious need to exploit the use of cheap and indigenous materials specific to local conditions for retarding nitrification of ammonium and ammonium forming fertilisers. Hence the present study was envisaged to

screen a few plant materials and products which are reported to have allelopathic and bactericidal properties for the probable nitrification inhibition in soil. The objectives of research are:-

1. Screening of materials for nitrification inhibition properties (based on ammoniacal nitrogen content).
2. Working out ration for effective nitrification inhibition of promising materials.
3. Studying the mineralisation pattern of promising materials at the appropriate ratios.
4. Testing the field response to application of potential nitrification inhibitors (Fodder maize to be the test crop).

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Recovery of fertiliser nitrogen by growing crops seldom exceeds 50 per cent. Proper placement, timely application, foliar spray, use of slow release fertilisers and nitrification inhibitors are the suggested means to decrease nitrogen losses.

Use of nitrification inhibitors

When amide and ammoniacal fertilisers are applied to the soil, they are converted to nitrate form under favourable conditions which is subject to leaching and denitrification losses. Nitrification inhibitors arrest the nitrification process and the ammoniacal form of nitrogen is retained in the soil with less of loss. The discovery and use of nitrapyrin (N-Serve) as an effective inhibitor of nitrification in soils by Goring (1962) has greatly stimulated the interest in nitrification inhibitors. Numerous compounds have since then been proposed for regulating nitrification in soils, including organic and inorganic compounds, pesticides, chelating agents and plant products.

Nitrapyrin or N-Serve (2-chloro-6-(trichloromethyl) pyridine)

Turner *et al.* (1962) found that N-Serve gave partial control of nitrification of all the fertilisers at

rates varying from 0.5 to 2 per cent of the ammonical nitrogen in the fertiliser. A higher level of recovery was got with enhanced rates of the chemical. Smirnov et al. (1981) also got similar results and they observed that the inhibitory effect lasted for 42 to 56 days. Inhibition of nitrification of fall applied ammonium sulphate with N-Serve prevented movement of applied nitrogen below 30.5 cm depth (Huber et al., 1969).

Several workers have reported the effectiveness of N-Serve in retarding nitrification of urea and ammoniacal fertilisers and its role in improving crop yields (Hughes and Welch, 1970b; Reddy and Prasad, 1975; Nelson et al., 1977; Wells, 1977; Smirnov et al., 1979; Hera et al., 1982; Mc Cormick, 1982; Mochkova, 1983; Semenishen, 1983; Sahota and Singh, 1984; Zublena, 1984).

Gostkowska (1980) found that among the different nitrification inhibitors used, N-Serve showed the greatest effectiveness. Sampei (1972) found that the inhibitory activity of N-Serve was greater at 19°C than at 29°C.

N-Serve increased tuber yields of potato by 42.4 per cent. N-Serve increased fixation of nitrogen in organic form by 10 per cent and produced a two fold decrease in loss of fertiliser nitrogen (Torina et al., 1977).

Gomes and Loynachan (1964) showed that the inhibitor allowed the application of ammonia far earlier in the fall without loss. Rodgers and Ashworth (1982) reported that nitrapyrin could inhibit nitrification by approximately 40 per cent compared with untreated soil.

Baizhigitov et al. (1980) reported that application of nitrogen with N-Serve at sowing of rice or in three split dressings without N-Serve increased the contents of N and P in plants. Thomas (1981) also observed that N-Serve treated urea gave higher N uptake and recovery of applied nitrogen. Among the various slow release nitrogen fertilisers and nitrification inhibitors tried, N-Serve treated urea was found to be the best.

White et al. (1978) observed that nitrapyrin decreased stalk rot infection of maize. This was due to the continuous supply of nitrogen throughout the growing season. The aspect of conserving energy with nitrification inhibitors was very well brought out by Nelson et al. (1977). They reported that in maize, 30 per cent more CO_2 per unit area of leaf was assimilated when treated with N-Serve, and lysine and tryptophan contents of maize grain and ear leaf tissue were higher in plants receiving ammonia. Skiba and Wainwright (1964) noticed that nitrate nitrogen appeared four weeks after addition of this chemical which

suggests that by this time degradation of the inhibitor occurred. They also found that addition of N-Serve prevented the accumulation of nitrite nitrogen in sands which was a noticeable feature when urea alone was added.

N-Serve did not have any inhibitory effect on heterotrophic nitrifying Aspergilli or on non-nitrifying heterotrophic bacteria. It had no deleterious effects on any chemoautotrophs tested apart from the nitrifiers or on photoautotrophic algae (Shattuck and Alexander, 1963).

Choden and Kucharaki (1979) have pointed out a decrease in the plant nitrate nitrogen concentration when N-Serve treated ammonium sulphate was applied to cocksfoot crop. Nitrapyrin was reported to have decreased the uptake of nitrate nitrogen, K and Ca by 24, 17 and 25 per cent respectively, whereas it doubled the uptake of chlorine by cucumber seedling.

Osiname et al. (1982) reported that nitrapyrin maintained 80 and 70 per cent of the applied ammoniacal nitrogen after six weeks of incubation at 20°C and 30°C respectively, but nitrification was rapid at 40°C. Nitrapyrin increased the amount of nitrogen immobilised in the soil. Mc Clung et al. (1983) found that at least 83 per cent inhibition of nitrification occurred due to nitrapyrin.

Nishihara (1962) reported that denitrification of added N was greatly suppressed by addition of nitrapyrin. Bremner et al. (1981) found that N_2O emissions by fertilisation of soil with anhydrous NH_3 were decreased by 63 per cent by addition of nitrapyrin. Rempe et al. (1982) and Liu et al. (1984) also reported similar effects of N-Serve.

Hendrickson et al. (1978) reported that potato plants in nitrapyrin treatment had stunted, bushy, dark green tops. High soil NH_4^+ levels induced by nitrapyrin interferred with plant metabolism so as to decrease yield and quality. Enzmann (1984) found that enhanced NH_4^+ nutrition induced by the inhibitor decreased uptake of other cations. Prasad et al. (1983) has suggested the possibility of using ammoniphilic plants such as rice, in conjunction with ammonium based fertilisers and nitrification inhibitors to prevent nitrate pollution of ground waters.

Pill (1981) noticed that nitrapyrin incorporation into a peat vermiculite medium decreased shoot growth of tomato. Maddux et al. (1985) and Smittle (1985) reported lack of yield response to nitrapyrin treatment in the absence of conditions conducive for losses of NO_3^- N

Guthrie and Bowke (1980) found that volatilisation of N-Serve severely limited its effectiveness in loamy sand and its application with solid fertilisers.

Dicyandiamide

In combination with ammoniacal nitrogen, dicyandiamide has been reported to be as useful as N-Serve in delaying nitrification (Reddy, 1962; Sommer and Rossig, 1978; Randall and Malzer, 1981; Zheng, 1981; Forster et al., 1984). Graetz et al. (1981) pointed out that the effect of dicyandiamide was evident upto 10 weeks after application. Amberger (1982) noticed that dicyandiamide inhibited the nitrification of cattle slurry for 2 to 4 months. Rodgers (1983) found that inhibition of nitrification by dicyandiamide increased the amount of ammonia lost by volatilisation by 20 to 65 per cent compared to soil treated with urea only.

Thiourea

Thiourea functioned as nitrification inhibitor by lengthening the lag period prior to the exponential growth of Nitrosomonas (Mc Beath, 1962). Khandelwal (1977) reported that thiourea delayed nitrate formation by 30 days. Malhi et al. (1979) claimed that the addition of Cu^{2+} enhanced the inhibitory effect of thiourea.

Malhi and Nyborg (1984) observed a decrease of nitrification by one half when urea mixed with thiourea was applied in bands.

Potassium azide

The usage of potassium azide (KN_3) as a nitrification inhibitor was established by Hughes and Welch (1970a). Papendick et al. (1971) reported that both levels (2 and 6 per cent) were effective in decreasing nitrification, the higher level being more effective later. Cochran et al. (1973) reported it to be ineffective in non-irrigated soils. Bremner and Bundy (1976) showed that the effectiveness of potassium azide depends on the soil and the form of nitrifiable nitrogen applied. Acidity promotes hydrolysis of potassium azide in aqueous solution and hence it is ineffective below pH 6.0.

Cyanoguanidine

Cyanoguanidine when applied at 5.5 to 24 per cent of N was found to be effective in inhibiting nitrification process. Efficiency of N fertiliser applied to wheat was increased by 50 per cent (Soubies et al., 1962). Tekhina and Bazilevich (1983) observed that cyanoguanidine increased yields only of the irrigated crop of wheat.

2 amino 4 chloro 6 methyl pyrimidine (AM)

Nishihara (1962) reported that AM possess nitrification inhibition property. Jaiswal et al. (1972) observed that millable cane yield, dry matter synthesis and N uptake were significantly increased by the use of this chemical.

Terrazole

The evaluation of terrazole as a nitrificide was carried out by Turner and Mac Gregor (1978), who concluded that under field condition, the control of nitrification by terrazole application was of limited duration. But it decreased nitrate content of both pasture and drainage water.

In addition to the above, a number of other compounds like sulphadrugs, carbondisulfide, methyl mercaptan, coaltar, potassium ethyl xanthate, etridiazole, potassium chloride etc. have been reported to possess nitrification inhibition property. In USA, the only proven compounds currently approved for use are N-Serve and Terrazole. In India, the use of these chemicals is limited due to their high cost.

Indigenous materials as nitrification inhibitors

In India, non edible oil cakes like neem and karanja have been used since time immemorial in admixtures with manures with advantages. One of the beneficial effects of these cakes can be attributed to their nitrification inhibition property.

Abraham et al. (1975) found that the application of 40 kg N ha^{-1} as neem coated urea was equivalent to 80 kg N ha^{-1} as urea. Urea treated with neem cake 20 per cent by weight increased grain yield of paddy (Kulkarni et al., 1975; Shanker et al., 1976; Oommen et al., 1977a; Reddy and Shinde, 1981; Singh et al., 1982; Jadhav et al., 1983).

Manickam et al. (1976) tested the efficacy of N-Serve, crushed neem seed, neem cake extract and mahua cake extract. Neem seed treated urea was superior to mahua cake extract treated urea but was on par with N-Serve treated urea and neem cake extract treated urea.

Khandelwal et al. (1977) recorded increased wheat yield with urea coated with neem extract. Sinha et al. (1979) reported that grain and straw yields of wheat were higher when urea was blended with neem cake than

with 5 per cent petroleum ether or alcohol extracts of neem cake. Vyas et al. (1980) observed that yield of wheat was more with sawdust + urea than neem cake coated urea.

Sivaraj (1978), Iruthayaraj (1981) and Jain et al. (1982) recorded increase in seed cotton yield of cotton with neem cake blended urea.

Sathianathan (1982) reported that neem, mahua, marotti, rubber and karanja cakes were effective as nitrification inhibitors, neem cake being the most effective.

Hulagur and Shinde (1982) studied the effect of neem, mahua, karanje, kokum and ratanjyoti cake and neem extract on rice. Neem extract gave highest yield. Sinha et al. (1982) observed that mustard and pongamia cake were superior to neem cake and N-Serve.

Patil (1972) reported that neem oil was effective in decreasing nitrification rate with increase in its level from 1.5 to 12 per cent. The total bitter fractions from 12 per cent neem oil was most responsible for inhibition followed by sulphur containing odourescent compounds, while pre-refined oil fraction did not show any effect.

Sahrawat et al. (1974) conducted detailed study to find the efficacy of extracts of seed, bark and leaves of karanja tree and observed that the components of the alcohol extracts of seeds were effective upto 60 days.

Sahrawat and Mukherjee (1977) established that karanjin is the major crystalline principle of karanja. It compared well with N-Serve. Studies showed that its furan ring is essential for showing the inhibitory effect.

Sahrawat (1982) compared the effect of alcohol extracts of karanja and neem seeds to that of karanjin. Application of seed extracts at a rate corresponding to 30 per cent of the nitrogen rate was comparable to karanjin applied at 5 and 10 per cent concentration. The extracts were effective for a period of upto 45 days, while karanjin was effective upto 60 days. The different patterns of nitrification inhibition observed with karanja and neem seed extracts suggested an advantage in using a mixture of the two.

Surve and Daftardar (1985) reported that neem products like neem cake, decoiled neem cake, neem oil and neem oil derivatives were superior to karanje cake.

Rajkumar and Sekhon (1981) found that neem cake is more effective in inhibiting nitrification of urea in alkali soils than AM.

Selvaseelan (1981) reported that neem and mahua cakes were efficient only for a limited period of 10 to 25 days. The nitrification inhibition was more pronounced in red sandy loam and black soils than laterite and alluvial soils. The denitrification process was accelerated in the presence of the applied indigenous oil cakes under anaerobic conditions leading to greater nitrogen loss when once the applied ammoniacal nitrogen is nitrified.

Urea treated with oil cakes increased the protein content of rice (Arunachalam and Morachan, 1974; Oommen et al., 1977b).

In contrast to the above observations, several workers have revealed the lack of response for various oilcakes in increasing the efficiency of urea (Arunachalam et al., 1974; KAU, 1975; Katti et al., 1976; Devi et al., 1980; Bhatia et al., 1985). Sadasivan and Sasidhar (1978) studied the comparative efficiency of urea alone and mixed with locally available materials on the yield of rice. Materials used were neem cake, rubber cake, coir dust, Salvinia molesta, sawdust, rice husk, straw powder, urea in paper packets and aldehyde urea. None of the treatments was significant in increasing the yield.

Sahrawat (1977) found that biuret content in urea inhibited the conversion of NH_4^+ to NO_2^- and NO_2^- to NO_3^-. This resulted in accumulation of large amounts of both NH_4^+ - N and NO_2^- - N in soil as compared to control. Hence biuret impurity in urea fertiliser is likely to enhance NO_2^- toxicity.

Krishnapillai (1979) reported that waste tea effectively inhibits nitrification. Incorporation of 8 per cent waste tea with soil inhibited nitrification until 16 days. The chemical nature of the inhibition by waste tea was attributed to the protective action of its polyphenolic substances and their ability to chemically combine with extracellular enzymes of microorganisms.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study was aimed at screening a few plant materials and products which are reported to have allelopathic and bactericidal properties for the probable nitrification inhibition in soil.

The study comprised of two parts.

A. Laboratory experiments

B. Field experiment

The experiments were conducted during the period from May 1984 to November 1985, 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 soil for the laboratory experiments was collected from the site specified for field experiment. Mechanical composition and important characteristics of the soil are given in Table 1.

Table 1. Mechanical composition and chemical properties of the soil.

1. Mechanical composition

Mechanical composition of the soil was determined by the International Pipette method (Piper, 1950).

Coarse sand	:	27.50 per cent
Fine sand	:	22.45 per cent
Silt	:	22.20 per cent
Clay	:	22.80 per cent
Textural class	:	Sandy clay loam

2. Chemical properties

Constituent	Content in soil	Rating	Method used for estimation
Total N	0.129 per cent	Medium	Macro Kjeldahl (Jackson, 1958)
Available P (Bray I extract)	4.53 ppm	Low	Chlorostannous reduced molybdophosphoric blue colour method (Jackson, 1958)
Available K (Neutral normal ammonium acetate extract)	150 ppm	Medium	Flame photometric method (Jackson, 1958)
Organic carbon	0.7 per cent	Medium	Walkley and Black method (Piper, 1950)
pH (1:2.5 soil water ratio)	5.15	Acidic	Elico pH meter (Jackson, 1958)

A. Laboratory experiments

Experiment No.1

A laboratory incubation study was undertaken to screen plant materials for nitrification inhibition properties and to study the mineralisation pattern of urea as influenced by nitrification inhibitors.

The treatments were:-

1. Control (no nitrogen)
2. Urea
3. Urea + N-Serve
4. " + neem cake
5. " + cashew shell
6. " + tobacco waste
7. " + Calotropis leaf
8. " + Eucalyptus leaf
9. " + turmeric rhizome
10. " + neem leaf
11. " + cassava leaf
12. " + Moringa leaf
13. " + Sesamum cake
14. " + maretti cake
15. " + castor cake
16. " + arecanut
17. " + punna cake

18. Urea + rubber cake
19. " + Eupatorium leaf
20. " + turmeric leaf

The treatments were replicated thrice.

Details of the incubation study

Soil samples (1 kg) having passed through 2 mm sieve were mixed with 100 ppm N in the form of urea as per treatment schedules in urea material ratios of 5:3. The plant materials used were dried and powdered well. In case of N-Serve, the chemical was diluted with acetone and added at the rate of 1 per cent of N. Appropriate quantity of distilled water was added to soil to bring the moisture level to 65 per cent of field capacity. From this, 10 g soil was transferred to 250 ml conical flasks and the mouths of the flasks were plugged with cotton. Enough number of replications were kept so that duplicate samples were removed at fixed intervals for one month. Samples were drawn at five days interval for one month and analysed for ammonium and nitrate nitrogen. Nitrite nitrogen was not detected in measurable amounts and hence its estimations were 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 one 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 suggested by Bremner (1965).

Experiment No.2

This experiment was aimed at studying the mineralisation pattern of urea applied at different doses. Soil samples were incubated with urea to supply 10, 25, 50 and 75 ppm N and estimations of NH_4^+ - N were done on 2, 5, 11, 18 and 21 days after incubation.

Experiment No.3

This experiment was conducted to study the mineralisation pattern of urea in soils taken from different locations and the effect of liming on it. Treatments in each soil consisted of a control and addition of a nitrogen source (urea at 100 ppm N), both of which were carried out in limed and unlimed conditions. Soil collected from crop museum and rubber plantation was used in the study. NH_4^+ - N contents were determined at 5 days intervals till 20th day after incubation.

Experiment No.4

Mineralisation pattern of urea at varying moisture levels was studied. Soil was incubated with 100 ppm N as urea at different moisture levels, namely 25, 50, 75 and 100 per cent of field moisture capacity. NH_4^+ - N contents were estimated 2, 3, 4, 5, 6, 9 and 11 days after incubation and the effect of moisture content on urea hydrolysis was noted.

Experiment No.5

An incubation study was carried out to study the mineralisation pattern of urea and ammonium sulphate added at the rate of 100 ppm N. Treatments were replicated twice. NH_4^+ - N was estimated on first, fourth, seventh, fourteenth and twentyfirst day.

Experiment No.6

The objective of this experiment was to study the effect of liming and inoculation with red (alfisol) and black (vertisol) soil on the mineralisation pattern of urea added to laterite (oxisol) soil. The rates were compared with those of red and black soils collected from Coimbatore. Treatments were as follows (pH values of the respective treatments are given in brackets).

1. Laterite soil - unlimed (5.15)
2. Laterite soil - limed (6.35)
3. Red soil (7.5)
4. Black soil (7.9)
5. 1 + 3 - Mixed in 9:1 ratio (5.5)
6. 1 + 4 - Mixed in 9:1 ratio (5.55)
7. 2 + 3 - Mixed in 9:1 ratio (6.4)
8. 2 + 4 - Mixed in 9:1 ratio (6.55)

Treatments were replicated twice. Estimations of NH_4^+ - N were carried out 5, 10, 15, 25 and 30 days after incubation by steam distillation method.

B. Field experiment

A field experiment was laid out to test the crop response to application of the materials used for nitrification inhibition studies.

Soil

The soil of the experimental site was deep, well drained sandy clay loam. The details of the physical and chemical characteristics of the soil are given in Table 1.

Season and climate

The field experiment was conducted during the period from 9.9.1985 to 9.11.1985. The meteorological

data for the crop period are presented as weekly averages in Appendix I. The maximum temperature during the crop period ranged between 29.06°C and 32.1°C and the range of minimum temperature was from 22.04°C to 23.54°C. Rainfall was almost distributed throughout the growth period of the crop and a total of 114.60 mm rainfall was received.

Layout

The experiment was laid out in a randomised block design with three replications.

Treatments

In addition to the 20 treatments of the laboratory experiment No.1, neem coated urea (NCU - 5 per cent coating) was included in the field trial as the 21st treatment.

Plot size : 3 m x 2.1 m

Planting materials

Test crop : Fodder maize

Variety : African Tall Maize

Field culture

The cultural practices recommended in the package of practices prepared by KAU (1982) were followed. Seeds were sown dibbled at a spacing of 30 cm x 15 cm. Gap filling

was done on seventh day. Watering was done as and when needed.

Fertiliser application

Entire dose of N (120 kg ha^{-1}) was applied basally according to the treatments fixed. All plots received a uniform basal dose of 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O. Single super phosphate and muriate of potash were used as sources of P and K.

After cultivation

Weeding, plant protection measures etc. were carried out.

Observations

1. Periodic soil analysis

Soil samples from three replications of each treatment were pooled and analysed for NH_4^+ - N and NO_3^- - N at 15 days intervals till harvest. NH_4^+ - N was estimated by steam distillation method (Bremner, 1965) and NO_3^- - N by chromotropic acid method (Sims and Jackson, 1971).

II. Plant characters

1. Biometric observations

Four plants were selected at random from net plot area after eliminating the border rows and the observations

were recorded from these plants at 15 days intervals. A separate sampling area was marked for destructive sampling for growth analysis.

Plant height

Height was recorded from the base of the plant to the tip of the longest leaf and the average was worked out.

Leaf area index (LAI)

Leaf area index was worked out adopting the method suggested by Montgomery (1911). Four sample plants were uprooted from the row earmarked for the same and the leaves were removed. Ten leaves were selected at random from the lot and measurements of their length and maximum width were done. The average value thus obtained was multiplied with the number of leaves and it was multiplied with the factor 0.75 to get the total leaf area of four plants. Leaf area index was computed as follows:

$$\text{LAI} = \frac{\text{Total leaf area of four plants}}{\text{Land area occupied by four plants}}$$

Dry matter production

The sample plants drawn out for measuring the leaf area were also used for assessing the dry matter production. The plants were oven dried to constant

weights at 70 ± 2°C and the total dry weight was expressed as g plant^{-1}.

2. Yield

The dry fodder yield from net plot area (2.79 m^2) was recorded and it was expressed as tons ha^{-1}.

3. Chemical studies

Nitrogen content of plants

Plant samples collected for recording dry weight were used for chemical analysis. The plant samples were ground and N contents of leaf and rest of plant parts were determined separately using Micro Kjeldahl method (Jackson, 1958).

Uptake of nitrogen

The nitrogen contents of leaf and rest of plant parts were multiplied with their respective drymatter yields and the values thus obtained were added together to get uptake of nitrogen and it was expressed as mg plant^{-1}.

Statistical analysis

The data from the laboratory study and field experiment were subjected to statistical analysis by using 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 field study.

A. Laboratory experiments

Experiment No.1

This laboratory experiment was to screen plant materials for nitrification inhibition properties and to study the mineralisation pattern of urea as affected by mixing with these materials.

Ammoniacal nitrogen

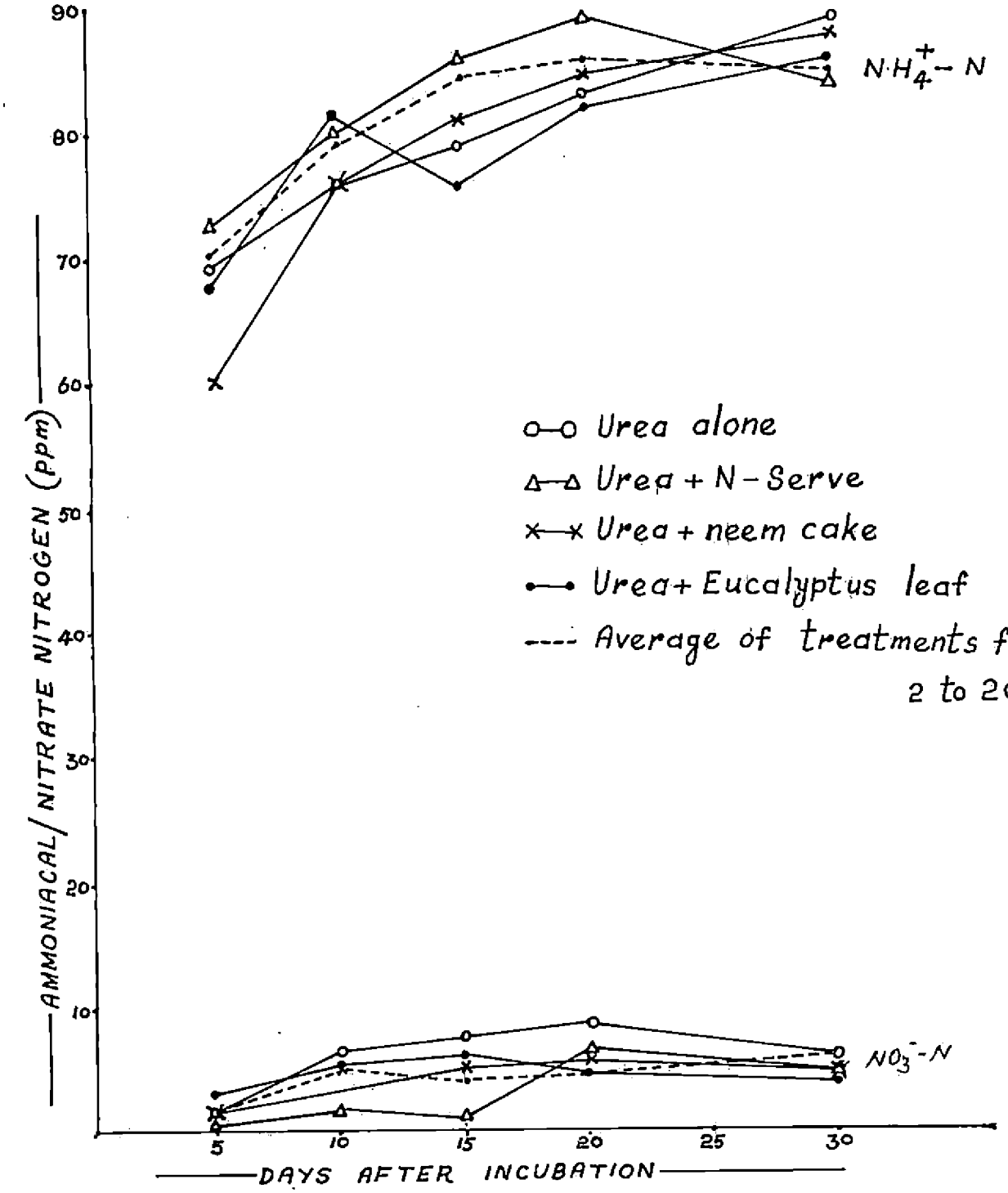
The data on NH_4^+ - N content in the soil are given in Table 2 and those of a few representative treatments shown in Fig.1. The analysis of variance is given in Appendix II. Ammoniacal nitrogen contents in various treatments were compared with untreated urea to assess the benefit of mixing urea with the various materials. Values of control have been substracted from values of treatments from 2 to 20 so that the content of NH_4^+ - N given comprise only that fraction mineralised from added urea.

Table 2. Mineralisation pattern of treated and untreated urea NH_4^+ - N (ppm)*

	Treatments	Days after incubation				
		5	10	15	20	30
2	(Urea alone)	69.20	76.33	79.13	83.80	89.07
3	(Urea + N-Serve)	73.73	80.67	86.27	89.07	84.87
4	(Urea + neem cake)	60.20	76.20	81.00	84.87	88.60
5	(Urea + cashew shell)	72.93	74.93	85.80	85.33	89.53
6	(Urea + tobacco waste)	68.66	81.60	81.13	83.33	92.80
7	(Urea + calotropis leaf)	76.80	81.00	83.33	85.33	87.60
8	(Urea + Eucalyptus leaf)	68.27	80.67	75.73	83.47	86.60
9	(Urea + turmeric rhizome)	74.93	80.67	83.93	86.73	86.73
10	(Urea + neem leaf)	73.53	85.60	83.93	80.67	84.87
11	(Urea + cassava leaf)	76.80	77.73	86.27	85.33	85.80
12	(Urea + Moringa leaf)	75.87	83.47	86.27	85.33	87.20
13	(Urea + Sesamum cake)	66.40	77.73	86.27	84.40	83.93
14	(Urea + marotti cake)	65.93	77.87	89.07	86.73	80.87
15	(Urea + castor cake)	70.00	77.27	83.80	87.67	84.40
16	(Urea + arecanut)	66.73	81.13	82.87	89.73	89.53
17	(Urea + punna cake)	65.93	81.47	86.27	86.27	79.60
18	(Urea + rubber cake)	69.67	73.40	82.87	83.47	84.87
19	(Urea + Eupatorium leaf)	73.53	65.67	87.20	86.27	87.67
20	(Urea + turmeric leaf)	75.27	83.93	84.87	86.73	84.40
	CD (5%)	NS	NS	NS	NS	NS
	SEm ±	5.47	3.78	3.30	2.26	2.51
1	NH_4^+ - N in control	14.93	16.80	14.47	15.87	16.33

* Values of control have been substracted from values of treatments from 2 to 20.

Fig.1. MINERALISATION PATTERN OF TREATED AND UNTREATED UREA - NH_4^+ AND NO_3^- - N CONTENTS



There was no significant difference in ammoniacal nitrogen content detected in the incubated samples receiving various treatments on any day of sampling. The values of all the treatments were found to be on par with untreated urea.

The highest value for NH_4^+ - N content (76.8 ppm) on 5th day was in T_7 (urea + calotropis leaf) and the lowest value (60.2 ppm) was in T_4 (urea + neem cake).

On 10th day, the highest amount of NH_4^+ - N (85.67 ppm) was registered in T_{19} (urea + Eupatorium leaf), followed by T_{10} (urea + neem leaf) and the lowest value (73.4 ppm) was in T_{18} (urea + rubber cake).

On 15th day, T_{14} (urea + marotti cake) recorded the highest value for NH_4^+ - N content (89.07 ppm). The least value was in T_8 (urea + Eucalyptus leaf).

Among the various treatments, T_{10} (urea + neem leaf) had the lowest NH_4^+ - N content (80.67 ppm) on 20th day, the highest being recorded in T_{16} (urea + arecanut).

On 30th day, T_{14} (urea + marotti cake) and T_{17} (urea + Punna cake) registered lower values compared to other treatments. The highest value of 92.8 ppm was for the treatment, urea + tobacco waste.

Out of the 100 ppm N added in the form of urea, on an average, 70 ppm N appeared as NH_4^+ - N by 5th day. By 10th day, hydrolysis of urea was almost over and the ammoniacal nitrogen content estimated in the soil at this time was about 80 ppm. After this period, there was only slight increase, reaching a value of 86 ppm on 30th day i.e. from 10th day onwards the values remained more or less steady. The content of NH_4^+ - N was not found to decrease in any of the treatments even with 30 days incubation. NH_4^+ - N formed from urea hydrolysis was not subject to further oxidation in any significant amounts. Mineralisation of urea almost stopped with completion of ammonification in all the treatments including untreated urea.

As a whole, it was seen that none of the treatments showed consistent superiority over untreated urea or consistent differences between treatments. Locating more effective materials was thus not possible based on the results on content of ammoniacal nitrogen of soil samples.

Nitrate nitrogen

The data on NO_3^- - N content in the soil are presented in Table 3 and those of a few representative treatments shown in Fig.1. The analysis of variance is given in Appendix XI. The amount of NH_4^+ - N mineralised ie. NO_3^- - N appearing in the soil was compared with that of

Table 3. Mineralisation pattern of treated and untreated urea NO_3^- - N (ppm)*

	Treatments	Days after incubation				
		5	10	15	20	30
2	(Urea alone)	1.87	6.60	7.80	8.53	6.07
3	(Urea + N-Serve)	1.07	1.87	1.40	6.67	5.60
4	(Urea + neem cake)	2.00	5.20	5.60	5.73	5.60
5	(Urea + cashew shell)	2.47	5.20	7.27	8.13	5.60
6	(Urea + tobacco waste)	2.93	7.07	5.60	5.90	4.50
7	(Urea + calotropis leaf)	2.00	5.67	5.13	5.60	5.60
8	(Urea + Eucalyptus leaf)	2.47	5.20	5.60	5.70	5.53
9	(Urea + turmeric rhizome)	1.70	5.67	5.40	6.20	5.40
10	(Urea + neem leaf)	2.93	6.60	5.60	6.20	3.87
11	(Urea + cassava leaf)	2.00	5.67	5.13	5.73	4.67
12	(Urea + Moringa leaf)	1.53	5.67	5.60	6.67	4.20
13	(Urea + sesamum cake)	3.20	5.93	5.93	4.33	5.60
14	(Urea + mahotti cake)	1.33	5.87	5.07	4.07	4.87
15	(Urea + castor cake)	1.80	6.13	5.13	6.20	5.13
16	(Urea + arecanut)	2.40	5.90	3.53	4.80	5.13
17	(Urea + punna cake)	3.40	5.23	5.13	5.73	5.13
18	(Urea + rubber cake)	2.93	6.67	5.60	5.73	5.53
19	(Urea + Eupatorium leaf)	3.87	6.93	6.53	7.13	4.20
20	(Urea + turmeric leaf)	2.00	7.53	6.07	5.27	4.67
	CD (5%)	NS	2.16	NS	NS	NS
	SEm ±	0.89	0.76	1.33	1.32	1.36
1	NO_3^- - N in control	6.40	6.47	7.93	7.33	8.40

* Values of control have been substracted from values of treatments from 2 to 20.

untreated urea for assessing the efficacy of the materials used as nitrification inhibitors. As in the case of NH_4^+ - N content, here also values of control have been substracted from values of treatments from 2 to 20.

Except on 10th day, NO_3^- - N estimated at the various sampling stages did not show any significant difference among treatments. All the treatments were on par with untreated urea. On 10th day, N-Serve treatment recorded significantly lower content of NO_3^- - N than untreated urea (T_2). No other treatment was found to differ significantly from T_2.

In general, nitrification steps were found to operate at a very low speed. Estimated NO_3^- - N content in the soil on 5th day was on an average, 2.31 ppm. From 10th day onwards, the amount of NO_3^- - N mineralised from added urea started increasing and attained a mean value of 6.02 ppm on 20th day. Thereafter, no further increase was noted. Thus, out of the 100 ppm N added as urea, only about six per cent was subject to nitrification. Rest of the nitrogen mineralised from urea remained in ammoniacal form itself.

From the NO_3^- - N content it was seen that, excepting in N-Serve treatment, the extent of nitrification was almost equal in all the treatments including untreated

urea. The only material that appeared helpful in retarding NO_3^- - N production was N-Serve. NO_3^- - N recorded in the N-Serve treatment on 10th day was only 1.87 ppm, compared to the mean value of 5.82 ppm in other treatments; but the contents estimated at succeeding samplings were not significantly lower than those recorded in untreated urea. Apart from this, no other treatment showed any superiority over untreated urea.

Nitrification rate

The data on the nitrification rate in the various treatments are given in Table 4 and those of a few representative treatments are graphically presented in Fig.2. The analysis of variance is given in Appendix III.

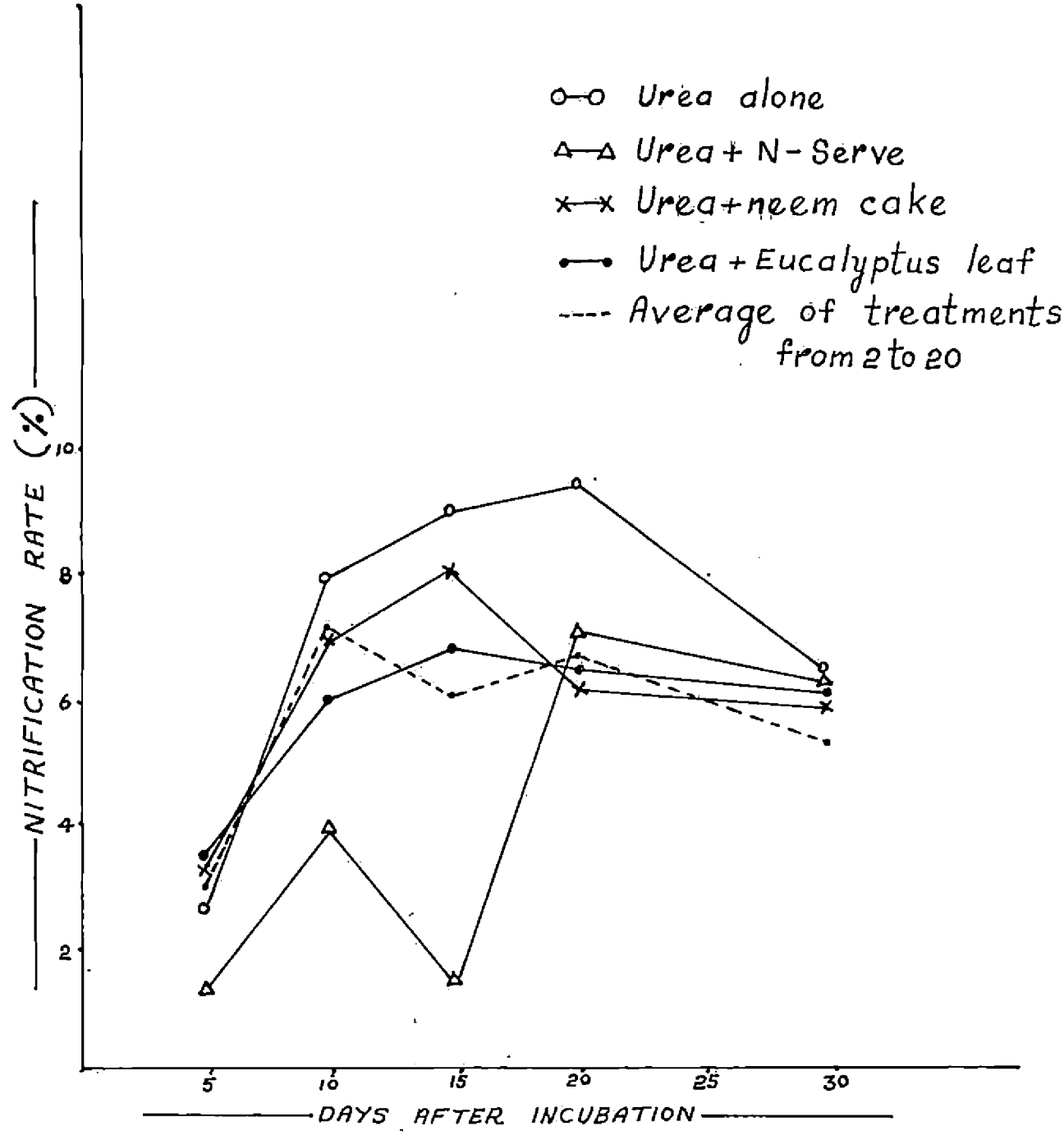
Nitrification rate in all the samples was found to be on par till the end of the incubation period.

Starting from an overall low rate of nitrification on 5th day (3.19 per cent), the value increased to 6.91 per cent by 10th day. The rate of nitrification remained more or less the same till 20th day and later it declined to 5.51 per cent by 30th day. At any time, the rate of nitrification of added urea was found to be below 10 per cent in all the treatments i.e. the proportion of

Table 4. Nitrification rate (%) of treated and untreated urea

	Treatments	Days after incubation				
		5	10	15	20	30
1	(Control)	-	-	-	-	-
2	(Urea alone)	2.73	7.97	8.96	9.31	6.40
3	(Urea + N-Serve)	1.42	3.95	1.56	6.95	6.21
4	(Urea + neem cake)	3.31	6.47	7.99	6.17	5.87
5	(Urea + cashew shell)	3.37	6.48	7.67	8.63	5.80
6	(Urea + tobacco waste)	4.47	7.97	6.44	6.60	4.60
7	(Urea + calotropis leaf)	2.57	6.66	5.77	6.17	6.08
8	(Urea + Eucalyptus leaf)	3.56	6.05	6.78	6.39	6.08
9	(Urea + turmeric rhizome)	2.26	6.57	7.07	6.70	5.80
10	(Urea + neem leaf)	3.73	7.16	6.25	7.10	4.29
11	(Urea + cassava leaf)	2.55	6.86	5.53	6.17	5.07
12	(Urea + Moringa leaf)	1.95	6.32	6.01	7.18	4.49
13	(Urea + Sesamum cake)	4.47	7.12	6.34	4.92	6.21
14	(Urea + marotti cake)	1.91	6.95	5.39	6.19	5.64
15	(Urea + castor cake)	2.58	7.42	5.81	6.29	5.65
16	(Urea + arecanut)	3.37	6.79	3.93	4.96	5.44
17	(Urea + punna cake)	4.04	6.12	5.61	6.20	5.53
18	(Urea + rubber cake)	3.98	8.36	6.40	6.45	6.07
19	(Urea + Eupatorium leaf)	5.00	7.63	6.97	7.67	4.59
20	(Urea + turmeric leaf)	2.58	8.29	6.68	5.72	4.87
	CD (5%)	NS	NS	NS	NS	NS
	SEm ±	1.28	1.10	1.36	1.37	1.46

Fig.2. NITRIFICATION RATE (%) OF TREATED AND UNTREATED UREA



NO_3^- - N formed, compared to total amount of inorganic N mineralised from urea was quite low.

Experiment No.2

The results of the experiment No.1 showed that the extent of nitrification of added urea was quite low. To examine if the high quantity of N (100 ppm) used in the experiment, most of which appeared and remained as the NH_4^+ form was inhibitory to nitrification, a laboratory experiment was run with urea added at different doses ranging from 10 ppm to 75 ppm N. The data on NH_4^+ - N content are presented in Table 5 and Fig.3.

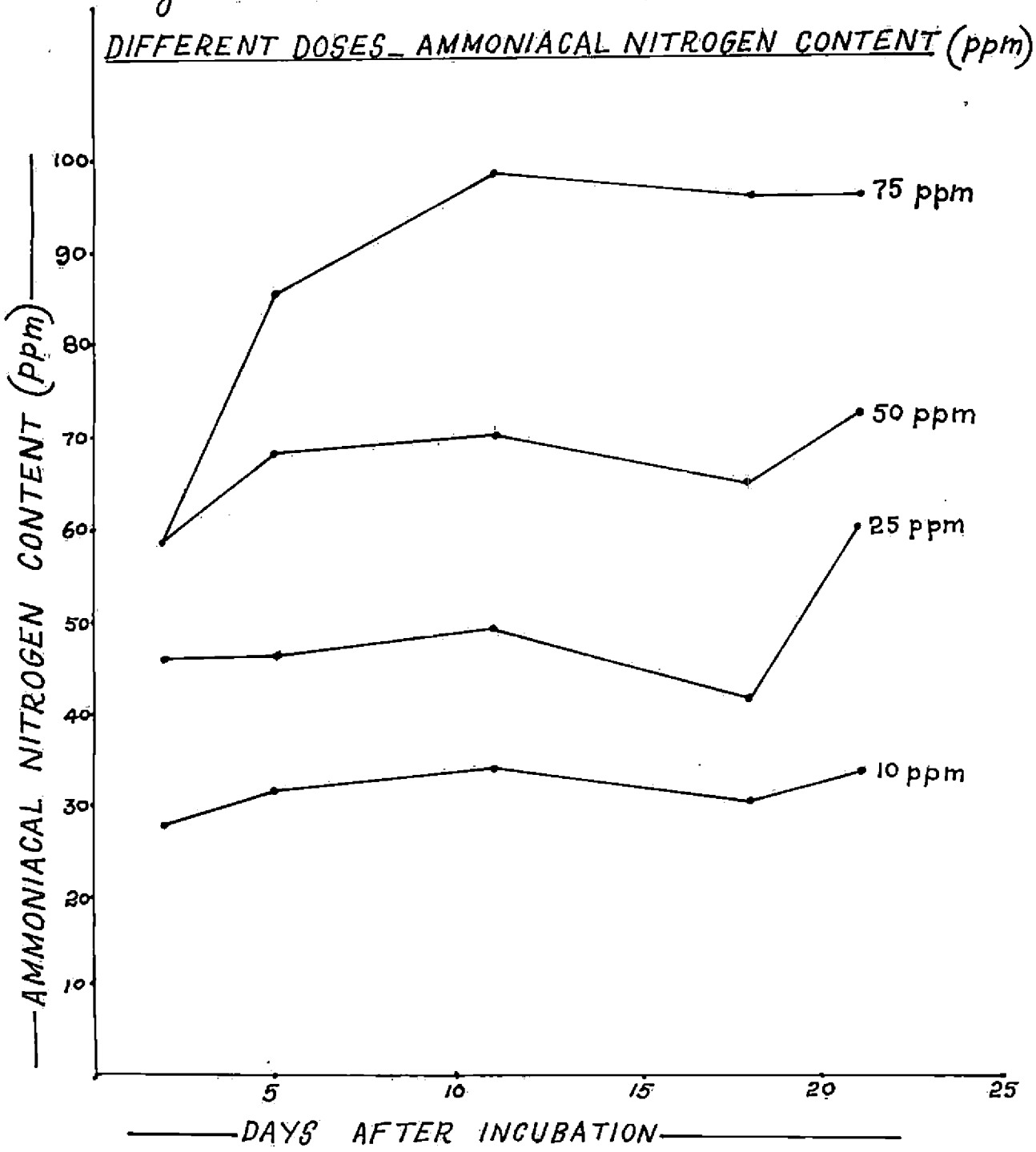
It was seen that in cases where the amount of urea added was lower (10 ppm and 25 ppm N), hydrolysis was completed by second day itself. The amount of NH_4^+ - N detected were 28.62 ppm and 46.11 ppm respectively, in treatments that received 10 ppm and 25 ppm N as urea. These values include that fraction of NH_4^+ - N mineralised from organic matter of the soil also.

In the soil sample which received 50 ppm N as urea, hydrolysis was over only by 5th day and the value of NH_4^+ - N was 68.37 ppm. In case where 75 ppm N was added, it took about 10 days for the hydrolysis to complete and the amount of NH_4^+ - N appeared at this period was

Table 5. Mineralisation pattern of urea applied at different doses - NH_4^+ - N (ppm)

Amount of nitrogen added (ppm)	Days after incubation				
	2	5	11	18	21
10	28.62	31.80	33.39	30.21	33.39
25	46.11	46.13	49.29	41.34	59.59
50	58.83	68.37	69.96	65.19	71.92
75	58.83	85.86	98.58	96.32	96.58

Fig.3. MINERALISATION PATTERN OF UREA APPLIED AT DIFFERENT DOSES_ AMMONIACAL NITROGEN CONTENT (ppm)



98.58 ppm. Thus, with higher amount of added urea, the time taken for the completion of hydrolysis was found to be prolonged.

Once the hydrolysis was over, no appreciable change in NH_4^+ - N content was found to occur in any of the treatments studied. As in experiment No.1, the whole of added nitrogen remained as NH_4^+ - N itself even after 20 days of incubation without much of nitrification.

It was concluded that the quantity of fertiliser nitrogen added did not appear to be a factor deciding nitrification and that there was apparently no inhibition of the reaction by the ammoniacal nitrogen produced.

Experiment No.3

The experiment was to study the effect of liming on mineralisation pattern of urea added to soils collected from two locations, namely rubber plantation which is supposed to have a high content of organic carbon and crop museum with a much lower amount of organic carbon.

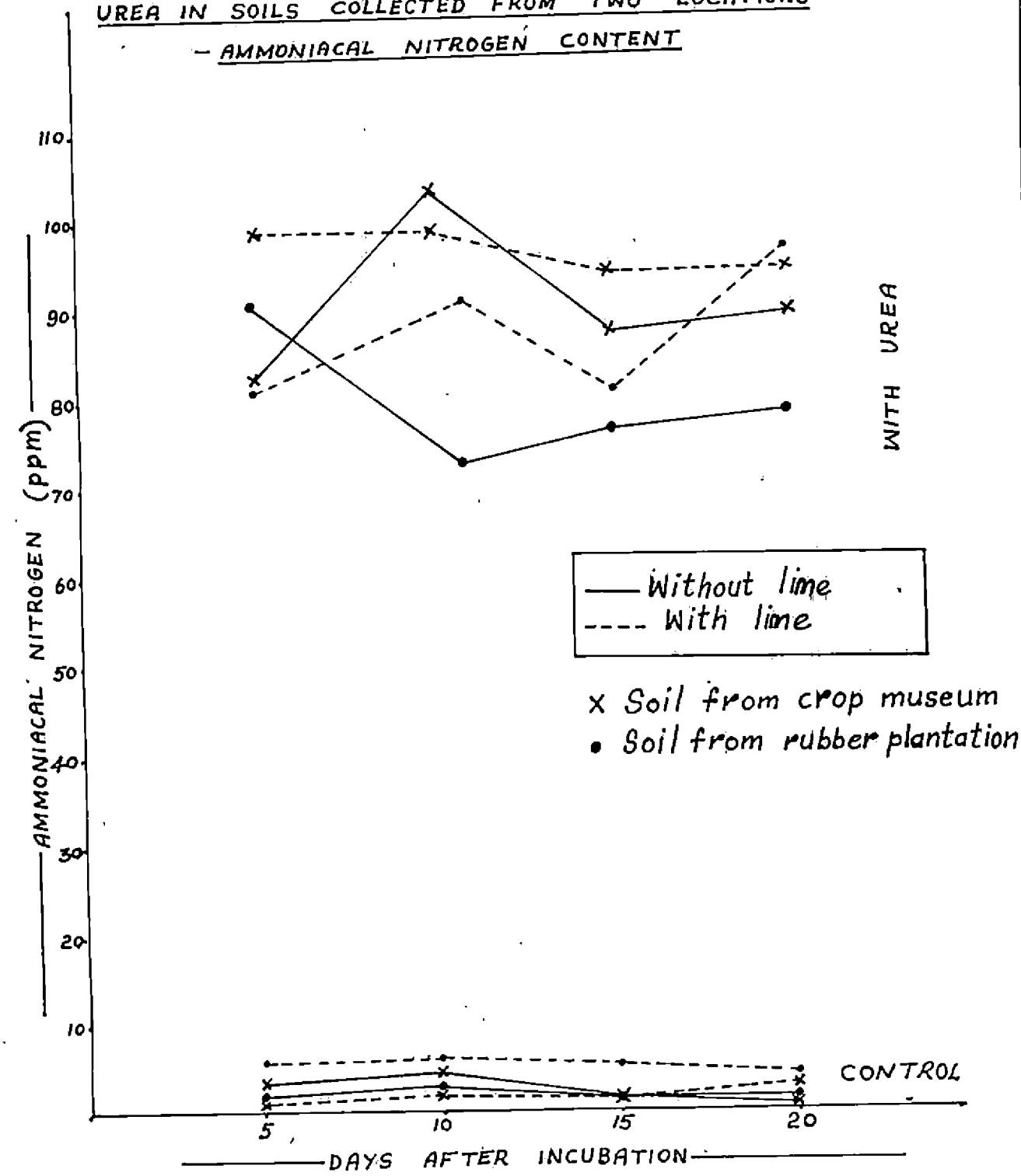
The values of NH_4^+ - N are presented in Table 6, and Fig.4. Amount of NH_4^+ - N that was detected in the soil taken from crop museum on 5th day was 3.18 ppm. The amount increased to 4.77 ppm by 10th day and thereafter

Table 6. Mineralisation pattern of urea in soils collected from two locations and the effect of liming them - NH_4^+ - N (ppm)

Treatments	Days after incubation			
	5	10	15	20
Soil from crop museum				
Control - without lime	3.18	4.77	1.59	1.59
Control - with lime	1.59	3.18	1.59	2.90
Urea - unlimed	82.68	103.35	87.45	89.04
Urea - limed	98.58	98.58	93.81	93.81
Soil from rubber plantation				
Control - without lime	1.59	3.18	1.59	2.06
Control - with lime	6.36	6.36	5.20	1.59
Urea - unlimed	90.63	73.14	76.78	77.91
Urea - limed	82.68	90.60	80.60	95.70

Fig. 4. EFFECT OF LIMING ON THE MINERALISATION PATTERN OF UREA IN SOILS COLLECTED FROM TWO LOCATIONS

– AMMONIACAL NITROGEN CONTENT



the value remained to be 1.59 ppm. When the soil was kept for incubation after liming to near neutral pH, the contents of NH_4^+ - N appeared were 1.59 ppm and 3.18 ppm respectively on 5th and 10th days reaching 2.9 ppm by 20th day. In the case where urea at the rate to supply 100 ppm N was added, amount of NH_4^+ - N recorded on 5th day was 82.68 ppm, the content being more or less the same without any decrease till 20th day. In limed condition also, urea mineralisation was found to show a similar trend.

Values of NH_4^+ - N content in the soil collected from rubber plantation was 1.59 ppm on 5th day. At subsequent samplings, contents of NH_4^+ - N were 3.18 ppm and 2.06 ppm, respectively, on 10th and 20th days. With liming, the value on 5th day was 6.36 ppm and it was found to decrease gradually from 10th day to a value of 1.59 ppm by 20th day. In the studies where incubation was carried out with addition of 100 ppm N as urea, content of NH_4^+ - N registered on 5th day was 90.63 ppm. Values on subsequent samplings showed little variation among themselves and were found to be in the range 73 to 77 ppm. In the limed condition also, contents of NH_4^+ - N detected at all samplings were in the range 80 to 90 ppm. No substantial decrease in NH_4^+ - N content, probable to occur by nitrification, was noticed in any of the treatments.

Raising the pH by liming at the rate of 2 tons ha^{-1} to pH values in the range from 6.2 to 6.7 was not found to exert any notable difference in the pattern of urea mineralisation. Also, mineralisation pattern was found to be similar in both the soils. Either a higher content of organic carbon or liming or a combination of both of these were not effective in triggering increased nitrification in the soil.

Experiment No.4

To examine if the moisture level maintained in the incubation study (65 per cent of field moisture capacity) was inhibitory to nitrification, a laboratory experiment was conducted by incubating soil samples at varying moisture levels ranging from 25 per cent to 100 per cent of field capacity level after addition of 100 ppm N as urea. Data on NH_4^+ - N are given in Table 7 and Fig. 5.

At the moisture level of 25 per cent field capacity, NH_4^+ - N content detected in the soil 24 hours after incubation was 25.92 ppm. Even upto 11 days, no further increase in the amount of NH_4^+ - N occurred. The value recorded on 11th day was 24.48 ppm.

When incubation was carried out at a higher moisture level (50 per cent field capacity), the content of NH_4^+ - N

Table 7. Mineralisation pattern of urea at varying moisture levels - NH_4^+ - N (ppm)

Moisture level	Days after incubation						
	1	3	4	5	6	9	11
*25 per cent F.C.	25.92	31.68	15.84	18.72	20.16	28.80	24.48
50 per cent F.C.	27.54	32.13	26.01	26.01	30.60	45.90	47.43
75 per cent F.C.	39.75	55.65	58.83	62.01	79.50	114.48	108.12
100 per cent F.C.	47.18	94.36	102.78	99.42	90.99	97.73	102.78

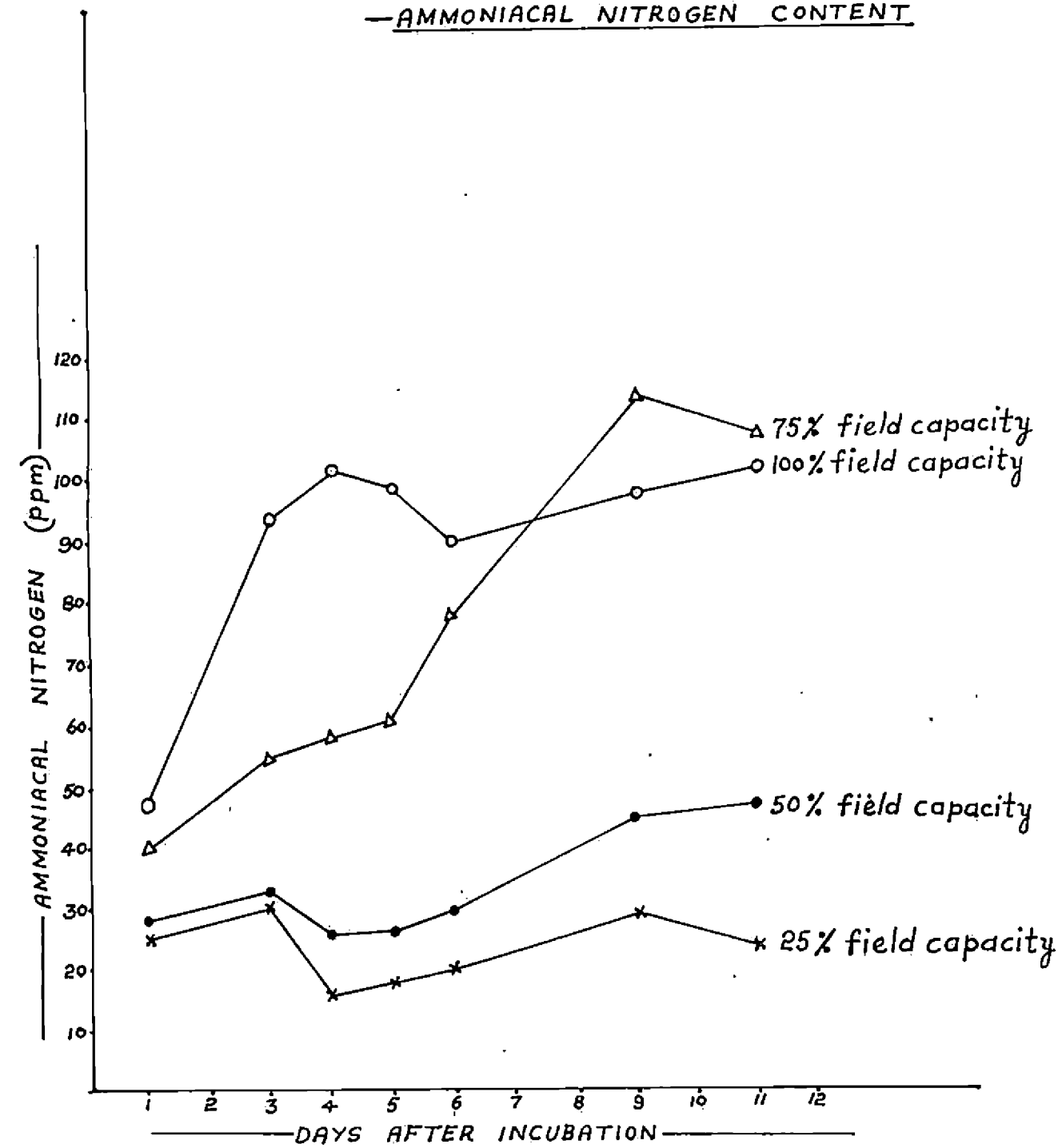
*F.C. - Field capacity

Table 8. Mineralisation pattern of urea and ammonium sulphate - NH_4^+ - N (ppm)

Treatments	Days after incubation				
	1	4	7	14	21
Urea	23.85	53.99	66.98	97.78	99.70
Ammonium sulphate	82.68	82.68	77.91	94.60	95.40

Fig.5. EFFECT OF VARYING MOISTURE LEVELS ON THE MINERALISATION PATTERN OF UREA

—AMMONIACAL NITROGEN CONTENT



increased gradually from a value of 27.54 ppm on first day to 47.43 ppm on 11th day.

At 75 per cent field moisture capacity, the rate of ureolysis was still faster. By 9th day, hydrolysis was completed and the amount of NH_4^+ - N recorded was 114.48 ppm. The content estimated on 11th day was 108.12 ppm.

At the highest moisture level of incubation tested (100 per cent field capacity), urea hydrolysis progressed at a still faster rate. NH_4^+ - N content registered on first day after incubation was 47.18 ppm. Almost the whole of urea was converted to ammoniacal form by fourth day itself. NH_4^+ - N content on subsequent samplings upto 11th day remained more or less the same.

The results showed that urea hydrolysis was slow at lower moisture levels. At 25 per cent field capacity, hydrolysis was even found to be curtailed as evident from the similar values of NH_4^+ - N on first as well as 11th days. With increasing wetness of the soil from 25 per cent to 100 per cent field capacity, a steady increase in the rate of hydrolysis was observed. But here again, once the hydrolysis was over, the entire amount of nitrogen remained in ammoniacal form itself without being subject to further conversion. At any of the moisture level tested, there was no appreciable nitrification.

Experiment No.5

The objective of the experiment was to study the mineralisation of urea and ammonium sulphate and thereby to ascertain whether any biuret impurity was present in the urea, which is reported to be inhibitory to nitrification.

Soil was supplied with fertiliser nitrogen (100 ppm) in the form of urea or ammonium sulphate and incubation was carried out at 65 per cent field moisture capacity. Data on NH_4^+ - N content are presented in Table 8 and Fig.6.

In the case where urea was the source of nitrogen, starting from a value of 23.85 ppm NH_4^+ - N on first day, it increased steadily and reached a maximum of 97.78 ppm by 14th day marking the completion of ureolysis and thereafter no appreciable change in the content could be noticed. It may be recalled that the results obtained were similar to those of the previous such experiments.

Where ammonium sulphate was the source, the amount of NH_4^+ - N recovered in the estimations on first and fourth days was 82.68 ppm and on 21st day the recovery was 95.4 ppm. Here again, no oxidation of NH_4^+ - N, which would be detected by a decrease in NH_4^+ - N content, occurred.

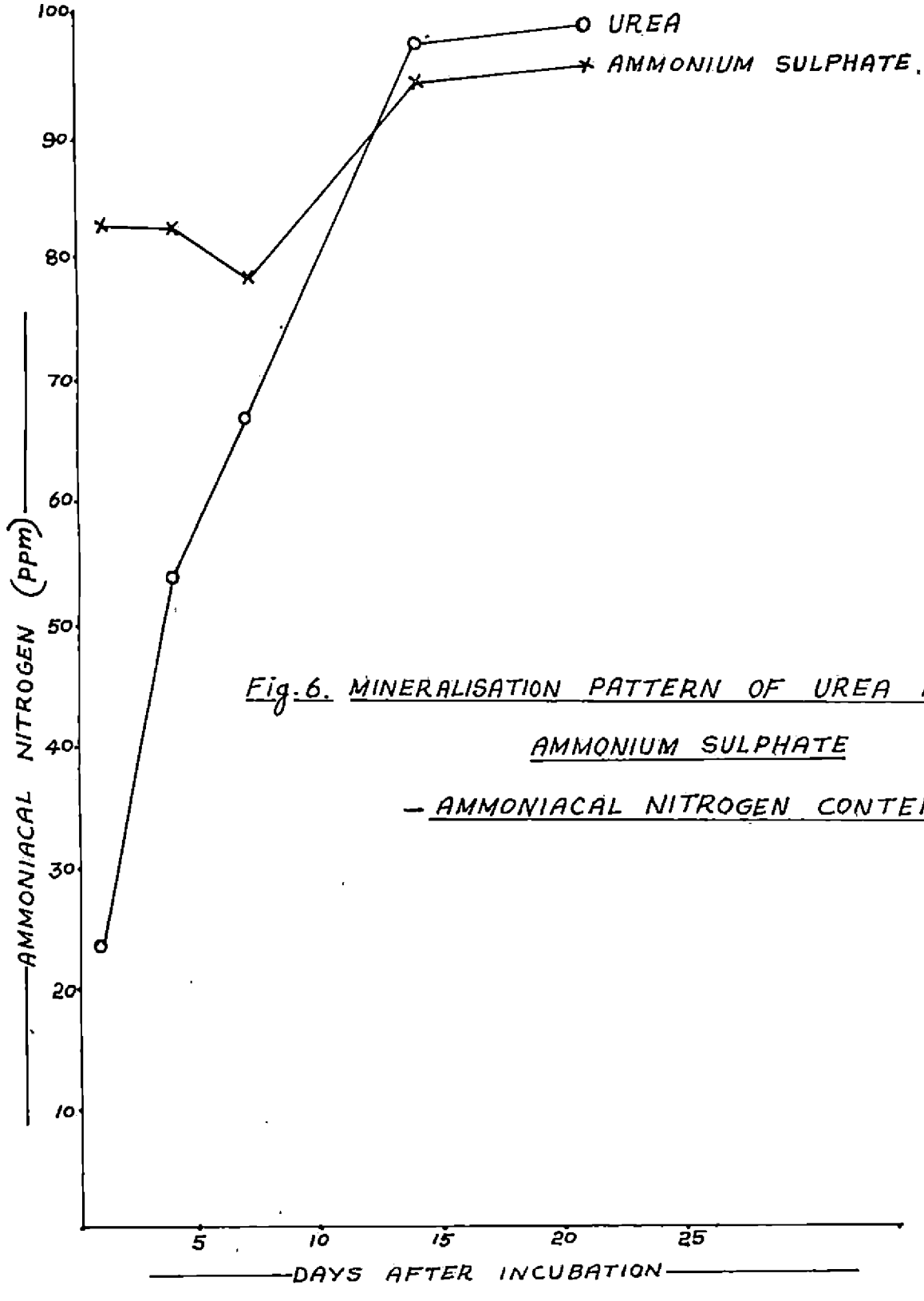


Fig. 6. MINERALISATION PATTERN OF UREA AND AMMONIUM SULPHATE

– AMMONIACAL NITROGEN CONTENT

Irrespective of the source of NH_4^+ - N, its subsequent conversion was arrested. Biuret content, if at all present in urea, cannot be suspected to be as a possible factor hindering nitrification since nitrogen in ammonium sulphate too was remaining in the soil in ammoniacal form itself.

Experiment No.6

The experiment was aimed to study if nitrification could be induced in the soil (laterite) used in the above experiments by liming to raise the pH and/or by mixing it with red soil or black soil which are reported to have high rate of nitrification to supply inoculum of nitrifying organisms which was probably inadequate. A comparison of mineralisation pattern of urea in these three soils was also done. All these received fertiliser nitrogen at 100 ppm in the form of urea. The study was replicated twice and the data statistically analysed.

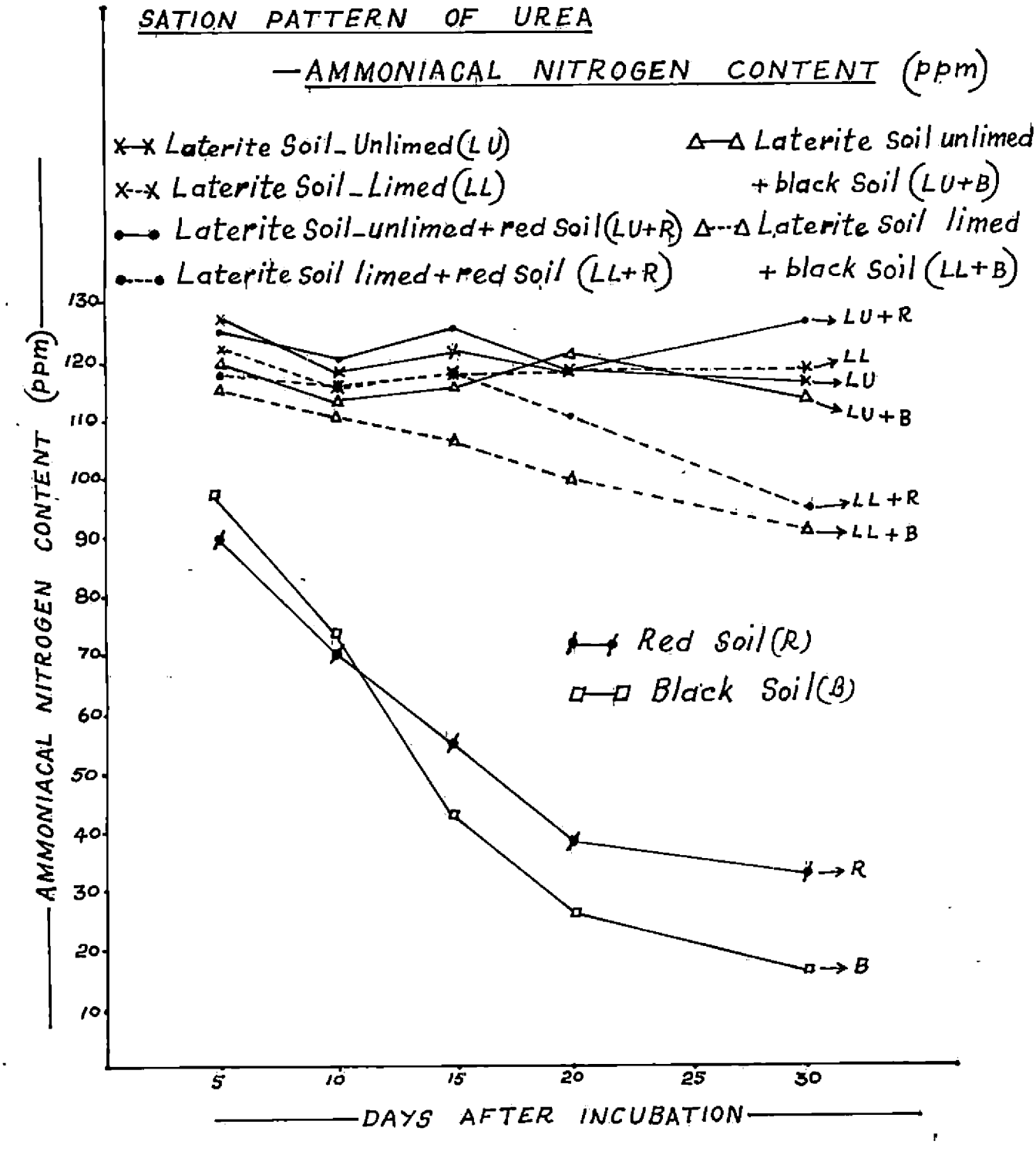
The results on NH_4^+ - N are given in Table 9 and Fig.7 and analysis of variance in Appendix IV.

On 5th day, NH_4^+ - N in T_3 (red soil - 89.6 ppm) and T_4 (black soil - 98 ppm) were found to be significantly lower than in all others. Between these two, T_3 recorded significantly lower amount than T_4. T_8 (laterite soil

Table 9. Effect of liming and/or addition of red soil or black soil on the mineralisation pattern of urea in laterite soil - NH_4^+ - N (ppm)

	Treatments	Days after incubation				
		5	10	15	25	30
1	(Laterite soil, unlimed)	127.20	118.30	121.10	119.00	116.20
2	(Laterite soil, limed)	121.80	115.50	118.30	119.00	118.30
3	(Red soil)	89.60	70.70	54.60	37.80	33.60
4	(Black soil)	98.00	72.80	43.40	26.60	16.10
5	(1+3 in 9:1 ratio)	124.60	119.70	124.60	119.00	126.00
6	(1+4 in 9:1 ratio)	119.70	114.80	117.80	120.40	114.80
7	(2+3 in 9:1 ratio)	120.40	115.50	116.90	110.60	95.20
8	(2+4 in 9:1 ratio)	116.20	113.40	107.80	100.80	92.40
	CD (5%)	8.16	7.61	11.27	8.54	24.82
	SEm ±	2.50	2.33	3.46	2.62	7.61

Fig.7. EFFECT OF INOCULATING LATERITE SOIL WITH RED SOIL OR BLACK SOIL TOGETHER WITH LIMING ON THE MINERALISATION PATTERN OF UREA



limed and mixed with black soil) had a significantly lower NH_4^+ - N content than T_1 (laterite soil - unlimed).

Data on 10th day showed that all treatments except T_3 and T_4 were on par with respect to the content of NH_4^+ - N in soil. T_3 and T_4 did not differ significantly between themselves, but they registered significantly lower NH_4^+ - N (70.7 ppm and 72.8 ppm, respectively) than all other treatments.

On 15th day, T_4 (43.4 ppm) and T_3 (54.6 ppm) had significantly lower NH_4^+ - N than others. NH_4^+ - N in T_8 (107.8 ppm) was significantly higher than in T_3 and T_4, but lower than in T_1, T_2, T_5 and T_6.

On 25th day also T_4 (26.6 ppm) followed by T_3 (37.8 ppm) and T_8 (100.8 ppm) registered significantly lower values for NH_4^+ - N than others. All these three treatments differed significantly among themselves.

NH_4^+ - N content in T_4 (16.16 ppm) and T_3 (33.6 ppm) were found to be on par on 30th day and they were significantly lower than others.

In laterite soil (unlimed), urea hydrolysis was completed by 5th day, registering an amount of 127.2 ppm NH_4^+ - N. There occurred a slight decrease in the content

during the days following, attaining a value of 116.2 ppm on 30th day. Quite similar were the results under limed condition (T_2).

In red soil and black soils, the amounts of NH_4^+ - N estimated at the first sampling (5 days after incubation) were 89.6 ppm and 98 ppm, respectively compared to 127.2 ppm in laterite soil.

In red soil, the contents of NH_4^+ - N were found to progressively decrease with each stage of sampling and it reached a value of 33.6 ppm on 30th day.

In black soil, from 5th day onwards, the disappearance of NH_4^+ - N was faster than in red soil, declining to 16.1 ppm by 30 days of incubation.

In T_5 and T_6 where laterite soil was mixed with red soil and black soil respectively, no appreciable decrease in NH_4^+ - N content was observed even by 30 days. The estimated NH_4^+ - N content on 5th day was 124.6 ppm in T_5 and 119.7 ppm in T_6. The amounts recorded on 30th day were 126 ppm in T_5 and 114.8 ppm in T_6 indicating that mixing with black soil resulted in a slightly lesser amount of ammonia accumulation.

In T_7 where mixing laterite soil with red soil in 9:1 ratio together with liming was done, ammoniacal content of 120.4 ppm on 5th day, dropped at a very low rate and reached a value of 95.2 ppm on 30th day. But the content of NH_4^+ - N at any stage was not significantly lower than that recorded in T_1 (laterite soils, unlimed).

In T_8 (laterite soil mixed with black soil in 9:1 ratio and the mixture limed to a near neutral pH) hydrolysis of urea was completed by 5th day. NH_4^+ - N content of 116.2 ppm on 5th day gradually decreased to 92.4 ppm on 30th day. NH_4^+ contents on 5th, 15th and 25th days were significantly lower than T_1 (laterite soil, unlimed).

Results of the experiment showed that there was a steady drop in NH_4^+ - N content in red and black soil till 30th day. Among the other treatments, only T_8 had a significantly lower NH_4^+ - N content.

Liming and/or mixing with red soil or black soil were not much helpful in effecting ammonia oxidation in laterite soils.

From the various laboratory experiments carried out it was concluded that nitrification rate in the soil taken for the study was comparatively low. Liming to

produce favourable pH (6.2 - 6.7), mixing with soils having high nitrification rate to supply inoculum etc. were not helpful in enhancing nitrification.

B. Field experiment

The results from the field experiment that was laid out to study the crop response of nitrification inhibitors using fodder maize as the test crop are furnished in this section.

I. Periodic soil analysis

The data on NH_4^+ and NO_3^- - N contents in soil at different stages of growth of maize are presented in Table 10.

On 15th day after sowing, the average value of NH_4^+ - N content in the soil was 74.16 ppm. The lowest amount was in control (40.43 ppm). NO_3^- - N content in T_1 (control) was 2.2 ppm, the mean value in other treatments was about 4.44 ppm. Lowest NO_3^- - N was detected in T_3 (urea + N-Serve).

The average values of NH_4^+ - N in subsequent stages were 21.9 ppm, 19.08 ppm and 20.2 ppm respectively and that of NO_3^- - N were 3.75 ppm, 0.12 ppm and 0.26 ppm.

Table 10. NH_4^+ and NO_3^- - N content (ppm) in soil at different stages of growth of maize as affected by treated and untreated urea.

	Treatments	Days after sowing							
		15		30		45		60	
		NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
1	(Control - No N)	40.43	2.20	19.98	0.11	19.86	0.04	22.17	-
2	(Urea alone)	62.20	5.50	19.98	5.23	19.86	0.11	22.17	0.23
3	(Urea + N-Serve)	65.31	3.11	26.63	2.23	23.17	0.04	22.17	-
4	(Urea + neem cake)	71.53	5.66	13.32	3.65	19.87	0.11	22.17	0.46
5	(Urea + cashew shell)	71.53	5.66	19.98	4.18	19.93	-	25.34	0.12
6	(Urea + tobacco waste)	71.53	4.53	19.99	5.38	16.55	-	12.67	0.12
7	(Urea + calotropis leaf)	93.30	5.50	16.65	4.96	16.55	0.49	12.67	-
8	(Urea + Eucalyptus leaf)	62.20	3.54	16.65	2.84	19.86	0.11	19.00	-
9	(Urea + turmeric rhizome)	93.30	3.77	19.95	4.56	23.17	0.07	25.34	-
10	(Urea + neem leaf)	99.52	3.99	26.64	3.74	16.55	-	19.00	-
11	(Urea + cassava leaf)	82.63	5.55	19.98	2.48	16.55	0.07	15.84	-
12	(Urea + Moringa leaf)	74.64	4.77	26.64	1.60	23.17	0.07	25.34	-
13	(Urea + Sesamum cake)	93.30	6.88	23.31	2.66	16.55	-	22.17	-
14	(Urea + marotti cake)	58.98	3.11	19.98	3.53	16.55	-	25.34	0.35
15	(Urea + castor cake)	64.83	4.56	23.31	3.22	16.55	0.11	19.00	0.23
16	(Urea + arecanut)	84.96	4.73	26.64	6.88	19.86	0.04	22.17	0.41
17	(Urea + punna cake)	68.42	4.10	29.97	4.08	19.86	0.15	15.84	-
18	(Urea + rubber cake)	74.64	3.90	23.31	6.00	23.17	-	19.00	-
19	(Urea + Eupatorium leaf)	55.98	4.01	19.98	2.31	16.55	-	22.17	-
20	(Urea + turmeric leaf)	71.53	4.33	19.98	4.96	16.55	0.11	19.00	0.12
21	(Neem coated urea)	99.52	3.80	26.64	4.08	19.86	-	15.84	-

A decrease in NH_4^+ - N and NO_3^- - N was observed in all the treatments over the stages. None of the treatments showed consistent superiority over untreated urea.

II. Plant characters

1. Biometric observations

Mean height of plants

The data on the mean height of plants are given in Table 11 and the analysis of variance in Appendix V.

Data on 15th day showed that the treatments did not differ significantly among themselves with respect to plant height.

On 30th day, all treatments except T_4, T_9, T_{10} and T_{11} were on par with T_2 (untreated urea). T_4, T_9, T_{10} and T_{11} produced significantly shorter plants than T_2.

Plant height in the different treatments on 45th and 60th day did not differ significantly among themselves.

Mean height of plants on 15th day was on an average 30.56 cm. The heights at the succeeding stages (30th, 45th and 60th days) were 85.43, 189.18 and 197.91 cm, respectively).

Table 11. Mean height of plants at different stages of growth of maize (cm)

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	31.46	83.67	153.75	151.67
2	(Urea alone)	34.79	99.83	204.58	214.50
3	(Urea + N-Serve)	30.94	86.17	191.67	193.92
4	(Urea + neem cake)	27.48	67.08	161.67	169.42
5	(Urea + cashew shell)	30.42	99.00	205.33	210.00
6	(Urea + tobacco waste)	31.13	97.00	194.17	195.75
7	(Urea + calotropis leaf)	29.87	78.58	180.42	200.00
8	(Urea + Eucalyptus leaf)	31.50	92.67	198.33	209.67
9	(Urea + turmeric rhizome)	27.38	88.25	185.00	193.17
10	(Urea + neem leaf)	28.17	66.42	187.92	188.67
11	(Urea + cassava leaf)	26.21	60.92	141.67	167.67
12	(Urea + Moringa leaf)	29.84	88.63	193.50	195.50
13	(Urea + Sesamum cake)	31.98	96.83	212.08	218.08
14	(Urea + marotti cake)	31.00	89.75	200.83	214.50
15	(Urea + castor cake)	31.79	90.92	195.67	210.17
16	(Urea + arecanut)	30.08	77.25	180.83	197.08
17	(Urea + punna cake)	27.92	80.00	183.33	193.00
18	(Urea + rubber cake)	30.62	103.08	215.42	223.63
19	(Urea + Eupatorium leaf)	33.17	94.25	187.92	199.42
20	(Urea + turmeric leaf)	33.50	98.75	217.92	209.00
21	Neem coated urea	32.42	84.92	193.33	201.25
	CD (5%)	NS	23.84	NS	NS
	SEm ±	2.22	8.34	14.62	14.12

Plants in T_1 (control) had lower height than T_2 at all stages. Mean plant height in control was 31.46, 83.67, 153.75 and 151.67 cm respectively at the different stages of sampling as compared to 34.79, 99.83, 204.58 and 214.50 cm in T_2.

In general, it was observed that plant height increased over the stages in all the treatments. It could be seen that the rate of increase in height was higher in the early stages. By 45th day, growth had almost ceased and increase in height at the subsequent stage (60th day) was very small. The various treatments were not effective in producing increased plant height over untreated urea.

Leaf area index (LAI)

The data pertaining to the leaf area index at different growth stages are presented in Table 12. and those of a few representative treatments graphically presented in Fig.8. The analysis of variance is given in Appendix V.

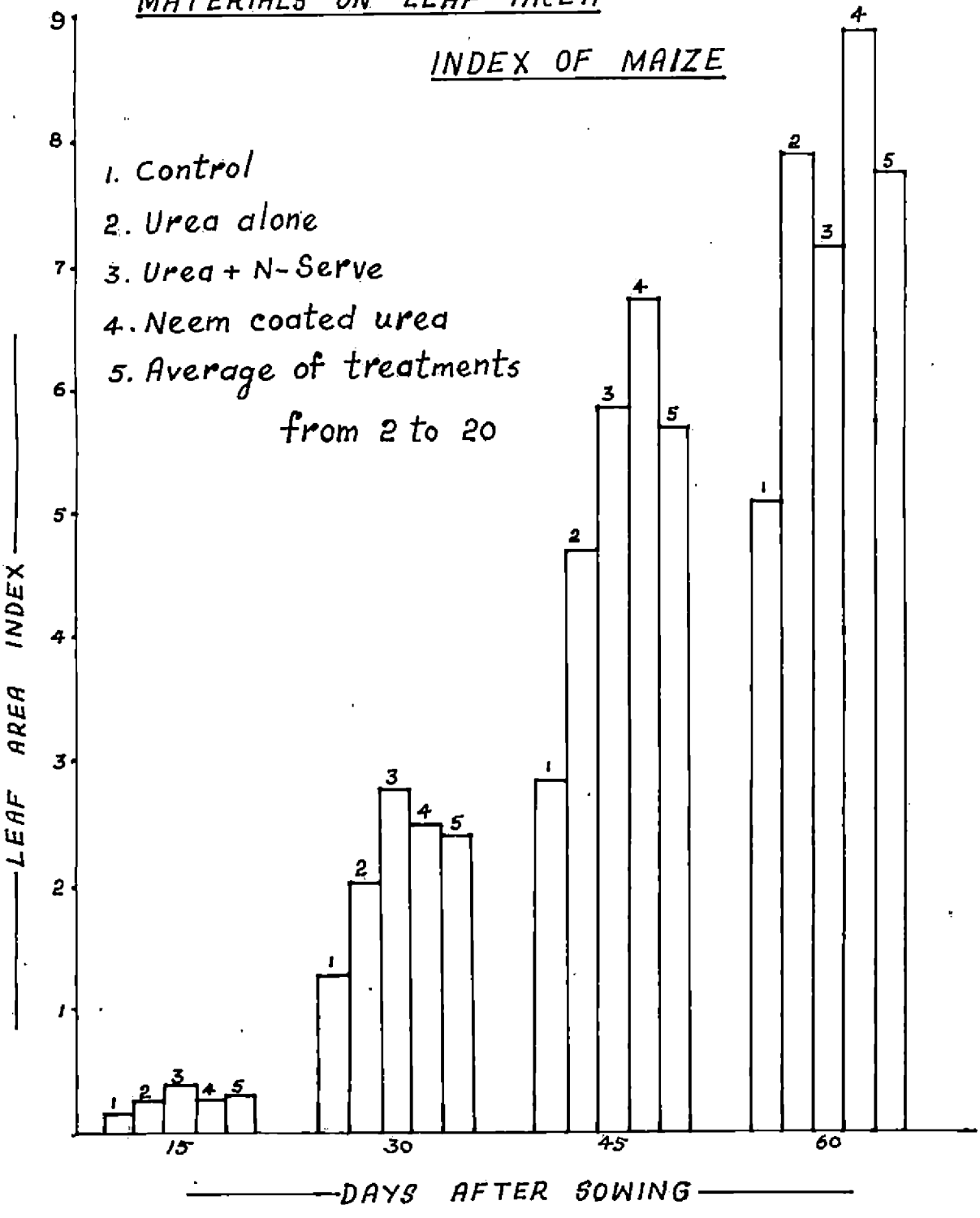
Values of LAI in the treatments were found to be on par at all stages of sampling.

T_3 (urea + N-Serve) had the highest value (0.38) on 15th day and T_1 (control), the lowest.

Table 12. Leaf area index at different stages of growth of maize

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	0.16	1.32	2.86	5.10
2	(Urea alone)	0.25	2.06	4.73	7.89
3	(Urea + N-Serve)	0.38	2.80	5.86	7.16
4	(Urea + neem cake)	0.17	2.69	4.63	9.01
5	(Urea + cashew shell)	0.21	1.87	6.91	6.94
6	(Urea + tobacco waste)	0.36	2.40	5.11	8.71
7	(Urea + calotropis leaf)	0.24	2.83	5.03	9.06
8	(Urea + Eucalyptus leaf)	0.20	2.53	6.18	6.66
9	(Urea + turmeric rhizome)	0.30	2.19	5.41	10.02
10	(Urea + neem leaf)	0.21	2.11	7.67	6.72
11	(Urea + cassava leaf)	0.29	2.09	3.94	6.41
12	(Urea + Moringa leaf)	0.22	3.05	5.83	7.62
13	(Urea + Sesamum cake)	0.37	2.64	6.35	7.95
14	(Urea + marotti cake)	0.25	2.42	7.50	9.06
15	(Urea + castor cake)	0.19	2.13	5.74	7.61
16	(Urea + arecanut)	0.27	1.90	6.27	7.17
17	(Urea + punna cake)	0.21	1.19	5.01	7.55
18	(Urea + rubber cake)	0.29	4.42	5.43	8.16
19	(Urea + Eupatorium leaf)	0.25	3.68	5.67	8.29
20	(Urea + turmeric leaf)	0.26	2.25	6.29	7.08
21	(Neem coated urea)	0.23	2.50	6.76	8.93
	CD (5%)	NS	NS	NS	NS
	SEm ±	0.06	0.61	0.98	0.94

Fig.8. EFFECT OF TREATING UREA WITH NITRIFICATION INHIBITION MATERIALS ON LEAF AREA INDEX OF MAIZE



Values of LAI on 30th day ranged from 1.19 to 4.42 in the various treatments. Values on 45th day were in the range from 2.86 to 7.67, the lowest being in control.

On 60th day also, LAI was lowest in control (5.10). T_{10} (urea + neem leaf) had the highest LAI, the value being 10.02.

It could be seen that with respect to the values of LAI, none of the treatments showed consistent superiority over untreated urea. T_1 recorded the lowest values at all stages, the values at the different stages being 0.16, 1.32, 2.86 and 5.10 respectively, whereas the average values registered in rest of the treatments were 0.25, 2.43, 5.68 and 7.77. It was clear that LAI steadily increased from sowing till harvest. N fertilisation helped in increased production of leaves than in control, though not significantly high. The treatments where various materials were used as nitrification inhibitors had no added advantage over untreated urea in increasing leaf area index.

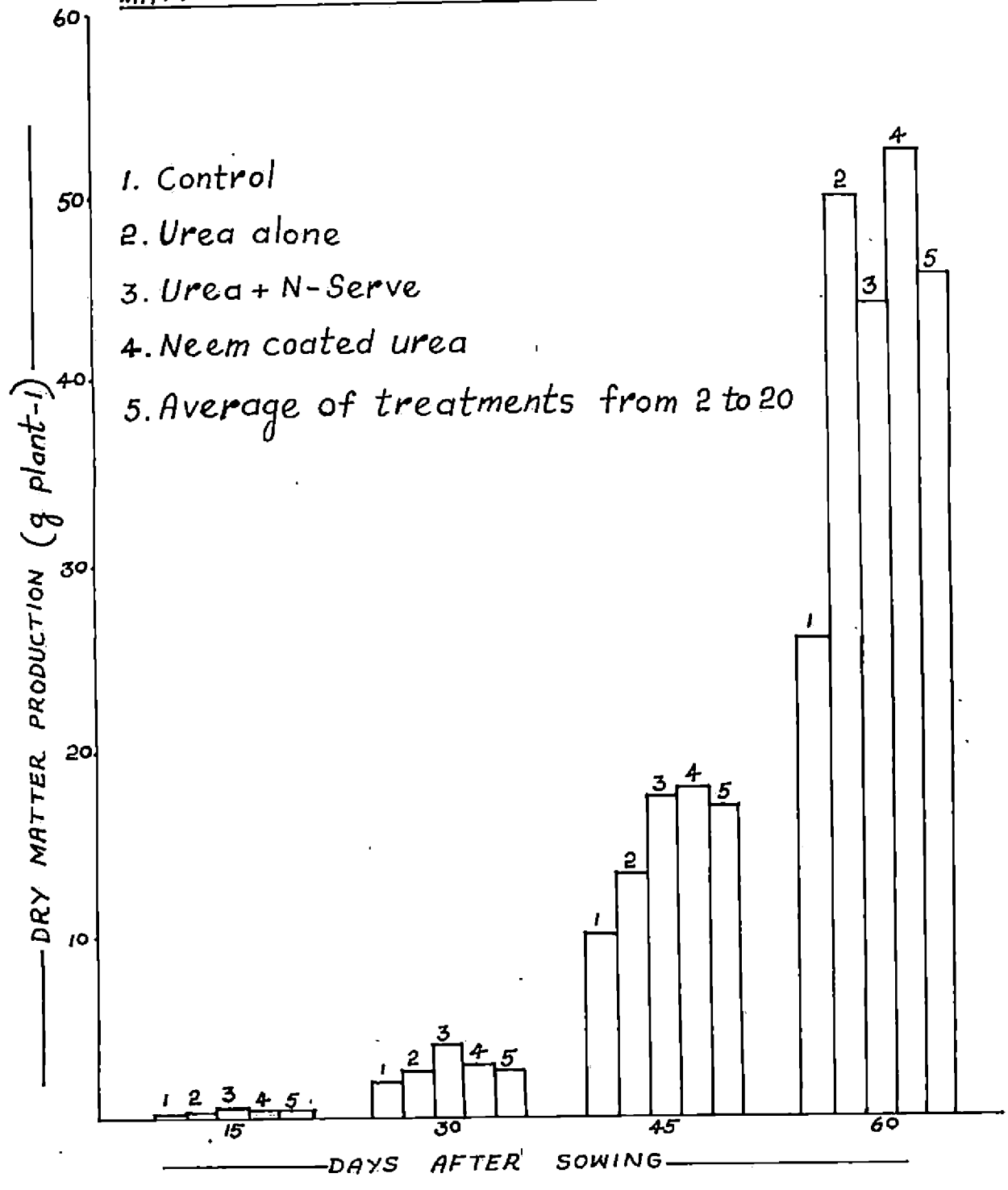
Dry matter production

The data on dry matter production of plants in the various treatments are presented in Table 13 and those

Table 13. Dry matter production at different stages of growth of maize (g plant^{-1})

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	0.24	1.95	10.10	26.13
2	(Urea alone)	0.37	2.69	13.24	49.71
3	(Urea + N-Serve)	0.53	3.86	17.18	44.14
4	(Urea + neem cake)	0.29	3.67	17.59	49.51
5	(Urea + cashew shell)	0.27	1.73	22.16	49.73
6	(Urea + tobacco waste)	0.34	2.98	15.98	47.90
7	(Urea + calotropis leaf)	0.37	3.37	12.40	44.72
8	(Urea + Eucalyptus leaf)	0.34	2.79	18.63	44.68
9	(Urea + turmeric rhizome)	0.43	3.01	12.73	51.19
10	(Urea + neem leaf)	0.36	3.05	23.32	36.02
11	(Urea + cassava leaf)	0.51	2.75	13.98	37.26
12	(Urea + Moringa leaf)	0.35	4.21	15.47	50.10
13	(Urea + Sesamum cake)	0.49	3.17	19.19	45.74
14	(Urea + marotti cake)	0.39	2.86	20.44	48.16
15	(Urea + castor cake)	0.30	2.41	17.25	45.76
16	(Urea + arsenut)	0.40	2.64	22.40	46.61
17	(Urea + punna cake)	0.32	1.72	16.74	39.37
18	(Urea + rubber cake)	0.41	5.47	18.04	44.89
19	(Urea + Eupatorium leaf)	0.39	5.57	16.32	50.73
20	(Urea + turmeric leaf)	0.38	2.73	21.22	49.69
21	(Neem coated urea)	0.37	3.07	17.67	53.90
	CD (5%)	NS	NS	NS	NS
	SEm ±	0.06	0.76	4.25	7.30

Fig. 9. EFFECT OF TREATING UREA WITH NITRIFICATION INHIBITION MATERIALS ON DRY MATTER PRODUCTION OF MAIZE



of a few representative treatments graphically presented in Fig. 9. The analysis of variance is given in Appendix VI.

Dry matter production in various treatments recorded at all the four samplings were on par. On an average, dry matter produced per plant by 15th day was 0.37 g. It increased to 3.13 g by 30th day. Dry matter accumulation at the last two stages were 17.24 and 45.52 g respectively.

In general, there was a sharp increase in dry matter production from sowing till harvest. T_1 recorded the lowest values at all stages though the difference was not significant when compared to those receiving fertilizer N. Mixing urea with the various materials to inhibit nitrification and thereby to prevent leaching losses of nitrogen were not helpful in effecting increased drymatter production over untreated urea.

2. Yield

The values on fodder yield at harvest are given in Table 14 and Fig. 10 and the analysis of variance in Appendix VI.

The highest fodder yield (7.2 tons ha^{-1}) was from T_{18} (urea + rubber cake). This was followed by

Table 14. Fodder yield of maize at harvest (tons ha^{-1})

	Treatments	Yield at harvest* (tons ha^{-1})	
1	(Control)	2.89	(1.69)
2	(Urea alone)	6.26	(2.49)
3	(Urea + N-Serve)	5.10	(2.24)
4	(Urea + neem cake)	4.83	(2.19)
5	(Urea + cashew shell)	5.91	(2.43)
6	(Urea + tobacco waste)	6.18	(2.48)
7	(Urea + calotropis leaf)	4.83	(2.20)
8	(Urea + Eucalyptus leaf)	5.58	(2.35)
9	(Urea + turmeric rhizome)	4.96	(2.18)
10	(Urea + neem leaf)	5.98	(2.43)
11	(Urea + cassava leaf)	4.07	(2.02)
12	(Urea + Moringa leaf)	5.27	(2.28)
13	(Urea + Sesamum cake)	6.29	(2.46)
14	(Urea + marotti cake)	5.53	(2.35)
15	(Urea + castor cake)	5.91	(2.43)
16	(Urea + arecanut)	5.07	(2.25)
17	(Urea + punna cake)	4.17	(2.04)
18	(Urea + rubber cake)	7.20	(2.68)
19	(Urea + Eupatorium)	5.77	(2.40)
20	(Urea + turmeric leaf)	6.27	(2.50)
21	(Neem coated urea)	5.65	(2.37)
	CD (5%)		(0.45)
	SEm ±		(0.16)

* Figures given in brackets are the transformed values

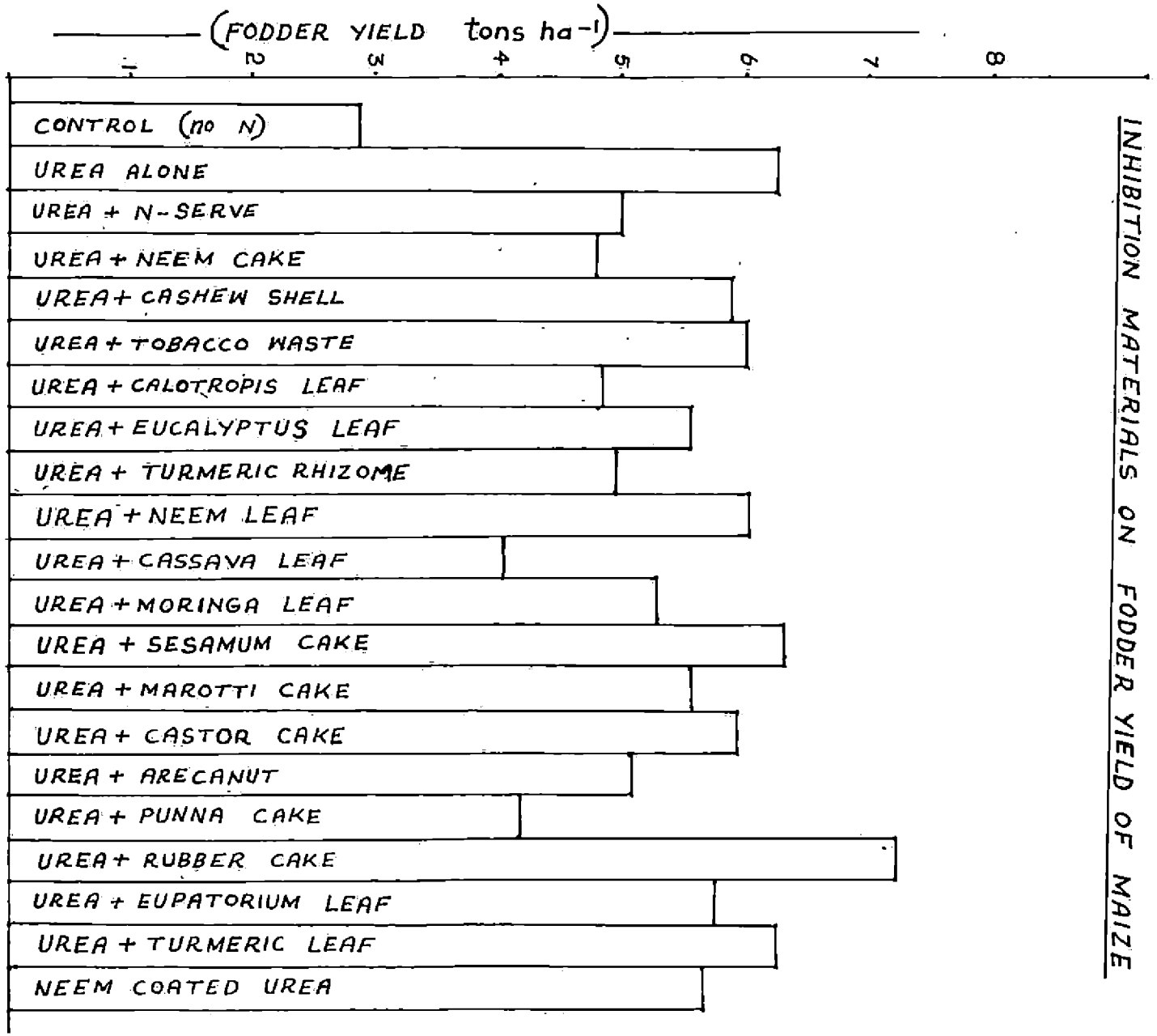


Fig.10. EFFECT OF TREATING UREA WITH NITRIFICATION INHIBITION MATERIALS ON FODDER YIELD OF MAIZE

T_{13} (urea + Sesamum cake) and T_{20} (urea + turmeric leaf) which recorded fodder yields of 6.29 tons ha^{-1} and 6.27 tons ha^{-1} respectively. From T_2 (untreated urea) fodder yield obtained was 6.26 tons ha^{-1}. Yield in many treatments were found to be lower than in T_2, but the differences were significant only in T_1, T_{11} and T_{17}. The lowest yield (2.89 tons ha^{-1}) was in control. Hence it was concluded that nitrogen fertilisation had a marked influence on yield. On an average, the fodder yield in treatments from 2 to 20 was 5.54 tons ha^{-1}. Yield in none of the treatments showed significant superiority over T_2 i.e. the various treatments could not produce any added advantage over untreated urea.

3. Chemical studies

Nitrogen content of plants

Nitrogen content of leaves and that of rest of plant parts were estimated separately. The data on N content of leaves at different stages of growth are presented in Table 15 and its analysis of variance in Appendix VII.

On 15th day, N content in none of the treatments were significantly higher than T_2 (untreated urea). The values of T_1, T_{20} and T_5 were significantly lower than T_2.

Table 15. N content of maize leaf at different stages of growth (%)

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	2.57	2.66	1.89	1.47
2	(Urea alone)	3.78	3.65	2.78	1.91
3	(Urea + N-Serve)	3.52	3.59	2.99	1.98
4	(Urea + neem cake)	3.55	3.69	2.94	2.34
5	(Urea + cashew shell)	3.03	3.43	2.94	2.17
6	(Urea + tobacco waste)	3.57	3.69	2.82	2.22
7	(Urea + calotropis leaf)	3.20	3.45	3.01	2.24
8	(Urea + Eucalyptus leaf)	3.34	3.48	2.85	2.36
9	(Urea + turmeric rhizome)	3.41	3.73	2.80	2.27
10	(Urea + neem leaf)	3.76	3.41	2.54	2.08
11	(Urea + cassava leaf)	3.29	3.59	2.61	2.15
12	(Urea + Moringa leaf)	3.55	3.43	3.01	1.94
13	(Urea + Sesamum cake)	3.52	3.62	3.08	2.01
14	(Urea + marotti cake)	3.62	3.64	3.06	2.03
15	(Urea + castor cake)	3.64	3.45	2.75	2.10
16	(Urea + arecanut)	3.64	3.52	2.63	2.24
17	(Urea + punna cake)	3.52	3.45	2.68	2.10
18	(Urea + rubber cake)	3.71	3.43	2.64	2.24
19	(Urea + Eupatorium leaf)	3.57	3.38	2.78	2.03
20	(Urea + turmeric leaf)	3.13	3.45	2.85	1.96
21	(Neem coated urea)	3.36	3.64	2.80	2.20
	CD (5%)	0.58	0.44	0.40	0.34
	SEm ±	0.21	0.15	0.14	0.12

On 30th and 45th days, N content in all the treatments were on par with T_2 except T_1 which had significantly lower values (2.66 and 1.89 per cent respectively).

At harvest also, N content of T_1 was significantly lower than T_2 (untreated urea). T_4 (urea + neem cake) and T_8 (urea + Eucalyptus leaf) had a significantly higher value than T_2.

Nitrogen content estimated in leaves on 15th day of sowing was on an average 3.49 per cent, whereas in control it was only 2.57 per cent. By 30th day, they recorded a slightly higher value of 3.54 per cent. N content in T_1 was increased to 2.66 per cent at this stage. Average values at the last two steges in treatments from 2 to 21 were 2.83 per cent and 2.13 per cent respectively, while the values in control were 1.89 per cent and 1.47 per cent.

Data on N content of rest of plant parts are shown in Table 16 and the analysis of variance in Appendix VII.

Nitrogen content of plant parts excluding leaves at all stages were found to be on par with T_2 except T_1 which had significantly lower values at the first three stages of sampling.

Table 16. N Content of plant parts excluding leaves at different stages of growth of maize (%)

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	2.14	1.91	1.19	0.84
2	(Urea alone)	2.61	2.96	1.98	0.98
3	(Urea + N-Serve)	2.52	3.13	1.96	1.10
4	(Urea + neem cake)	2.59	3.29	2.08	1.31
5	(Urea + cashew shell)	2.31	3.15	1.91	1.00
6	(Urea + tobacco waste)	2.38	3.24	1.98	1.24
7	(Urea + calotropis leaf)	2.38	2.89	2.19	0.98
8	(Urea + Eucalyptus leaf)	2.19	2.80	2.08	0.96
9	(Urea + turmeric rhizome)	2.42	2.94	2.08	1.07
10	(Urea + neem leaf)	2.33	2.92	1.87	1.21
11	(Urea + cassava leaf)	2.66	2.99	2.24	0.98
12	(Urea + Moringa leaf)	2.43	3.17	2.15	0.91
13	(Urea + Sesamum cake)	2.48	2.87	2.12	0.96
14	(Urea + marotti cake)	2.57	3.15	2.15	1.24
15	(Urea + castor cake)	2.52	2.80	2.19	1.59
16	(Urea + arecanut)	2.57	2.80	2.10	1.28
17	(Urea + punna cake)	2.38	2.82	2.10	1.31
18	(Urea + rubber cake)	2.03	3.08	2.01	1.19
19	(Urea + Eupatorium leaf)	2.47	2.71	2.01	1.16
20	(Urea + turmeric leaf)	2.29	2.89	2.12	1.21
21	(Neem coated urea)	2.47	3.13	2.12	1.26
	CD (5%)	0.56	0.50	0.44	NS
	SEm ±	0.20	0.17	0.15	0.15

Nitrogen content estimated in T_1 (control) at the four stages (15, 30, 45 and 60 days after sowing) were 2.14, 1.91, 1.19 and 0.84 per cent respectively. At all stages N content assumed higher values than control in all other treatments, the average values being 2.43, 2.99, 2.07 and 1.15 per cent respectively over the stages studied.

Compared to N content in leaves, values of N content in rest of plant parts were found to be lower. In both the cases, N content showed an increase upto 30th day and thereafter declined. The various materials added to urea did not exert any influence on nitrogen content.

Total nitrogen uptake

The data on total nitrogen uptake are given in Table 17 and the analysis of variance in Appendix VIII.

Values of N uptake on 15th day were on par with T_2 (untreated urea) except T_1 (control) and T_5 (urea + cashew shell) which had significantly lower values.

On 30th day, T_{18} (urea + rubber cake) and T_{19} (urea + Eupatorium leaf) had significantly higher N uptake values than T_2. All other treatments were on par

Table 17. Total N uptake by maize at different stages of growth (mg plant^{-1})

	Treatments	Days after sowing			
		15	30	45	60
1	(Control)	5.37	47.12	142.62	289.51
2	(Urea alone)	13.15	94.34	317.89	675.66
3	(Urea + N-Serve)	16.97	131.76	424.96	689.17
4	(Urea + neem cake)	9.75	118.59	434.66	811.56
5	(Urea + cashew shell)	7.35	58.62	533.40	736.89
6	(Urea + tobacco waste)	11.34	106.60	384.70	852.28
7	(Urea + calotropis leaf)	11.10	112.07	322.21	693.31
8	(Urea + Eucalyptus leaf)	10.42	91.15	463.76	675.38
9	(Urea + turmeric rhizome)	13.61	109.85	316.92	719.38
10	(Urea + neem leaf)	12.42	99.10	523.58	541.67
11	(Urea + cassava leaf)	15.97	95.05	348.84	573.90
12	(Urea + Moringa leaf)	11.66	141.40	399.05	666.24
13	(Urea + Sesamum cake)	16.12	109.79	497.32	615.38
14	(Urea + mahotti cake)	13.42	99.29	535.22	762.80
15	(Urea + castor cake)	9.95	80.16	436.50	754.61
16	(Urea + arecanut)	13.69	87.78	575.59	897.50
17	(Urea + punna cake)	10.37	58.95	404.33	659.77
18	(Urea + rubber cake)	13.91	183.64	416.23	807.40
19	(Urea + Eupatorium leaf)	13.61	184.31	392.46	835.84
20	(Urea + turmeric leaf)	11.13	92.19	517.48	772.44
21	(Neem coated urea)	11.70	110.68	550.05	867.95
	CD (5%)	5.79	70.81	NS	NS
	S$\bar{x}$m ±	2.02	24.78	104.85	137.58

with T_2. At the last two stages, N uptake by plants in all the treatments were found to be on par.

In the treatments which received fertiliser nitrogen, the average values of nitrogen uptake over the stages were 12.38, 108.27, 439.75 and 733.91 mg plant^{-1} respectively. In control, N uptake assumed values of 5.37, 47.12, 142.62 and 269.51 mg plant $^{-1}$ respectively at the different stages.

In short, N uptake increased progressively with successive stages of crop growth. Lowest values were for T_1. Mixing urea with various materials showed no additional benefit over untreated urea.

DISCUSSION

DISCUSSION

The present study was aimed at screening a few plant materials that are reported to have allelopathic and bactericidal properties as nitrification inhibitors, standardising the doses of promising materials and to test them finally in the field. As programmed, the screening and dose standardisation were to be done using laboratory incubation. A total of 17 materials were used for screening using already proved nitrification inhibiting materials like N-Serve (2 chloro-6 (trichloro methyl) pyridine) and neem cake as reference. The incubation study was started in May 1984 using sieved typical laterite soil. The experimental procedure involved bringing the soil (1 kg) to 65 per cent field moisture capacity, incubating it with 100 ppm N in the form of urea. The new materials to be tested were added at urea: material ratio of 5:3 and in the case of N-Serve the rate of application was 1 per cent of N. Samples were drawn at intervals of 5, 10, 15, 20 and 30 days for estimations of NH_4^+ and NO_3^- - N.

The results of the study showed appearance of appreciable quantities of NH_4^+ - N from the amide form

applied even at the very first sampling five days after incubation, the quantities being in the range from 60.2 to 76.8 ppm in the various treatments (The values from control were substracted from the NH_4^+ - N contents of samples supplied with urea) (Table 2). There was no significant difference between treatments. With advancing periods of incubation, there was increase in content of NH_4^+ - N upto 10 days after which the level remained nearly steady. Contrary to expectation, there was no significant difference in the NH_4^+ - N content between treatments at any of the stages, though estimations continued upto 30 days. Even in cases where the standard inhibiting materials, N-Serve and neem cake were applied, there was no added build up of NH_4^+ - N as compared to untreated urea.

The explanation for the above unexpected behaviour in the lack of differences between treatments can be given based on the data on the absolute quantities of NH_4^+ and NO_3^- - N in the incubated soil samples. It is frequently reported that nitrification occurs in soils under suitable aerated conditions at such rates that result in appearance of NO_3^- in substantial quantities and a simultaneous disappearance of the NH_4^+ form (Brady, 1974). In the present study, the content of NH_4^+ - N which was in the range from 60.2 to 76.8 ppm five days

after incubation in the different treatments supplied with urea tended to either increase gradually with advancing stage or to remain nearly the same. Even upto the last stage of estimation (30 days after incubation) there was no indication of any decrease in the NH_4^+ - N content in any of the treatments including the one that was supplied with urea alone. The content of NO_3^- - N was comparatively very low during the entire period of study upto 30 days, though it increased from values in the range from 1.07 to 3.87 ppm five days after incubation to those in the range from 1.87 to 7.53 ppm 10 days after. After the 10th day, the content of NO_3^- - N remained nearly the same. The only exception to the above trend was in the case of urea treated with N-Serve in which case NO_3^- - N content remained at a low level of 1.07 to 1.87 ppm upto the 15th day. Assuming that N-Serve was thus effective in inhibiting nitrification, the extent of difference in the NO_3^- - N build up was very small (say around 5 to 6 ppm). The conclusions from the above substantial build up and maintenance of NH_4^+ - N upto the last stage and the lack of any substantial quantity of NO_3^- - N in the soil has to be that there were strong inhibiting factors for nitrification in the soil naturally. Inasmuch as there

was no marked nitrification occurring in the soil, significant treatment differences in NH_4^+ or NO_3^- - N contents could not be observed. However, in the case of NO_3^- - N content 10 days after incubation, the differences attained the level of statistical significances, the soil treated with N-Serve recording significantly lower values. This difference was not noticed at the earlier and later stages of incubation.

Data on nitrification rate (Table 4) also tally with the above observations on NH_4^+ and NO_3^- - N contents, the values being conspicuously low during the entire period of incubation. Starting from a low value of 2.73 per cent in untreated urea it rose to 7.97 per cent 10 days after incubation and tended to remain more or less at comparable values. In the case of all the samples treated with different materials, the trend was nearly the same and the values comparable.

Based on the conclusion that the nitrification rate in the soil under study was basically low, further attempts were made to locate the factors that were responsible for this unusually low rate of nitrification. The suspected factors were the following:

1) The substantial build up of NH_4^+ - N to over 100 ppm following application of urea at 100 ppm N might result in inhibition of nitrifying organisms.

2) The pH of the laterite soil is very low (5.15) and such a low pH may be unfavourable for the growth and activity of nitrifiers. It has been reported that the favourable pH range for the growth of nitrifying organisms is around 6.2 to 7.6 and that at lower pH values, nitrification rate will be lowered (Morril and Dawson, 1962).

3) The soil for the study was collected from an area that was comparatively low in organic matter content. The field was without crop at the time of collection of soil samples. A soil with a higher organic matter content supporting an active vegetation might perhaps have a higher population of nitrifiers.

4) The moisture content of the incubated soil might be unfavourable for nitrification. It has been reported (Tisdale and Nelson, 1975) that both high and low moisture contents suppress the activity of nitrifying organisms, the adverse effect being more pronounced at higher moisture contents.

5) The urea fertiliser that was used for supplying nitrogen might contain inhibitors like biuret which may

impede nitrification. Sahrawat (1977) observed inhibition of nitrification due to biuret content in urea.

6) The laterite soil may be basically low in the population of nitrifying organisms and even when pH is amended, there may not be enough of their population for build up and activity within a reasonable period. Inoculating this soil after emending pH with a soil known to have high nitrifying activity might induce nitrification.

7) The favourable effect consequent to application of nitrification inhibitors, especially organic materials like neem cake in terms of crop response might arise from advantageous factors other than nitrification inhibition.

To assess the involvement of the above factors, seperate studies were conducted.

1. Study on the mineralisation pattern of urea applied at different doses

This study involved incubation of the soils with urea at 10, 25, 50 and 75 ppm N. The objective was to study if there would be nitrification and substantial decrease in NH_4^+ - N content of soils following incubation. Estimations of NH_4^+ - N content were made at 2, 5, 11, 18 and 21 days after incubation. The results (Table 5) showed

no indication of any decrease in NH_4^+ - N content even upto the last stage of sampling, 21 days after incubation. With increasing rates of applied urea there was near proportionate increase in NH_4^+ - N content also, which at the last stage of sampling were 33.4, 59.6, 71.9 and 96.6 ppm when supplied with 10, 25, 50 and 75 ppm N through urea, respectively. As there was practically little difference in the trend of NH_4^+ build up at any of the rates, it was concluded that inhibition of nutrification by NH_4^+ may not be a factor for the noted low rate of nitrification. Also, Stojanovi and Alexander (1958) have reported that inhibition of nitrification occurs only when NH_4^+ - N content in the soil is 250 ppm or above; at rates lower than this, there was no depression of NO_3^- - N formation.

2. Studies on the mineralisation pattern of urea in soils collected from two locations and the effect of liming them.

As indicated earlier, the soil samples for the study were collected from an area which was comparatively low in organic matter content and was not under crops at the time of collection. For purpose of comparison, soil samples were collected from an area rich in organic matter and which was under an existing crop of rubber. These two

soils were incubated with and without lime to study the effects of involvement of organic matter content of soil and liming on nitrification. Estimations of NH_4^+ - N content were made 5, 10, 15 and 20 days after incubation. Both the soils, with and without lime, were studied with addition of urea at 100 ppm N and without added urea. The results (Table 6) showed that the only conspicuous and consistent effect on the NH_4^+ - N content was from the addition of urea. Without added fertiliser, the NH_4^+ - N content was less than 4.8 ppm in the original soil and less than 6.4 ppm in the organic rich soil. Liming led to no consistent effect at any of the stages though there was a tendency for a higher content of it in the limed set at the last two stages, 15 and 20 days after incubation. The difference between soils was also not appreciable. The conclusion that was drawn from this incubation study was that pH, organic matter content and cropping history did not, appear to be important factors deciding the lack of nitrification in the soil under study. This is in contrast to the observations of Alexander (1976) who reported that nitrification in acid soils is usually markedly enhanced by liming. Also, Stepanova (1961) observed that nitrification was greater under cultivated crops than under other crops and the dynamics of NO_3^- accumulation was affected by the preceeding crop.

3. Studies on the mineralisation pattern of urea at varying moisture levels

All the soil samples for the earlier incubation studies were maintained at 65 per cent field moisture content which is reported as the standard moisture level for nitrogen mineralisation studies (Jackson, 1958). In order to find out whether this moisture content is not appropriate for nitrification, soil samples with 100 ppm N as urea were incubated at moisture contents of 25, 50, 75 and 100 per cent field capacity. Estimations of NH_4^+ - N were made 1, 3, 4, 5, 6, 9 and 11 days after incubation. It was found (Table 7) that when supplied with moisture at 100 per cent field capacity, urea hydrolysis was nearly complete by about the fourth day. With decreasing moisture contents, there was progressive delay in appearance of peak NH_4^+ - N content, the period at 75 per cent field capacity being about nine days. At 50 and 25 per cent field capacity, there was continuous increase in NH_4^+ - N build up and even on the last stage, 11 days after incubation, the values at these two moisture contents were very much lower than the value of about 100 ppm noted at higher moisture contents on completion of urea hydrolysis. On the last day (11th day), the NH_4^+ - N contents were 24.5, 47.4, 108.1 and 102.8 ppm, respectively, at 25, 50, 75 and 100 per cent field moisture. As the results indicate, the

standard moisture content of 65 per cent field capacity was not high enough for a fast hydrolysis of urea to NH_4^+ form. However, irrespective of the moisture contents at which soil samples were maintained, there was no indication of a decrease in NH_4^+ - N content after a peak which shows that further conversion of NH_4^+ to NO_3^- form did not occur at any of the moisture contents. The main objective of this study was to assess whether soil aeration was a limiting factor in nitrification at the level of moisture at which the soil samples were maintained. As there was no decrease in NH_4^+ - N content with advancing stage in any of the treatments, the involvement of moisture contents as an inhibiting factor may be ruled out. There are reports that nitrification rate is not much affected between moisture levels 0.1 bar tension (higher than that at field capacity) to 7 bars, which is comparatively dry (Tisdale and Nelson, 1975).

4. Studies on the comparative rates of mineralisation of urea and ammonium sulphate

In order to assess whether inhibiting materials contained in the urea fertilizer (like biuret) were responsible for naturally inhibiting nitrification, separate incubation studies were conducted with addition of 100 ppm N supplied through urea and ammonium sulphate. Samples for estimations were drawn 1, 4, 7, 14 and 21 days

after incubation. As the results in Table 8 show, there was a steady increase in the NH_4^+ - N content of soils treated with urea upto the 14th day after which it remained nearly the same. Even one day after incubation, there was substantial quantity of NH_4^+ - N in this set which rose rapidly to 67 ppm 7 days after incubation. As expected, the NH_4^+ - N content of ammonium sulphate treated soil was high starting from the first stage of sampling, the value one day after incubation being 82.7 ppm and that at the last day being 95.4 ppm. There was no indication of a drop in NH_4^+ - N in either of the cases, starting from the first stage of sampling in the case of ammonium sulphate and from 14th day in the urea treated set. As the contents of NH_4^+ - N were comparable in the soils treated with the two fertilisers and as the values remained nearly the same or were showing progressive increase with advancing stage, it was presumed that inhibitors in urea were not involved in the nitrification inhibition.

5. Studies on the effects of liming and inoculation with soils with high nitrification rates.

This part of the study involved the use of red and black soils of Tamil Nadu Agricultural University, Coimbatore with pH values of 7.5 and 7.9 respectively,

and which are reported to have high nitrification rates. One of the purposes of using these soils was to find if the conditions of incubation in this study were not suitable for nitrification. For this, these two soils were incubated along with experimental laterite soil under the standard incubation conditions. The study continued upto 30 days, samples being drawn 5, 10, 15, 25 and 30 days after incubation. Another important objective was to use these soils as inoculants for the supply of nitrifying organisms on the assumption that the laterite soils did not support high native population of these organisms. Treatments of liming were also included in combination to find out if supply of inoculum to amended soil will induce nitrification. The results (Table 9) showed appreciable decrease in NH_4^+ - N content of red and black soils of Coimbatore. Even on the first sampling, five days after incubation, the NH_4^+ - N content of red and black soils were 89.6 and 98.0 ppm, respectively, which were much lower than the limed and unlimed laterite soil which had values of 121.8 and 127.2 ppm, respectively. Starting from these values of 89.6 and 98.0 ppm, there was a conspicuous and steady decrease in NH_4^+ - N to reach the lowest values of 33.6 and 16.1 ppm in the red and black soils. The data thus show reasonably fast nitrification and disappearance of NH_4^+ - N in these two soils. In the

laterite soil samples which were also set for incubation under the same conditions during the same period, the peak values of NH_4^+ - N content noted after five days of incubation remained nearly the same. As was observed in the earlier incubation studies, the values even after 30 days incubation were comparable to the peak values. In the laterite soil samples which were incubated with the red and black soils at a ratio of 9:1 also, there was no marked decrease in NH_4^+ - N content though the limed set had lower values at the last stage of sampling, 30 days after incubation. However, here also the extent of decrease was not appreciable and not in any way comparable to the corresponding values of red and black soils of Coimbatore. It is thus apparent that the laterite soils do not favour any measurable rate of nitrification, not comparable to soils of Coimbatore and those whose nitrification rates are commonly reported. A probable supply of inoculum by soil mixing also does not appear to change the situation irrespective of whether the soils are limed or not.

All the incubation studies discussed above repeatedly show a consistent maintenance of NH_4^+ - N produced in or supplied to the soil. As have been concluded elsewhere, the only logical conclusion appears to be that

no appreciable nitrification occurs in the laterite soil under ordinary condition. Though attempts to locate the factors responsible for this were not successful, the fact that nitrification probably does not occur in appreciable amounts is brought out consistently from all the incubation studies and estimations.

Studies on the effect of nitrification inhibition materials on growth and yield of maize.

This replicated field experiment with maize was conducted with a total of 21 treatments which included a control with no N supply, urea alone and neem coated urea at 120 kg ha^{-1}, and urea at this rate along with all the materials used for the incubation study. Among these materials were the standard nitrification inhibitors applied at the standard rates. The fodder maize variety, African Tall Maize, was grown for a period of 60 days and observations on various growth characters and N content and uptake were recorded at periodic intervals. NH_4^+ and NO_3^- - N contents of soils were also estimated at these intervals. The results on chemical analysis of soil (Table 10), as expected, showed conspicuous differences apparently arising from sampling errors. The only conspicuous treatment effects were the comparatively lower NH_4^+ - N contents of control

at the first stage of sampling and the very low NO_3^- - N contents in all the treatments.

Data on growth parameters including plant height, leaf area index and dry matter production showed indications of advantage due to application of N though it was not statistically significant. When supplied with N, the differences between the accompanying inhibitor materials were not significant at any of the stages. Similar were the results on total fodder yield at harvest, but the yield in the control was significantly lower than in the treatments that received fertiliser N. The yield in the control was 2.89 tons ha^{-1} compared to values in the range from 4.07 to 7.20 tons ha^{-1} in the other treatments. Results on N contents of plant parts at various stages and those on total N uptake also gave similar results. As indicated by the increasing trend in growth and yield of the test crop by addition of fertilisers, the N supplying power of the soil was low compared to crop requirement. As there was such a marked response to added N, any real difference between nitrification inhibition materials would have become apparent as compared to the treatment supplying urea alone. This is especially so as there was enough of rain to result in substantial loss of NO_3^- - N from soil through leaching. The results of the field studies also

thus support the conclusions from the incubation studies showing that the inherent rate of nitrification in the laterite soil is inadequate to bring about any savings in N use efficiency from the addition of nitrification inhibition materials.

As had been indicated in the list of objectives, the main purpose of the study was to identify indigenous and effective nitrification inhibition materials. As the soil did not support any conspicuous degree of nitrification, such a screening could not be effectively done. The study has, however, shown consistently that quite contrary to expectation, the laterite soils do not favour significant nitrification under ordinary conditions. Locating the factors responsible for this unusual behaviour was not possible from the experiments conducted in this study. Further studies on these are suggested as practically and scientifically relevant.

SUMMARY

SUMMARY

A study was conducted during the period from May 1984 to November 1985 at the College of Horticulture, Vellanikkara, Trichur to screen plant materials for nitrification inhibition properties and to test the field performance of the promising materials using fodder maize as the test crop. The screening part was done using laboratory incubation studies. A total of 17 materials were used for screening using standard nitrification inhibition materials like N-Serve (2 - chloro -6 (trichloromethyl) pyridine) and neem cake for comparison. The study was done using laterite soil of pH 5.15. The soil was supplied with 100 ppm N in the form of urea and maintained at 65 per cent of field moisture capacity. The materials were added at urea: material ratio of 5:3 and in the case of N-Serve, the rate of application was one per cent of N. Samples were drawn at intervals of 5, 10, 15, 20 and 30 days and NH_4^+ and NO_3^- - N contents were estimated. The study was replicated thrice.

Since there was no marked nitrification in the soil, separate incubation studies were conducted to examine if factors like build up of NH_4^+ - N to values around 100 ppm,

pH, organic matter content, cropping history, moisture level of incubation, source of fertiliser N and lack of microbial population were responsible for the naturally low rate of nitrification.

In the field trial, in addition to the materials used in the laboratory screening study, neem coated urea also was included. Nitrogen at the rate of 120 kg ha^{-1} was applied basally. The fodder maize variety, African Tall Maize, was grown for a period of 60 days and observations on various growth characters, N content and uptake at periodic intervals and fodder yield at harvest were recorded. The results of the study are summarised below.

1. By 5th day of incubation itself, appearance of appreciable quantities of NH_4^+ - N from amide form occurred. Hydrolysis of urea was nearly over by 10th day.

2. There was no significant difference between treatments in the pattern of urea hydrolysis.

3. The content of NH_4^+ - N increased upto 10th day due to conversion of amide form to NH_4^+ form, after which the level remained nearly steady.

4. There was no significant difference in the NH_4^+ content between treatments at any of the stages. Hence selection of promising materials to be used as nitrification inhibitors could not be done based on NH_4^+ - N content in the soil.

5. The content of NO_3^- - N produced was comparatively very low, though it increased from a mean value of 2.31 ppm on 5th day to 6.02 ppm on 20th day. Hereafter the content remained nearly the same.

6. NO_3^- - N contents in the different treatments were not significant at any of the stages except in the case where urea was treated with N-Serve, which on 10th day recorded significantly lower NO_3^- - N content than other treatments.

7. The nitrification rate also was found to be very low. Starting from an overall mean value of 3.19 per cent on 5th day, it rose to 6.91 per cent 10 days after incubation after which the level tended to remain more or less at comparable values.

8. Nitrification rates in all the treatments was found to be on par till the end of the incubation period. From these results it was concluded that the rate of

nitrification naturally occurring in the soil under study was negligible.

9. With higher amount of added urea, the time taken for the completion of hydrolysis was found to be prolonged.

10. The quantity of fertiliser nitrogen added was not a factor deciding nitrification and there was apparently no inhibition of the reaction by the NH_4^+ - N produced.

11. Raising the pH by liming could not increase nitrification rate in the soil.

12. Mineralisation pattern of urea was found to be similar in soils of different levels of organic matter content and varying cropping history.

13. Urea hydrolysis was slow at lower moisture levels. When supplied with 100 ppm as urea at 100 per cent field moisture capacity, hydrolysis was nearly complete by 4th day. With decreasing moisture content, there was progressive delay in appearance of peak NH_4^+ - N content. At 25 per cent field capacity, hydrolysis was not complete even after 11 days of incubation.

14. At any of the moisture levels tested, there was no appreciable nitrification and hence the moisture level

maintained in the incubation experiments was not an inhibiting factor for nitrification.

15. Irrespective of whether the source of nitrogen was urea or ammonium sulphate, there was no appreciable conversion of NH_4^+ to NO_3^- - form. As the contents of peak NH_4^+ - N were comparable in the soils treated with the two fertilisers and as the values remained nearly the same, it was presumed that inhibitors like biuret in urea were not involved in the nitrification inhibition.

16. The red and black soils of Coimbatore showed reasonably fast nitrification. Decrease in NH_4^+ - N content started before 5th day itself in these soils.

17. Inoculating laterite soil with red and black soil at a ratio of 9:1 did not markedly decrease NH_4^+ - N content, irrespective of whether the soil was limed or not.

18. In the field experiment, NH_4^+ and NO_3^- - N contents of soil estimated at periodic intervals did not show consistent treatment differences, except in control where NH_4^+ - N content at the first stage of sampling remained comparatively low. NO_3^- - N content in all the treatments was very low.

19. Observations on various growth characters like mean height, LAI and dry matter production did not show any significant treatment differences. The lowest values were recorded in control, though the differences were not statistically significant.

20. Plant height increased with advancing age; the rate of increase was higher in the early stages. Increase in height after 45th day was low. LAI and dry matter production showed a steady increase from sowing till harvest.

21. The fodder yield in none of the treatments receiving fertiliser N showed significant superiority over untreated urea. In control, which received no fertiliser nitrogn, the yield was significantly lower than in the other treatments.

22. Compared to nitrogen content in leaves, values of nitrogen content in rest of plant parts were found to be lower. In both the cases, nitrogen content showed an increase upto 30th day and thereafter it declined.

23. Nitrogen contents of plant parts in all the treatments were on par with untreated urea except in control where the values were significantly lower.

24. Nitrogen uptake increased progressively with increasing age of the crop.

25. In the treatment which received fertiliser nitrogen, nitrogen uptake values were significantly higher than in control upto 30th day.

26. From the crop response, urea treated with various materials including neem coated and N-Serve treated urea were found to be on par with untreated urea.

27. The overall conclusions from the study were that

(i) The soil had naturally low rate of nitrification and hence no added advantage can be expected with the use of nitrification inhibitors.

(ii) Factors like organic matter content, pH, cropping history and microbial population did not appear to be responsible for the low rate of nitrification.

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* Originals not seen

APPENDICES

Appendix I. Weather data (weekly average) for the cropping period (September 1985 to November 1985)

Week No.	Month and date	Rainfall (mm)	Temperature		Relative humidity		Sunshine hours
			Maximum (°C)	Minimum (°C)	Forenoon	Afternoon	
36	September 3-9	5.00	30.36	23.16	93.43	71.71	4.23
37	September 10-16	8.44	29.06	22.24	91.86	71.14	5.19
38	September 17-23	-	31.40	23.11	91.57	59.43	7.81
39	September 24-30	2.42	31.16	23.34	88.71	72.14	5.23
40	October 1-7	19.03	30.64	22.84	91.86	74.71	4.14
41	October 8-14	6.82	30.50	22.49	92.43	67.43	5.99
42	October 15-21	32.97	30.91	22.04	82.57	63.71	8.17
43	October 22-28	36.97	32.10	22.40	85.57	62.29	6.86
44	October 29-4 Nov.	-	31.97	23.54	80.00	59.43	7.70
45	November 5-11	2.93	30.56	22.89	87.29	72.00	2.50

Source: Meterological observatory, Vellanikkara

Appendix II. Analysis of variance for NH_4^+ and NO_3^- nitrogen content in soil

Source	df	Mean squares									
		NH_4^+ - N (ppm)					NO_3^- - N (ppm)				
		5th day	10th day	15th day	20th day	30th day	5th day	10th day	15th day	20th day	30th day
Total	56	-	-	-	-	-	-	-	-	-	-
Treatments	18	62.31	36.38	29.65	13.67	29.06	1.81	4.17*	5.38	3.06	1.00
Error	38	92.07	43.99	33.47	15.75	19.33	2.41	1.77	5.43	5.38	5.68

* Significant at 5% level

** Significant at 1% level

Appendix III. Analysis of variance for nitrification rate in the soil

Source	df	Mean squares				
		Nitrification rate (%)				
		5th day	10th day	15th day	20th day	30th day
Total	56	-	-	-	-	-
Treatment	18	3.22	3.03	7.26	3.44	1.31
error	38	4.93	3.62	5.51	5.62	6.41

Appendix IV. Analysis of variance for NH_4^+ - N content in laterite soil on liming and/or addition of red soil or black soil

Source	df	Mean squares				
		NH_4^+ - N (ppm)				
		5th day	10th day	15th day	25th day	30th day
Total	15	-	-	-	-	-
Treatment	7	363.80**	855.24**	2086.82*	3027.08**	3447.57**
Error	8	12.52	10.90	23.89	13.72	115.89

* Significant at 5% level

** Significant at 1% level

Appendix III. Analysis of variance for nitrification rate in the soil

Source	df	Mean squares				
		Nitrification rate (%)				
		5th day	10th day	15th day	20th day	30th day
Total	56	-	-	-	-	-
Treatment	18	3.22	3.03	7.26	3.44	1.31
Error	38	4.93	3.62	5.51	5.62	6.41

Appendix IV. Analysis of variance for NH_4^+ - N content in laterite soil on liming and/or addition of red soil or black soil

Source	df	Mean squares				
		NH_4^+ - N (ppm)				
		5th day	10th day	15th day	25th day	30th day
Total	15	-	-	-	-	-
Treatment	7	363.80**	855.24**	2086.82*	3027.08**	3447.57**
Error	8	12.52	10.90	23.89	13.72	115.89

* Significant at 5% level

** Significant at 1% level

Appendix V. Analysis of variance for mean height of plants and leaf area index at different stages of growth of maize

Source	df	Mean squares							
		Mean height (cm)				Leaf area index			
		15 DAS●	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
Total	62	-	-	-	-	-	-	-	-
Replication	2	3.85	727.69**	686.00	685.63	0.01	6.59**	27.61**	12.74**
Treatments	20	14.28	527.80**	1099.36	917.89	0.01	1.53	3.86	3.90
Error	40	14.73	208.72	641.54	597.91	0.01	1.12	2.89	2.64

* Significant at 5% level
** Significant at 1% level
● Days after sowing

Appendix VI. Analysis of variance for dry weight per plant at different stages of growth of maize and fodder yield at harvest

Source	df	Mean squares				
		Dry weight (g plant^{-1})				Fodder yield at harvest (tons ha^{-1})
		15 DAS@	30 DAS	45 DAS	60 DAS	
Total	62	-	-	-	-	-
Replication	2	0.00	9.10**	290.73**	1636.41**	0.04
Treatments	20	0.02	3.05	37.16	121.31	0.14*
Error	40	0.01	1.75	34.23	159.91	0.07

* Significant at 5% level
** Significant at 1% level
@ Days after sowing

Appendix VII. Analysis of variance for nitrogen content of leaf and rest of plant parts at different stages of growth of maize

Source	df	Mean squares							
		Nitrogen content leaf (%)				Nitrogen content of rest of plant parts (%)			
		15 DAS@	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
Total	62	-	-	-	-	-	-	-	-
Replication	2	0.17	0.18**	0.13*	0.03	0.34**	1.94**	0.06	0.02
Treatments	20	0.24*	0.15*	0.20**	0.11**	0.30**	0.25**	0.14*	0.09
Error	40	0.13	0.07	0.06	0.04	0.12	0.09	0.07	0.07

* Significant at 5% level
** Significant at 1% level
@ Days after sowing

Appendix VIII. Analysis of variance for total nitrogen uptake at different stages of growth of maize

Source	df	Mean squares			
		Total nitrogen uptake (mg plant^{-1})			
		15 DAS●	30 DAS	45 DAS	60 DAS
Total	62	-	-	-	-
Replication	2	3.03	10222.66**	144394.50**	548143.00**
Treatments	20	23.20*	3597.24*	31583.05	57751.70
Error	40	12.30	1841.60	32982.50	56786.00

* Significant at 5% level
** Significant at 1% level
● Days after sowing

SCREENING PLANT MATERIALS FOR NITRIFICATION INHIBITION PROPERTIES AND TESTING THE FIELD PERFORMANCE OF PROMISING MATERIALS

By

GRACY MATHEW

ABSTRACT OF A THESIS

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the requirement for the degree of

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Department of Agronomy
COLLEGE OF HORTICULTURE
Vellanikkara - Trichur

1986

ABSTRACT

The present study 'screening plant materials for nitrification inhibition properties and testing field performance of promising materials' was conducted during May 1984 to November 1985 at the College of Horticulture, Vellanikkara, Trichur. A total of 17 materials were used for screening using already proved nitrification inhibition materials like N-Serve and neem cake as reference. Nitrification rate in the soil was found to be very low and there was no appreciable conversion of NH_4^+ form to NO_3^-. Since there was no significant difference in the NH_4^+ content between treatments due to the naturally low rate of nitrification, selection of promising materials possessing nitrification inhibition property could not be done. Attempts were made to locate the factors that resulted in the low rate of nitrification in the soil. Organic matter content, pH, cropping history, amount of NH_4^+ - N build up in the soil, incubation conditions and low microbial population were not indicated as responsible for the noted low degree of nitrification.

In red and black soils of Coimbatore, nitrification was appreciable and there was fast disappearance of NH_4^+ - N.

Data on various growth parameters like mean height, LAI and dry matter production of the test crop, fodder maize, did not show any treatment difference. The yield in the treatment which received no fertiliser nitrogen was significantly lower than in other treatments. Similar were the results on nitrogen content of plant parts at various stages and those on total nitrogen uptake. The addition of materials used as nitrification inhibitors did not show any added advantage over untreated urea since the degree of nitrification in the soil was not appreciable.