EVALUATION OF METHODS TO IMPROVE THE NITROGEN USE EFFICIENCY OF UREA IN RICE

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Evaluation of methods to improve the nitrogen use efficiency of urea in rice"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similiar title, of any University or Society.

Vellanikkara,
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Certified that this thesis entitled "Evaluation of methods to improve the nitrogen use efficiency of urea in rice" is a record of research work done independently by **Miss.Sapheena, K.S.** 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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We, the undersigned, members of the Advisory Committee of **Miss.Sapheena,K.S.**, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled "Evaluation of methods to improve the nitrogen use efficiency of urea in rice" may be submitted by Miss.Sapheena,K.S. in partial fulfilment of the requirement for the degree.

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SAPHEENA, K.S.

C O N T E N T S

To my parents

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Introduction

INTRODUCTION

Fertilizer nitrogen has contributed largely towards augmenting food production in the country. Nitrogen is needed in most rice soils for good return particularly in places where nitrogen responsive modern rice varieties are grown under improved practices. Urea is the principal source of nitrogen fertilizer for rice and, when applied to soil it is subjected to chemical and biochemical reactions resulting in significant losses of nitrogen from the root zone of the crop.

Methods like split application of urea, adjusting the time of application and placing them in the root zone are generally practiced to reduce loss of N from urea. But these methods are not feasible during rainy days and under submerged condition. So attempts were made to regulate N supply to crops either by reducing the rate of hydrolysis or nitrification or both, so as to ensure continuous and optimal supply of nitrogen to match the requirements of crop at different stages of growth.

A practical solution to this problem was first suggested by Goring (1962) through the use of 2-choloro-6-(trichloro methyl) pyrimidine as a specific inhibitor of nitrosomonas, an organism responsible for nitrification in soils. Since then considerable advances have been made in the development of nitrification inhibitors. However, most of the chemicals used as nitrification inhibitors are not locally available and their high cost stands in the way of their widespread use in agriculture. This necessitates the need for identifying indigenous cheap materials as nitrification inhibitors.

It is now well known that non-edible oil cakes like neem (Azadirachta indica) and Karanj (Pongamia glabra) retard nitrification of urea and thereby increase the availability of nitrogen over a long time during the crop growth. The use of neemcake mixed/coated urea has been recommended to prevent the quick nitrification of ammoniacal nitrogen and thereby to increase the period of nitrogen availability to the crop (KAU, 1989). But this practice could not attract the attention of the farmers to a large extent mainly due to the cumbersom methodology involved in coating urea with neemcake and the lack of ready availability of neemcake.

Recently a concentrated neem extract, Nimin containing as much as 5 per cent neem bitters responsible for nitrification inhibition in soils, has been prepared by processing industrial grade neem oil by M/s.Godrej Soaps Ltd. Nimin is self adhesive and no external adhesives are required.

In the light of the above, the present study was taken up to find out whether 'Nimin' is more effective in increasing N use efficiency of urea compared to neemcake.

Review of Literature

REVIEW OF LITERATURE

1. Nitrogen and rice

Rice is the staple food for nearly 40 per cent of the world's population. The process of nutrient uptake of the rice plant at different stages of growth was studied as early as in 1918 by Aso. Subsequently Gericke (1924) systematically studied the mineral nutrition of rice plant. The quantity of N generally absorbed by rice plant to produce a unit of grain yield is nearly a constant of 19-21 kg N t^{-1} brown rice (Takahashi, 1961; Yamazaki, 1965).

2. Urea as a source of fertilizer nitrogen

Urea is the most important and widely manufactured nitrogenous fertilizer in the world. In India also it constitutes 75 per cent of the country's total N production and indications are that it will continue to dominate the Indian fertilizer scene, in the future (FAI, 1977). Urea is the principal source of N fertilizer for rice because of its' high N content and cheapness (Tangamuthu _et al._, 1984).

3. Transformation of urea in submerged paddy soils

Soon after the application to the soil, urea undergoes hydrolysis resulting in the production of ammonia. This urea hydrolysis, an enzymatic reduction, has been conclusively proved by many workers (Hoffman and Schmidt, 1954; Shaw and Bordeaux, 1955; Fisher and Parks, 1958). Applied urea was hydrolysed within two days (Volk, 1966). The nitrogen applied in the oxidised surface layer is nitrified and moves into the anaerobic zone where it gets denitrified biologically and possibly chemically to gaseous nitrogen. This process has been confirmed by many researchers (Shioiri and Tanada, 1954; Mitsui, 1955; Broadbent and Tusneem, 1971).

The loss of fertilizer N occurs through denitrification, leaching, ammonia volatilization and surface run off. In addition, biological immobilization and fixation of ammonium by clays make nitrogen temporarily unavailable to rice crop but do not cause loss of N from soil system (De Datta, 1981).

3.1 Nitrification process and loss of nitrogen due to nitrification

Ammonium formed as a result of urea hydrolysis serves as the starting point for the process known as nitrification, the biological formation of nitrite or nitrate from compounds containing reduced nitrogen. This takes place in a sequence of reactions namely, ammonium to hydroxylamine, hydroxylamine to nitrite and nitrite to nitrate through microbial oxidation. The overall reaction is brought about by transfer of electrons and production of energy (Vyas and Singh, 1990). Tandon (1974) stated that nitrification of added amide or ammonium nitrogen was completed within 3 to 5 weeks.

Possible disadvantages of nitrification are losses of nitrogen by denitrification, leaching and run off including movement of nitrate out of the crop root zone with eventually nitrate accumulation in ground water and surface waters. The nitrification process has major impact on relatively low recovery of nitrogen and N use efficiency with corresponding decline in crop growth, yield and quality. Laboratory studies have shown that under alternate draining and submergence, the loss of mineral nitrogen could be as high as 75 per cent within a period of 8 weeks after transplanting (Rajale, 1970). However, in growth chamber experiments Stefanson and Greenland (1970) measured losses of the order of 22 kg N ha^{-1} as nitrous oxide in three weeks if the moisture was maintained close to field capacity with adequate nitrate supply.

3.1.1 Factors affecting nitrification

Nitrification is brought about by specialized group of bacteria which are obligately aerobic. They prefer neutral to slightly acid condition (Munck, 1958). In soils of low pH or in waterlogged soils the nitrification is thus restricted or even completely inhibited. Saratchandra (1978) observed that once the pH was lowered from 7.5 to 5.5 the nitrification rate decrease in the order of corresponding decrease in the number of nitrifying bacteria. In laterite soils of Kerala low nitrification rate was reported by Mathew (1986), Anilakumar (1989) and Zacharias (1989).

The alternate submergence and drained conditions in rice soils favoured nitrification of ammonium or urea-nitrogen applied to soil (Prasad and Bains, 1968).

Potassic and phosphatic fertilizers reduced both the rate of decomposition of urea and the nitrification of ammonium nitrogen produced by the decomposition (Vostal et al., 1976). Nitrifying potential in acid soil was almost halved by the long term application of mineral fertilizers (Lebediva and Zagumennikov, 1977; Roy et al., 1985).

The process of nitrification is highly aerobic and favoured by lower soil water potential (More and Varade, 1977). The optimum temperature for nitrogen mineralization was observed to be 50°C and that for nitrification it was 26°C (Beck, 1983).

3.2 Loss of nitrogen due to leaching and run off

The loss of nitrogen from soil systems can be high, with the leaching of nitrate being the main source of loss (Allison, 1966). The constant head of standing water in a flooded soil results in greater downward percolation of the soil solution and more leaching loss (Patrick and Mahapatra, 1968).

It was observed that leaching losses as nitrate particularly in rice fields could be as high as 70 per cent (Pande and Adak, 1971). On the basis of ^{15}N studies it was reported that leaching loss of nitrate-nitrogen was 4-25.6 per cent, urea-nitrogen 1.2-16.2 per cent, and that of ammoniacal nitrogen was negligible (Daftardar, 1973). Field experiment conducted at Pattambi showed that the leaching loss of N was 2.7 to 5.3 per cent during kharif season and 0.39-2.8 per cent during rabi season (Anon., 1987). The leaching loss of fertilizer nitrogen as NH_4-N and NO_3-N ranged from 10-31 per cent for neemcake-coated urea and 8-35 per cent for prilled urea (IRRI, 1987).

Under normal fertilization practices run off losses of 4-16 kg N ha^{-1} (Takamura _et al._, 1977) and 19-30 kg N ha^{-1} (Bilal _et al._, 1979) were reported. Seventy per cent of total applied nitrogen was lost when a field was drained on the same day of nitrogen fertilization and the loss continuously decreased up to 5 days (Padmaja and Koshy, 1978).

3.3 Loss of nitrogen by denitrification

Substantial losses of nitrogen from the soil have prompted studies on denitrification in flooded rice soils. Nitrogen in the nitrate form may get converted to gaseous form that are unavailable for crop use. This factor is very important in the could be oxidised to nitrate in the aerobic layer and nitrate could diffuse into the anaerobic layer and be lost by denitrification. The loss of applied N through denitrification was reported to be 39-56 per cent (Abichandani and Patnaik, 1958). Nitrification and denitrification proceeded simultaneously in soils probably due to trapped oxygen of the air (Greenland, 1962).

Various estimates have been made regarding the extent of the loss due to denitrification. While Bremner and Shaw (1958) reported that 80-86 per cent of nitrate nitrogen was lost by denitrification within 5 days under favourable condition for denitrification, Patrick and Wyatt (1964) reported large losses of nitrogen as high as about 20 per cent of the total nitrogen as a result of several drying and flooding cycles. In a tracer study of nitrogen transformation under waterlogged soils, Patnaik (1965) could not account for 23-24 per cent of the applied nitrogen at the end of the incubation. He attributed this loss of nitrogen to the oxidation of ammonium to nitrate nitrogen in the surface layer of soil with subsequent leaching or diffusion, and denitrification in the reduced zone. In India these losses are estimated to range from 20-40 per cent (Abichandani and Patnaik, 1958). Substantial losses of nitrogen occurred under flooded condition due to the mechanism of nitrification-denitrification (Broadbent and Tusneem, 1971). Under green house condition, 7-19 per cent of applied urea was lost by denitrification. About one half to two-thirds of the labelled nitrogen was lost during the 4 months of application (Patrick and Tusneem, 1972). They showed that losses of nitrogen could occur not only under alternate wetting and drying, but also under continuously flooded soils mainly due to nitrification-denitrification process.

Nitrogen loss due to denitrification generally related to the thickness of the aerobic layer (Patrickand Gotoh, 1974). Denitrification losses were significant only when low land rice soils were subjected to alternate draining and reflooding (Reddy and Patrick, 1975). Studies at IARI, however, have shown that nitrification-denitrification losses due to alternate flooding and draining may not appreciably affect nitrogen uptake and growth of rice in soils unfertilized with nitrogen. But with high rates of nitrogen, there was significant decrease in nitrogen uptake and yield of rice (Sahrawat, 1978).

4. Use of nitrification inhibitors in increasing the efficiency of applied urea

The efficiency of urea can be increased by treating urea with nitrification inhibitors. The discovery and use of Nitrapyrin (N-serve) as an effective inhibitor of nitrification in soils has greatly stimulated the interest in nitrification inhibitors

(Goring, 1962). Numerous compounds have been proposed for regulating nitrification in soils, including organic and inorganic compounds, pesticides, chelating agents as well as urease inhibitors manufactured and patented in the USA and Japan (Ranney, 1978).

Prasad et al. (1971) grouped herbicides, insecticides, fungicides and fumigants as potential inhibitors of nitrification. They tested a number of compounds for their nitrification retarding properties.

The inhibitors of nitrification are effective if they retard one or more steps in the following chain of reaction NH_4^+ → hydroxyl amine → nitroxyl → nitrohydroxyl amine → NO_2 → NO_3^- (Hauck, 1972).

The objectives of nitrification inhibitors are to prevent leaching loss of NO_3-N especially in light textured soils with low water holding capacity and under irrigation practices (Malzer, 1979). If ammonium forming fertilizer is applied before a period of rain it is necessary to prevent nitrification and thus leaching to secure high efficiency of nitrogen (Harrison et al., 1977; Hendrickson et al., 1978).

An ideal nitrification inhibitor should block the conversion of ammonium to nitrate, it should move with the fertilizer and the material should stay active in soil for an adequate period (Hauck, 1972; Turner and Mac Gregor, 1978).

4.1 Potential of neem (*Azadirachta indica*) as nitrification inhibitor

Due to cost consideration, in India, it is difficult to use the synthetic nitrification inhibitors and it is imperative to direct our efforts to the development of products of indigenous origin. It is now well known that non-edible oil cakes retard nitrification of urea-nitrogen and thereby increase the availability of nitrogen over a long time during the crop growth (Khandelwal *et al*., 1977).

Bains *et al*. (1971) reported that the neem seed-crush treated urea gave higher efficiency than untreated urea in rice and stated that neem contains alkaloid nimbidin which acts as nitrification retarder. Neem oil, particularly its two fractions viz., total bitters and odourescent compounds possess the nitrification inhibition property (Patil, 1972).

The lipid associate of neem seed checked the conversion of ammonia to nitrate (Sahrawat and Parmar, 1975). Neem bitters reported to be responsible for nitrification inhibition namely nimbin, nimbinin, nimbidin,nimbininin etc. are lipid associates and constitute about 2 per cent (W/W) of oil (Vyas *et al*., 1991).

Reddy and Prasad (1975) reported that urea blended with neemcake inhibited nitrification for a period of about two weeks. Neemcake and crushed neemcake extract treated urea were similar to N-serve in suppressing the effect of nitrification (Manickam et al., 1976). Neem seed crush could be used effectively as a nitrification inhibitor (Mani and Palaniappan, 1979; Hulagur and Shinde, 1981). Neemcake and crushed neemcake-extract treated urea were similar to N-serve in suppressing the effect of nitrification (Manickam et al., 1976).

A number of workers have reported increased efficiency of fertilizer N when it was coated with neemcake (Subbiah et al., 1979; Subramanian and Venkataramanan, 1979; Sinha et al., 1980; Reddy and Shinde, 1981 and Rambabu et al., 1983).

Sathianathan (1982) reported that neem, marotti, rubber and karanja cakes were effective as nitrification inhibitors, neemcake being most effective. Neemcake coating of urea imparted both nitrification inhibition as well as slow release effects on urea (Thomas and Prasad, 1982). Nitrogen recovery percentage was the highest when neemcoated-urea was applied in paddy (Mathew, 1985). The basal application of neem-coated urea was found more effective in controlling the leaching loss of labelled NH_4-N + NO_3-N (Rao and Shinde, 1985).

Recently a neem extract, 'Nimin' containing neem triterpenes responsible for nitrification inhibition in soil has been developed by M/s.Godrej Soaps Ltd. which avoids the use of neemcake, coaltar and kerosine required for conventional neemcake-coated urea. Nimin contains 6-7 per cent unsaponifiable matter, out of which nearly 30 per cent (about 5 per cent W/W in the finished product) is composed of neem bitters responsible for nitrification inhibition in soils. Besides, it also contains 15-20 per cent of unrecovered free fatty acids. The elemental composition of Nimin is as follows. Carbon 75-79 per cent, hydrogen 11-12 per cent, nitrogen 1.45-0.55 per cent and the remaining is contributed by oxygen, sulphur and traces of phosphorus and potassium (Vyas *et al.*, 1991). Significant inhibition of nitrification in Nimin-coated urea treated soils has been reported by Vyas *et al.* (1991) and Vimala (1991).

4.2 Effect of nitrification inhibitors on mineralization of urea

Largest amount of ammoniacal nitrogen content was recorded with nitrification inhibitor treated urea and least with untreated urea. Largest amount of NO_3-N was obtained with untreated urea and least amount with nitrification inhibitor treated urea (Reddy and Prasad, 1975). Nitrate concentration remained low when urea was treated with neem seed, neem or mahua cake extract even after 30 days of incubation (Manickam *et al.*, 1976). Treating urea with nitrification inhibitors recorded significantly more NH_4-N than untreated urea (Muthuswamy *et al.*, 1977). Neemcake-coated urea was found very effective in retarding nitrification of urea for two weeks (Pillai, 1981).

Urea blended with neemcake, urea-coated with coaltar and application of neemcake in moist soils prior to urea application favoured the production of NH_4-N and NO_2-N whereas NO_3-N formation was significantly inhibited (Sarkunan and Biddappa, 1981). Nitrification inhibitors, N-serve blended urea, neemcake-blended urea and neemcake-coated urea contained higher NH_4-N content in soil and coating urea with neemcake performed better than its physical mixture with urea (Thomas and Prasad, 1982).

The concentration of NO_3-N in soils which received the N through neemcake-blended urea was lower at the initial stages and was higher at the later stages compared to the concentration of NO_3-N in soils fertilized with urea alone. The reverse trend was noticed in the case of NH_4-N (Singh and Singh, 1986). Blending urea with neemcake significantly increased NH_4-N content in the soil, showing retarded nitrification of applied urea due to neemcake (Tiwari, 1989). In contrast to a sharp increase in nitrite and nitrate N levels within a period of 7 to 15 days with untreated urea, a gradual increase in nitrite and nitrate N levels up to a period of one month when soils were treated with Nimin-coated urea was observed in a laboratory experiment. The rate of hydrolysis of the two urea forms, prilled urea and Nimin-coated urea did not reveal any notable difference, indicating that the neem extract coating had negligible influence on the activity of urease enzyme (Vyas <u>et al.</u>, 1991).

Increased ammoniacal nitrogen content by treating urea with Nimin over untreated urea was reported by Vimala (1991). She has also reported that maximum amount of NO_3-N was recorded on 4th day of incubation in prilled urea whereas in Nimin-coated urea and neem-coated urea the highest NO_3-N was registered on 8th and 15th days of incubation.

4.3 Effect of nitrification inhibitors on crop growth and yield of rice

Application of neemcake-treated urea increased the number of effective tillers and number of filled grains per panicle (Bains _et al_., 1971). Neemcake-extract treated urea increased the main panicle length and dry matter content (Arunachalam, 1972).

The investigation carried out at the Model Agronomic Research Station, Karamana showed that all slow release N sources used were superior to untreated urea. Highest percentage of productive tillers was recorded by neemcake-blended urea (Oommen _et al_., 1977).

Application of neemcake-coated urea as basal or in two equal splits was invariably superior to uncoated urea in increasing the dry matter production (Ramaiah _et al_., 1986). Urea in combination with neemcake showed significant increase in plant height at active tillering, panicle initiation and at harvest (Varughese, 1988).

Experiment conducted by Rayar (1990) showed that the dry matter yield increased linearly with N levels at both growth stages of 40 and 70 days. The maximum yield of dry matter at 70 days of growth was recorded at the N level of 120 kg ha^{-1} supplied through urea blended with neem seed-crush.

Neem extract and coaltar treated urea at 100 kg ha^{-1} was found to be on par with ordinary urea at 200 kg ha^{-1} in their effect on yield (Bains et al., 1971). An increase of 369 kg ha^{-1} of paddy grains by blending urea with neemcake over untreated urea was obtained and it was found profitable at low as well as high levels of N application (Ketkar, 1974). Experiment conducted at the College of Agriculture, Vellayani showed that application of 40 kg N ha^{-1} as neemcake-coated urea was equivalent to 80 kg N ha^{-1} as urea alone as far as yield of grain was concerned (Abraham et al., 1975). An increase of 24 per cent in grain yield by applying urea coated with 20 per cent by its weight with neemcake was reported by Reddy and Prasad (1975) and Prasad et al. (1980). Eleven per cent increase in yield due to neemcake-coated urea over untreated urea at 120 kg N ha^{-1} was reported by Shankar et al. (1976).

The results from 325 trials in Taluka Seed Multiplication Farm and in progressive farmers field during 1973-1976 showed significant increase in yield when fertilizer N was applied with neemcake (Ketkar, 1976). In a demonstration trial in Operational

Research Project, Miryalaguda, neemcake-coated urea applied at transplanting gave better results in terms of yield compared to recommended split application of ordinary urea (KAU, 1978).

The treatment of urea with neemcake and farm yard manure gave a significant increase in rice yield and higher recovery of applied N (Chakravarti, 1979). Higher grain yield by treating urea with neem seed extract was reported by Subramanian and Venkataramanan (1979). Urea 100 kg N ha^{-1} blended with 44 kg neemcake recorded significantly higher yield (Sinha et al., 1980). Hulagur and Shinde (1981) studied the efficiency of urea applied alone and with ether extracted and whole cakes. It was found that the extracted cakes significantly increased the yield of rice by about 25 per cent over that of whole non-extracted cakes. Neem oil, karanja and kokum cakes treated urea increased dry matter yield.

Urea blended with neemcake resulted in the highest straw yield (Joshi et al., 1981). Application of 75 kg N ha^{-1} blended with 33 kg neemcake recorded significantly more grain yield over 100 kg N ha^{-1} as urea alone (Jadhav et al., 1983). The multilocation trials at All India Co-ordinated Rice Improvement Project and All India Co-ordinated Agricultural Research Project showed yield increase for urea coated with neemcake (Pillai, 1983). Increase in yield of rice grain using nitrification inhibitors vary from 18.8 to 66.6 per cent with different treatments, the highest being with neemcake-coated urea (Prasad _et al_., 1984).

Application of urea super granules and prilled urea coated either with dicyandiamide or with neemcake and coaltar as basal or in two equal splits was superior to uncoated urea in increasing dry matter production (Ramaiah _et al_., 1986). Grain yield of rice at 80 kg ha^{-1} as neemcake-coated urea was equal to that of split dressing of prilled urea at 120 kg N ha^{-1} (Ramaiah _et al_., 1987). Fresh neem leaf at 5 t ha^{-1} produced higher rice yields (Shanthi and Palaniappan, 1987). Highest grain yield was obtained with neemcake-coated urea at 75 kg N ha^{-1} in kharif season (Duraiswamy and Palaniappan, 1989).

Placement of urea super-granules, neemcake and coaltar coated urea at higher N level has produced significantly higher yield than prilled urea in kharif season (Rajagopalan and Subramanian, 1989). Split application of neemcake-blended urea produced higher rice yields than that of prilled urea (Chauhan and Mishra, 1989; Saheb _et al_., 1990).

Nimin-coated urea increased the grain yield compared to those obtained in the case of untreated urea for rice, wheat and maize ranging from 4.3 to 71.6 per cent depending upon the crop, soil and other environmental conditions (Vyas _et al_., 1991). Nimin-coated urea gave significantly higher yield in rice than prilled urea (Vimala, 1991).

In contrast to the above findings several workers have reported the lack of response of coating urea with neemcake in increasing yield of rice (Sadanandan and Sasidhar, 1978; Devi et al., 1980). It was found that neemcake-coated urea and shellac-coated urea did not offer any significant improvement in yield over urea in three splits (Mishra and Sharma, 1982). Although neemcake-coated urea and coaltar-coated urea recorded more yield than prilled urea, the differences were not wide enough to attain the level of statistical significance and were on par with ordinary urea (Savithri and Ramanathan, 1990).

4.4 Effect of nitrification inhibitors on the content and uptake of nutrients

Fertilizer N increased the N content both in grain and straw (Khan et al., 1971). Nitrogen content was increased when N-serve or neem-coated urea was used (Tyagi and Agarwal, 1989).

The uptake of N was increased with increasing levels of applied nitrogen (Thirunavukkarasu et al., 1978). The efficiency of combined application of urea and compost increased significantly when the same were admixed with neem as indicated by higher grain yield and N uptake (Chakravarti, 1979). Higher uptake of N both in grain and straw with neemcake-coated urea was reported by Rambabu et al. (1983). Neemcake-coated urea at 100 kg N ha^{-1} was superior to the other modified sources of urea treated in respect of uptake of N (Prasad et al., 1984).

Due to nitrification inhibition or slow release action of the inhibitors used on mineralization of urea, a higher uptake of N by rice was noted by blending urea with some neem and karanj products (Surve and Daftardar, 1985). Increased uptake of N in grain using neem-coated urea was reported by Ramaiah et al. (1986). At 40 days of growth, application of N at the rate of 60 and 120 kg N ha^{-1} as urea treated with neem seed-crush recorded significantly lower N uptake, than untreated urea. But at 70 day growth period a significant increase was noticed (Rayar, 1990). Enhanced uptake of N using Nimin-coated urea was reported by Vimala (1991).

In contrast to the above observations Sarkunan and Biddappa (1981) reported that in acid soils application of neemcake-blended urea failed to increase significant response of N in the N uptake and grain yield.

Increased uptake of P by nitrogen application has been reported by many workers (Singh, 1968 and Majumdar, 1973). It was observed that application of N significantly influenced the uptake of P during maximum tillering, flowering and harvest. There was a gradual increase in P uptake from maximum tillering to flowering and then a rapid increase from flowering to harvest (Alexander et al., 1974). Blending urea with neemcake resulted in higher uptake of P by grain (Shankar *et al*., 1976). Increased uptake of N and P due to neemcake-blending of ammonium sulphate was reported by Subbiah (1979). Blending neemcake with urea helped in making more of phosphate available to plants resulting in significantly higher uptake of P (Sinha *et al*., 1980). Phosphorus content and uptake was increased by the application of urea treated with nitrification inhibitors (Tyagi and Agarwal, 1989; Vimala, 1991).

Increased levels of N increased the content and uptake of K in many crops (Sankaran and Kaliappa, 1974). Blending urea with neemcake exerted an adverse effect on the uptake of K (Shankar *et al*., 1976). A decreasing trend in the uptake of K both in grain and straw with every increase in the levels of N application was reported by Subbiah *et al*. (1979). This was more pronounced at 120 kg N ha^{-1} level compared to other levels tried. Between the doses of neemcake applied 40 per cent neemcake-blended urea was found to be better in increasing the K uptake both in grain and straw.

Split application of modified form of urea caused higher uptake of K compared to the split application of prilled urea (Shanmugasundaram, 1987). With advancement of crop growth K uptake by rice showed an increasing trend and treatment with nitrification inhibitors showed higher K uptake than prilled urea (Vimala, 1991).

Mathers et al. (1982) assessed the effect of nitrification inhibitor, nitrapyrin on the relative uptake of K, Ca and Mg by winter wheat and found that when the nitrification inhibitor was added the plants took up less NO_3-N. The plants also had lower concentration of Ca and Mg. Nitrapyrin decreased the plant organic acid concentration and this probably decreased Mg and Ca uptake. But it was found out that uptake of Ca and Mg by ragi was increased markedly by the nitrogenous fertilizer application (Chellamuthu et al., 1988).

5. Efficiency of added nitrogen

It has been established that the efficiency of N fertilizers and N recovery in plants are by and large low. Only 30 to 50 per cent of applied N was recovered by crop (Prasad et al., 1971). All commonly used N fertilizers have an efficiency of only about 30 per cent under many soil and cropping conditions, which would be further less under flooded conditions (Parr, 1967). It has been reported that the upland crops frequently used 40 to 60 per cent of the applied nitrogen (Mitsui, 1955), whereas flooded rice crop used only 20 to 40 per cent (Prasad et al., 1971; Krishnappa and Shinde, 1980; Rao and Shinde, 1985; Perumal et al., 1986) and it rarely exceeded 40 per cent of applied N under the Asian farmers management practice (De Datta, 1981).

Use of modified or coated forms of urea had resulted in a substantial recovery of applied N in rice. The apparent recovery of urea nitrogen by rice was only 28 per cent which was enhanced to 41.7 per cent by treating urea with nitrapyrin and to 47.4 per cent by coating urea with neemcake (Sharma and Prasad, 1980). The recovery of urea nitrogen was only 21.9 per cent by rice plant under controlled irrigation which was increased to 46.5 per cent when urea was applied after blending with neemcake (Reddy and Shinde, 1981). The superiority of neemcake-coatd urea in terms of recovery of added N was also observed by Awasthe and Mishra (1987).

Materials and Methods

MATERIALS AND METHODS

The studies contemplated in the research programme are aimed to evaluate the methods used to improve the N use efficiency of urea in rice. With this view an incubation study and field experiments were conducted during the first and second crop seasons of 1991-92.

1. Details of the incubation study

A laboratory incubation study was carried out at the College of Horticulture, Vellanikkara, Thrissur in a completely randomised design with four replications. The treatments were:

Notation	Treatment
T_1	Control (no nitrogen)
T_2	Prilled urea 90 kg ha^{-1}
T_3	Neemcake-coated urea 90 kg ha^{-1}
T_4	Neemcake-mixed urea 90 kg ha^{-1}
T_5	Nimin-coated urea 90 kg ha^{-1}

The quantity of neemcake used for mixing was at the rate of 20 per cent of the quantity of urea used for different treatments. Calculated quantity of well powdered neemcake was mixed thoroughly with the urea in the case of treatments involving neemcake-mixed urea.

For coating neemcake with urea, coaltar was used as an adhesive and a 67 per cent weight/volume (2 kg coaltar in 3 litres of kerosene) solution was employed for this purpose. Known amount of urea was taken in a polythene bag and coaltar solution was added (2 ml/100 g fertiliser) and the contents were thoroughly mixed. Well powdered neemcake was added at the rate of 20 g neemcake/100 g urea and the contents of the bag were again thoroughly mixed.

Nimin was coated with urea at the rate of 500 g of Nimin per 100 kg urea. The calculated quantity of urea and Nimin were thoroughly mixed and kept in shade for 24 hours before application.

Prilled urea, neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea were applied so as to provide a uniform level of 90 kg N ha^{-1} for all the treatments.

Surface soil collected at 0-15 cm depth from the area of field experiment (Agricultural Research Station, Mannuthy) was used for the incubation study. The physico-chemical properties of soil are given in Table 1.

The soil was airdried and ground with a wooden mallet. One kg each of soil samples was transferred to PVC columns of 10 cm diameter and 10 cm long. The filled up PVC columns were fixed vertically in the green house using wooden stands

Table 1. General characteristics of the soil

Coarse sand, %	28.2
Fine sand, %	24.3
Silt, %	22.1
Clay, %	25.4
Total N, %	0.101
Available N, kg ha^{-1}	285
Available P, kg ha^{-1}	135
Available K, kg ha^{-1}	338.8
Organic carbon, %	0.675
pH	5.65
Specific conductance dS m^{-1}	0.099
Cation exchange capacity cmol(+) kg^{-1}	13.14

and support. The collection of soil solution was made by a funnel and tube arrangement provided at the bottom of each column. The soil samples were kept under submergence, with 2 cm standing water for 90 days. Soil and solution samples were collected at the specified intervals (0, 1, 2, 4, 6, 8, 10, 15, 20, 30, 45, 60, 75, 90 days after treatment application). Both soil and solution samples were analysed for determining pH, NH_4-N and NO_3-N. Total nitrogen of soil samples was also determined.

2. Details of the field experiment

2.1 Location

The experiment was carried out at the Agricultural Research Station, Mannuthy under the Kerala Agricultural University. The station is located at 12° 32' N latitude and 74° E longitude. The experimental field lies at an altitude of 22 m above MSL.

2.2 Climate and soil

Typical humid tropical climate is experienced by the area. The soil of the experimental field was sandy clay loam in texture(oxisol).

2.3 Cropping history of the experimental field

The experimental field was a double cropped wetland and has been under banana and vegetables during the previous two seasons.

2.4 Variety

Rice variety Jyothi with a duration of 110-125 days was used for the experiment. This variety has red kernel, long and bold grains.

2.5 Treatment details

Treatment notation	Form	Level, N kg ha^{-1}	Distribution in splits, %
T_1	No nitrogen	0	-
T_2	Prilled urea	90	50:50
T_3	Prilled urea	90	75:25
T_4	Neemcake-coated urea	90	50:50
T_5	Neemcake-coated urea	90	75:25
T_6	Neemcake-mixed urea	90	50:50
T_7	Neemcake-mixed urea	90	75:25
T_8	Nimin-coated urea	90	50:50
T_9	Nimin-coated urea	90	75:25
T_{10}	Prilled urea	67.5	50:50
T_{11}	Neemcake-coated urea	67.5	50:50
T_{12}	Neemcake-mixed urea	67.5	50:50
T_{13}	Nimin-coated urea	67.5	50:50

The fertilizers used for the experiment was, urea (46 per cent N), mussoriphos (24 per cent P_2O_5) and muriate of potash (58 per cent K_2O). Neemcake used for coating and mixing urea contained 1.65 per cent N and Nimin contained 0.55 per cent N and traces of P and K. Nimin used for coating urea was obtained from M/s.Godrej Pvt. Ltd., Madras.

Neemcake-mixing, neemcake-coating and Nimin-coating was done in the same way as that of the incubation study.

The basal application of the treatments was carried out at the time of transplanting and top dressing was done 30 days after transplanting.

A randomised block design with three replications was adopted for the study. The layout plan is given in Fig.1.

2.6 Spacing and plot size

a) Spacing	:	20 x 15 cm for the first crop 20 x 10 cm for the second crop
b) Plot size	:	5 x 4 m
2.7 Border rows	:	Two rows of plants were left as border rows all around each plot

2.8 Nursery

A dry rice nursery was prepared.

2.9 Land preparation

The experimental field was wet-ploughed, puddled and levelled. The plots were laid out and bunds of 30 cm width and height were taken with provisions of irrigation channels. The individual plots were agains dug, puddled and levelled.

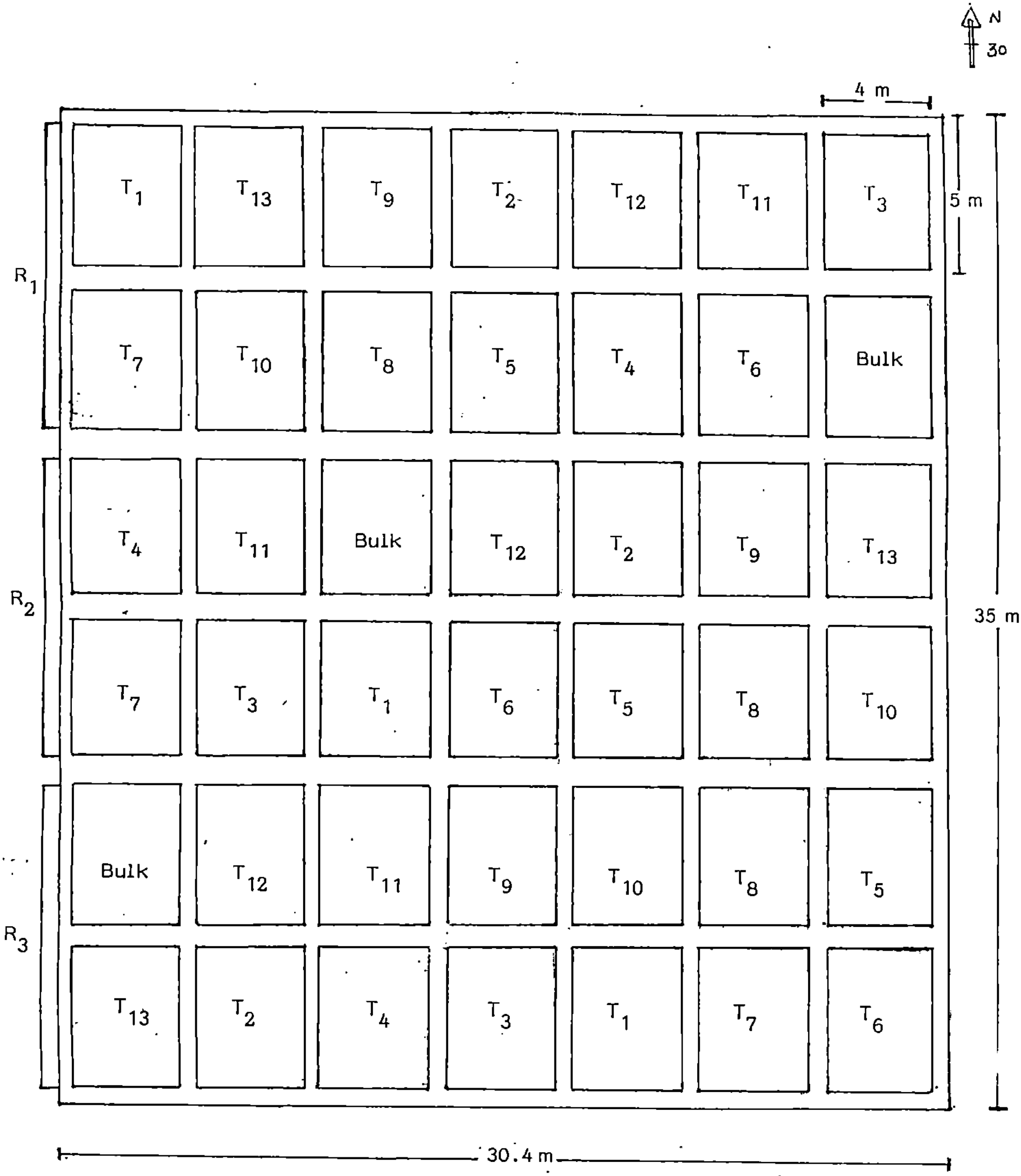

Fig.1. Layout of the experimental field

2.10 Fertilizer management

A common dose of P and K @ 45 kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1} was given to all plots. The entire quantity of P as mussoriphos and half the quantity of K in the form of muriate of potash were applied as basal and the remaining quantity of K was applied 30 days after transplanting.

2.11 Transplanting

Thirty day-old seedlings were transplanted in the experimental plots on 1st July 1991 at the rate of two or three seedlings per hill. Gap filling was done one week after transplanting.

2.12 Water management

A uniform level of 5 cm standing water was maintained. Water was drained out two weeks prior to harvest.

2.13 Weeding

Hand weeding was done as and when necessary.

2.14 Plant protection

Carbaryl 1 per cent plus BHC 1 per cent was sprayed to control leaf rollers during the maximum tillering stage and methyl parathion 0.05 per cent was sprayed at flowering to control rice bugs during the first crop and second crop seasons.

2.15 Harvesting

Harvesting was done when more than 80 per cent of grains of the panicle matured. Border plants were harvested and removed first. The net plots were harvested and threshed separately.

The experiment was continued during the second crop season with the same set of treatments in order to assess the continued effect of treatments. The crop was planted on 28th October, 1991. The cultural practices and application of fertilizers and treatments were done in the same manner as that of the first crop.

2.16 Observations

2.16.1 Growth characters

Ten hills were selected from pre-designed sample rows in each plot for periodical growth observations.

a. Plant height

Plant height, was recorded from the base of the plant to the tip of the top-most leaf.

b. Number of tillers

The total number of tillers were counted from the above ten hills at maximum tillering, panicle initiation, 50 per cent flowering and at harvest stages and the number per m^2 was worked out.

c. Dry matter production

The dry weights of samples collected at maximum tillering, panicle initiation, 50 per cent flowering and harvesting stages were taken as the dry matter production at the respective stages.

2.16.2 Yield character

a. Grain yield

The grains from each plot were dried, cleaned, winnowed and weighed and expressed in kg ha^{-1}. The weight was adjusted to 14 per cent moisture.

b. Straw yield

The straw yield from each plot was dried under sun. The weight was recorded and expressed in kg ha^{-1}.

3. Laboratory studies

3.1 Collection of soil samples

Soil samples were collected replication-wise (composite) before planting to study the basic characteristics of the soil. These samples were collected with the help of a spade.

Funnel method of Abichandani and Patnaik (1957) was followed for collecting soil samples at intervals in incubation study. Soil samples were collected at different stages of crop growth and at harvest using a wet soil sampler in field experiment. Moisture content was determined in the soil samples simultaneously to adjust values obtained to oven dry basis.

3.2 Collection of plant samples

Plant samples were collected at random from each plot avoiding border plants. Three hills were pulled out, roots were removed and washed with water.

3.3 Soil analysis

Particle size distribution of the initial soil was found out by hydrometer method (Piper, 1942).

The pH of the soil-water suspension was determined using a soil-water ratio 1:2.5 by a pH meter (Jackson, 1958). For the determination of organic carbon content of soil, Walkely and Black's method (Piper, 1942) was followed. Cation exchange capacity of soil was determined by normal ammonium acetate method (Piper, 1942).

For the determination of total N, Kjeldahl's digestion and distillation method (Jackson, 1958) was followed.

Ammoniacal nitrogen content of soil was extracted with 10 per cent of sodium chloride solution (pH 2.5) employing a 1:2 soil:extractant ratio and determined by microkjeldahl method (Jackson, 1958).

Nitrate nitrogen was estimated using the same sodium chloride extract by chromotropic acid method (Sims and Jackson, 1971).

Available P in the soil was extracted by Bray No.1 extractant and the P content was determined colorimetrically by the ascorbic acid blue colour method (Watanabe and Olsen, 1965). Available K in the soil was extracted by neutral normal ammonium acetate and was read in EEL flame photometer (Jackson, 1958).

3.4 Soil solution analysis

Ammoniacal nitrogen and NO_3-N content of the soil solution were determined following the procedure adopted for the analysis of the extracts of soil samples.

3.5 Preparation of plant sample

The collected samples were dried in a hot air oven at 70°C and the dry weights were recorded. The samples were powdered and composite samples were taken for the analysis.

3.6 Analysis of plant sample

The total N content of the samples was determined by micro-kjeldahl digestion and distillation method (Jackson, 1958). For the determination of P, K, Ca and Mg in plant samples triacid extract (HNO_3:H_2SO_4:$HClO_4$ in the ratio of 10:1:4) of the plant material was made use of. Phosphorus was determined by vanadomolybdo phosphoric yellow colour method (Jackson, 1958). Potassium was determined using EEL flame photometer. Calcium and magnesium were determined using versanate titration method (Hesse, 1971). Analysis of grain was done in the same way as that of the plant samples.

4. Uptake of nutrients

The uptake of N, P, K, Ca and Mg by rice at the maximum tillering, panicle initiation, 50 per cent flowering and by grain and straw were computed from their respective nutrient contents and phytomass.

5. Statistical analysis

The results obtained were subjected to analysis of variance technique as described by Panse and Sukhatme (1985).

Results and Discussion

RESULTS AND DISCUSSION

1. Incubation study

1.1 Ammoniacal nitrogen content of the soil

Influence of various forms and levels of nitrogen on the NH_4-N content of soil at different periods of incubation is presented in Table 2 and Fig.2.

The treatments showed significant difference in the NH_4-N content of soil at most of the periods of incubation. The control recorded the lowest value at all the intervals. The treatments with nitrification inhibitors namely neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea recorded higher values compared to prilled urea at all the intervals from the 2nd day of incubation. But difference between these treatments with nitrification inhibitors (T_3, T_4 and T_5) was not statistically significant at most of the intervals. Increased NH_4-N content of the soil due to the application of nitrification inhibitors has been reported by many workers (Reddy and Prasad, 1975; Muthuswamy _et al._, 1977; Sarkunan and Biddappa, 1981 and Thomas and Prasad, 1982). Nimin-coated urea recorded the maximum NH_4-N content and it was found significantly superior to prilled urea from 20th day onwards.

The result indicated that Nimin-coated urea was more efficient than the untreated prilled urea in maintaining higher

Table 2. Ammoniacal nitrogen in soil as influenced by the treatments at different period of incubation, ppm

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	10.75	8.60	19.35	10.75	12.90	22.58	17.20	17.20	17.20	15.59	8.40	7.32	5.70	6.51
T_2	10.75	16.35	20.43	18.80	20.43	25.80	26.88	32.25	30.10	19.35	11.33	8.54	7.73	7.73
T_3	12.90	11.83	21.50	19.90	27.95	27.43	31.18	29.03	34.40	25.80	13.19	9.35	10.16	10.57
T_4	12.90	13.98	25.80	20.43	25.80	29.03	34.40	32.25	40.85	23.58	13.05	8.95	8.14	8.14
T_5	10.75	10.75	27.95	26.35	24.73	26.43	29.03	32.25	40.85	27.95	17.20	11.38	10.97	12.19
CD (0.05)	NS	3.924	NS	6.547	13.790	NS	NS	10.810	9.463	7.660	3.765	2.143	2.273	2.880

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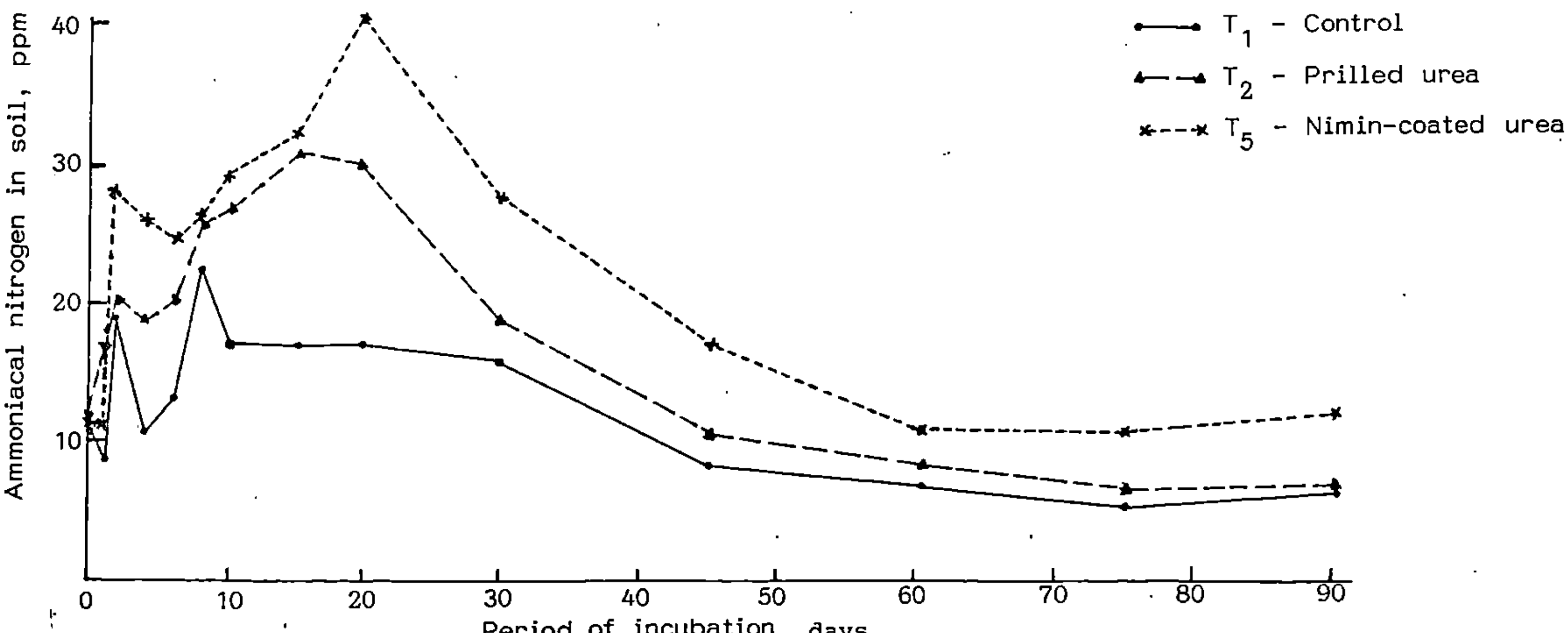


Fig.2. Ammoniacal nitrogen in soil as influenced by the treatments at different period of incubation

NH_4-N content in soil for a long period. Nimin-coated urea was also found superior to neemcake-coated urea and neemcake-mixed urea though the difference between them was not statistically significant. Beneficial effects of Nimin-coated urea may be due to the retardation of the conversion of NH_4-N to NO_3-N. These results are in agreement with the observation made by Vyas et al. (1991) and Vimala (1991).

In the control pot, maximum NH_4-N content was noticed on the 8th day (22.58 ppm) of incubation and thereafter it gradually decreased. In general, NH_4-N content of the soil in all the other treatments which have received treated urea as well as untreated prilled urea increased upto a period of 15-20 days. This indicates that application of nitrification inhibitors had negligible influence on the activity of urease enzyme as the hydrolysis of prilled as well as the urea treated with nitrification inhibitors was completed to a large extent in about 15-20 days.

1.2 Nitrate nitrogen content of the soil

Nitrate nitrogen contents in the soil during various periods of incubation are presented in Table 3 and Fig.3.

The difference due to treatments was not significant at most of the intervals in the initial periods but significant difference was noticed from 10th day of incubation. The control

Table 3. Nitrate nitrogen in soil as influenced by the treatments at different period of incubation, ppm

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	0.62	0.75	0.73	0.76	0.98	0.98	0.88	0.33	0.52	0.55	0.25	0.32	0.45	0.10
T_2	0.68	0.79	0.73	0.67	1.51	1.92	1.44	1.26	1.06	1.06	1.00	0.58	1.15	0.31
T_3	0.71	0.76	0.77	0.72	1.33	2.06	0.88	1.51	1.23	1.84	1.09	0.72	1.05	0.24
T_4	0.72	0.77	0.65	0.94	1.25	1.93	0.92	1.18	1.62	1.45	1.26	0.53	1.35	1.15
T_5	0.74	0.79	0.73	0.55	1.06	1.08	0.77	0.96	1.21	1.33	1.30	1.71	1.43	0.46
CD (0.05)	0.083	NS	0.067	NS	NS	NS	0.502	0.811	0.662	0.472	0.723	0.372	0.515	0.282

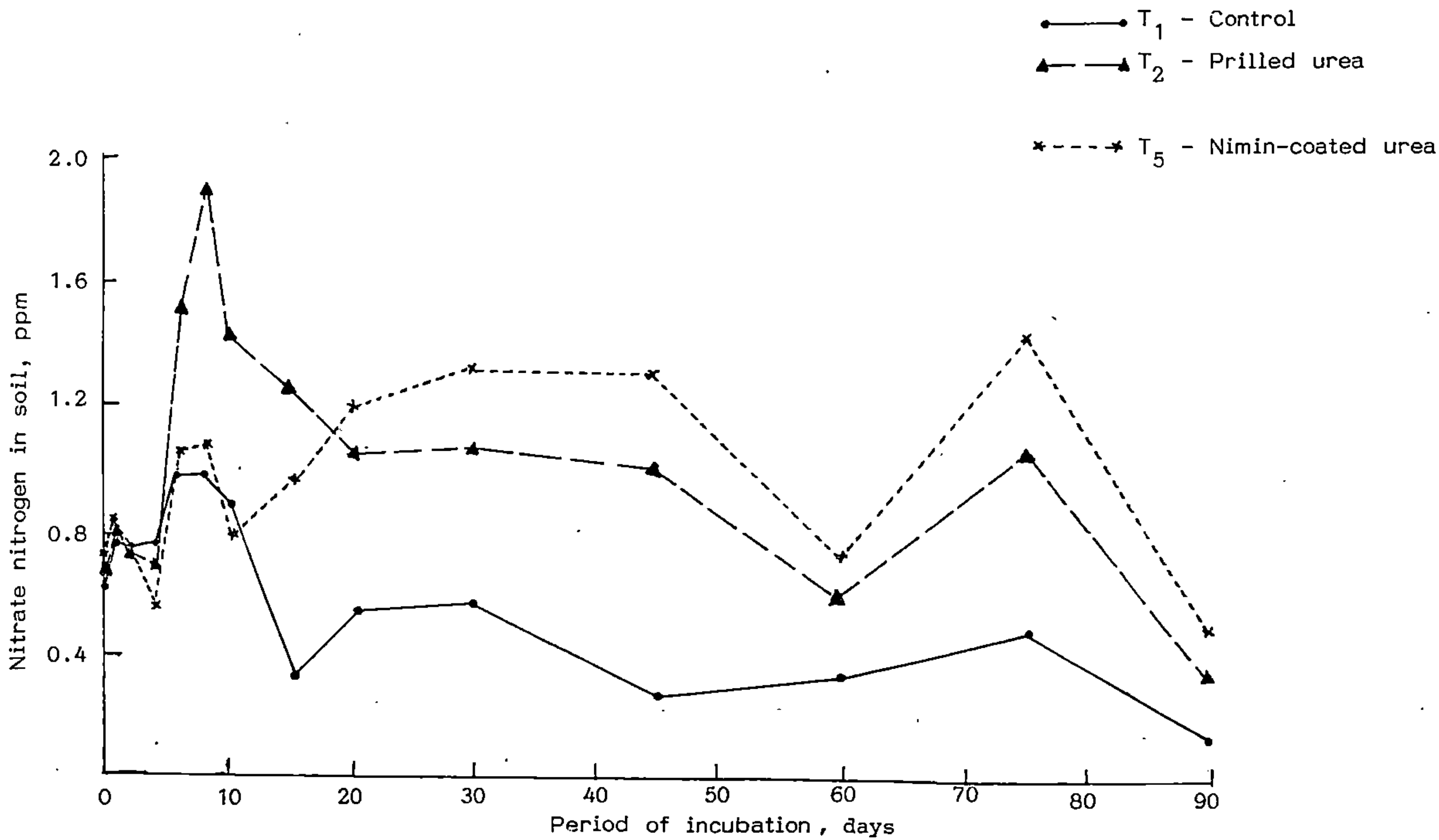


Fig.3. Nitrate nitrogen in soil as influenced by the treatments at different period of incubation

recorded low NO_3-N content at most of the periods especially after 15th day. No definite trend was noticed in the initial periods of incubation up to 6th day. Prilled urea recorded higher NO_3-N content during the periods from 6th to 15th day compared to Nimin-coated urea which indicated the hydrolysis followed by rapid nitrification of prilled urea. Reverse trend was noticed at all the intervals after 15th day though the difference between prilled urea and Nimin-coated urea was not statistically significant.

Among the three treatments with nitrification inhibitors, both neemcake-coated urea and neemcake-mixed urea recorded higher NO_3-N as compared to Nimin-coated urea at most of the intervals in the initial periods. The difference between neemcake-coated urea and neemcake-mixed urea in the content of NO_3-N did not show a uniform trend at different periods of incubation.

It was found that the proportion of NO_3-N formed compared to total nitrogen present in the soil was quite low. The low rate of nitrification in laterite soils of Kerala have been reported by many workers (Mathew, 1986; John, 1987; Anilakumar, 1989; Zacharias, 1989). The reasons that may be attributed for this low nitrification rate is the low pH of laterite soils.

1.3 Total nitrogen content of the soil

Influence of various treatments on the total N content of the soil at different periods of incubation is presented in Table 4.

There was no considerable variation in the total N content of soil due to the treatments. The values ranged from 0.07 to 0.12 per cent and this may be attributed to the high initial available N content of the soil (285 kg ha^{-1}) and the amount of N added was relatively low compared to total soil N.

1.4 Soil reaction

The variation in the pH of the soil during the various periods of estimations are presented in Table 5.

The values of pH recorded for soils revealed that the treatments had no significant influence on the soil reaction. The values increased from 5.65 to near neutral 20 days after submergence and stabilised thereafter till the end of incubation. This may be due to the effect of flooding. This is in conformity with the general observation that pH increases in acidic soils on submergence. The restricted diffusion of oxygen in flood water followed by soil reduction which involve the consumption of H^+ ion would have resulted in the increase in soil pH. A nearly stable pH attained after a few weeks of

Table 4. Total nitrogen in soil as influenced by the treatments at different period of incubation, per cent

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.07	0.08	0.09	0.08	0.07	0.08	0.08
T_2	0.08	0.10	0.07	0.67	0.09	0.09	0.08	0.11	0.09	0.09	0.09	0.08	0.09	0.09
T_3	0.08	0.09	0.07	0.09	0.08	0.09	0.08	0.09	0.09	0.09	0.09	0.08	0.09	0.08
T_4	0.09	0.09	0.08	0.10	0.09	0.08	0.08	0.09	0.09	0.09	0.09	0.08	0.09	0.09
T_5	0.09	0.08	0.07	0.09	0.11	0.10	0.08	0.12	0.09	0.10	0.09	0.09	0.09	0.09

Table 5. pH of the soil as influenced by the treatments at different period of incubation

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	6.46	6.20	6.66	6.49	6.52	6.58	6.64	6.60	6.97	6.85	6.90	6.95	7.00	6.90
T_2	6.68	6.48	6.59	6.35	6.32	6.65	6.70	6.70	6.97	6.90	6.90	7.00	6.90	7.00
T_3	6.64	6.56	6.75	6.20	6.56	6.61	6.60	6.70	7.02	6.95	6.85	7.00	6.85	6.90
T_4	6.49	6.76	6.45	6.41	6.56	6.64	6.65	6.82	7.23	7.00	6.90	6.95	6.95	6.90
T_5	6.39	6.36	6.34	6.28	6.54	6.64	6.70	6.80	7.02	6.90	7.00	7.01	6.90	6.95

submergence may be due to the stabilization of partial pressure of CO_2 and due to the production of substances like ferrous carbonate and ferrous hydroxide as a result of submergence.

1.5 Ammoniacal nitrogen content of soil solution

The data of NH_4-N content of soil solution as influenced by different treatments are presented in Table 6.

Treatments showed no significant difference in the NH_4-N content of soil solution at any of the intervals and the values ranged from 0.46 to 12.99 ppm. The control recorded the lowest value throughout the period of incubation. There was not much variation among the other treatments. Though there was significant difference in the NH_4-N content of soil due to treatments that was not seen in the soil solution and that may be due to the adsorption of NH_4^+ at the exchange sites of the soil.

Ammoniacal nitrogen content of the soil solution was highest during the initial periods both for control and for treatments. It gradually decreased towards the end of the incubation period. Increased quantity of NH_4-N produced in the soil during the initial stages naturally resulted in its higher content in soil solution.

1.6 Nitrate nitrogen content of soil solution

The data pertaining to NO_3-N content of soil solution are presented in Table 7.

Table 6. Ammoniacal nitrogen in soil solution as influenced by the treatments at different period of incubation, ppm

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	1.01	1.01	1.01	0.68	0.79	0.68	0.56	0.73	0.84	0.67	0.62	0.56	0.46	0.46
T_2	4.75	2.69	3.47	2.93	1.79	1.79	1.29	1.68	1.18	0.90	0.67	0.60	0.56	0.57
T_3	6.95	4.92	3.25	11.88	1.91	2.91	1.79	2.56	1.79	1.01	0.67	0.60	0.77	0.87
T_4	7.97	6.38	3.47	11.09	2.47	2.47	2.13	2.80	1.48	0.90	0.66	0.56	0.92	0.80
T_5	5.83	6.05	2.25	12.99	3.58	3.25	2.58	4.34	1.68	0.90	0.84	0.72	0.77	0.70
CD (0.05)	0.155	1.185	NS	0.250	NS	NS	0.155		0.200	0.115	NS	NS	NS	NS

Table 7. Nitrate nitrogen in soil solution as influenced by the treatments at different period of incubation, ppm

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	2.52	1.62	1.13	2.08	2.54	2.61	1.11	2.29	2.19	1.60	1.36	1.16	0.83	0.69
T_2	3.03	2.88	2.55	3.38	4.00	3.49	4.45	3.14	2.75	2.41	3.13	2.07	1.35	1.01
T_3	3.07	1.47	2.07	2.68	3.28	2.70	3.23	2.13	2.50	3.45	2.62	3.40	2.84	1.47
T_4	2.87	1.79	1.93	3.34	3.34	2.97	3.56	2.39	2.48	3.19	2.43	2.78	1.92	1.50
T_5	2.85	1.40	1.69	2.43	2.65	2.69	2.71	2.04	2.05	2.31	2.07	2.51	2.75	1.68
CD (0.05)	NS	NS	1.170	NS	1.250	0.975	1.827	1.500	0.89	0.865	1.419	1.675	1.368	1.587

Table 8. pH of the soil solution as influenced by the treatments at different period of incubation

Treatment	Period of incubation, days													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	7.00	7.05	7.10	7.20	7.26	7.26	7.00	6.80	6.70	6.70	6.75	6.65	6.60	6.60
T_2	7.20	7.30	7.31	7.30	7.35	7.35	7.10	6.90	6.85	6.80	6.75	6.70	6.75	6.65
T_3	7.23	7.30	7.30	7.40	7.60	7.65	7.20	6.95	6.85	6.90	6.90	6.80	6.75	6.75
T_4	7.09	7.26	7.30	7.40	7.55	7.60	7.30	7.00	6.90	6.85	6.80	6.75	6.70	6.70
T_5	7.00	7.30	7.50	7.65	7.50	7.70	7.50	7.20	6.90	6.85	6.80	6.80	6.75	6.75

Results indicated that the difference due to treatments was significant at all the intervals from 6th day of application. The control recorded the lowest value at most of the intervals.

Among the four treatments which have received N fertilizers, application of Nimin-coated urea recorded the lowest value at most of the intervals which indicates the low nitrification rate in this treatment.

1.7 pH of the soil solution

Data relating to the pH of the soil solution are presented in Table 8.

The pH of the soil solution was not significantly influenced by the treatments at different intervals of incubation. It showed a trend to increase up to 8 days after fertilizer application and thereafter decreased for all the treatments.

2. Field experiment

2.1 First crop

2.1.1 Ammoniacal nitrogen content of soil

Influence of various treatments on the NH_4-N content of soil is presented in Table 9 and Fig. 4, 5 and 6.

Significant difference was noticed in the NH_4-N content of the soil throughout the period of study. The control plot

Table 9. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (first crop), ppm

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	29.24	32.58	35.12	14.45	9.45	7.33	5.48	7.25	4.30	17.52	12.63	10.44	4.97	3.70
T_2	33.88	33.53	38.11	42.30	60.75	43.60	29.89	17.86	12.10	21.46	46.44	31.93	12.46	5.41
T_3	45.29	45.50	51.84	58.89	67.93	43.60	26.59	17.86	10.59	23.69	36.94	27.13	10.63	6.50
T_4	53.39	51.75	51.84	64.27	70.31	50.73	40.57	29.45	17.96	24.89	30.98	28.33	15.85	9.50
T_5	46.73	52.63	56.01	63.41	71.50	49.93	39.78	28.11	21.00	28.60	35.75	25.03	12.53	8.43
T_6	37.71	41.93	42.28	49.03	57.20	41.19	33.27	28.11	20.45	27.41	46.47	32.60	11.01	9.50
T_7	44.09	51.03	58.39	56.23	56.02	41.19	37.59	22.68	14.41	32.17	44.68	27.13	14.87	7.87
T_8	68.15	62.43	63.97	62.97	63.17	51.42	43.12	30.98	21.00	32.17	50.30	42.37	21.73	13.67
T_9	51.64	55.37	61.96	60.25	52.52	43.60	40.10	29.46	23.93	39.75	46.46	37.40	19.50	9.23
T_{10}	37.96	47.50	56.01	55.37	56.99	40.49	34.40	29.46	20.45	35.33	36.92	21.37	12.53	5.53
T_{11}	45.15	48.43	54.82	46.58	44.01	42.01	36.65	28.11	19.91	21.46	38.73	23.90	12.53	6.50
T_{12}	42.77	46.30	47.82	43.66	41.62	34.91	29.97	27.84	16.40	21.46	38.10	28.70	10.63	5.53
T_{13}	46.48	50.03	53.95	60.75	77.46	55.93	46.97	33.79	24.56	34.74	42.90	30.00	13.00	6.50
CD (0.05)	8.148	4.796	7.326	9.863	12.293	10.693	6.369	8.978	5.380	7.942	11.048	5.474	3.462	2.263

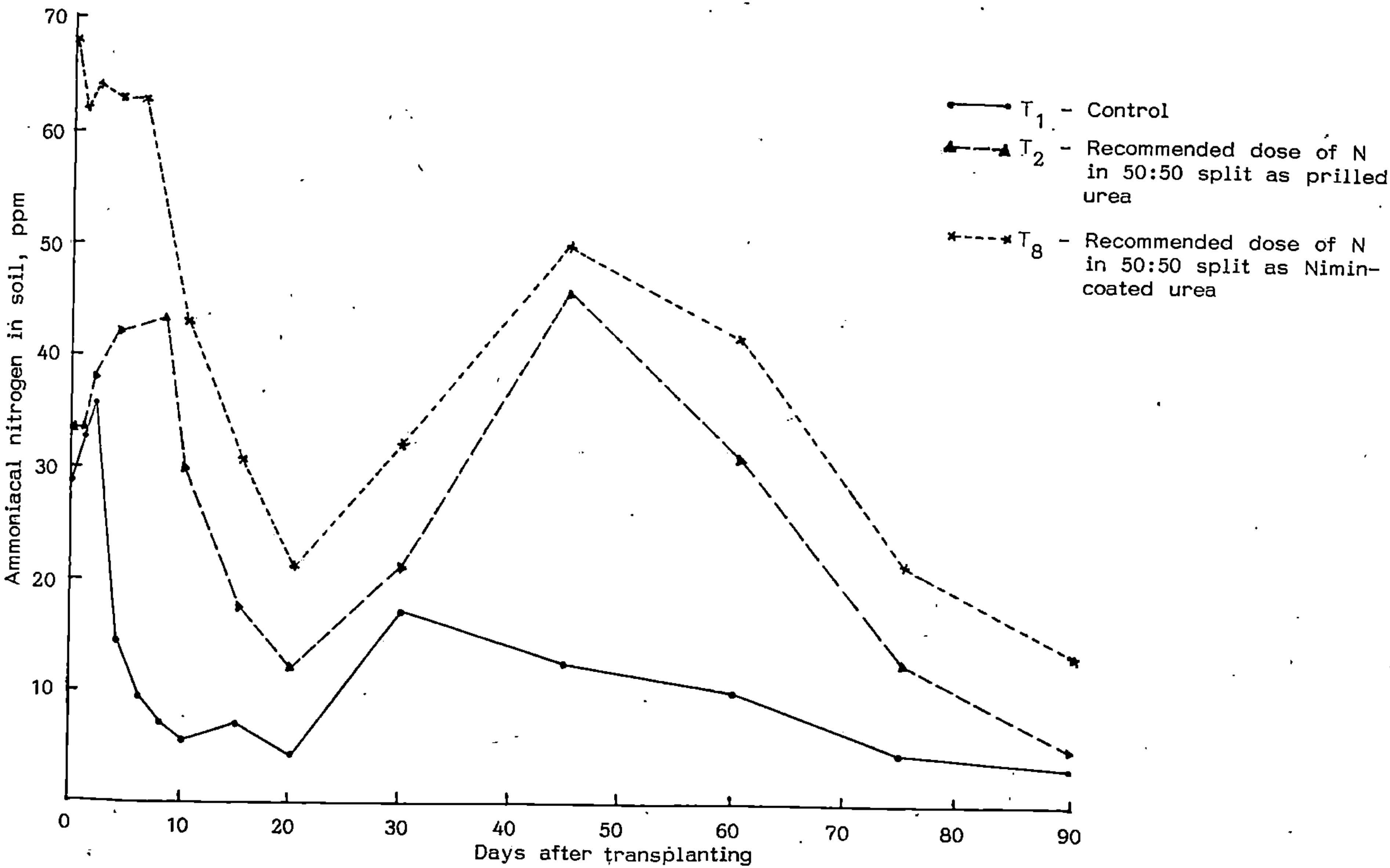


Fig. 4. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (first crop)

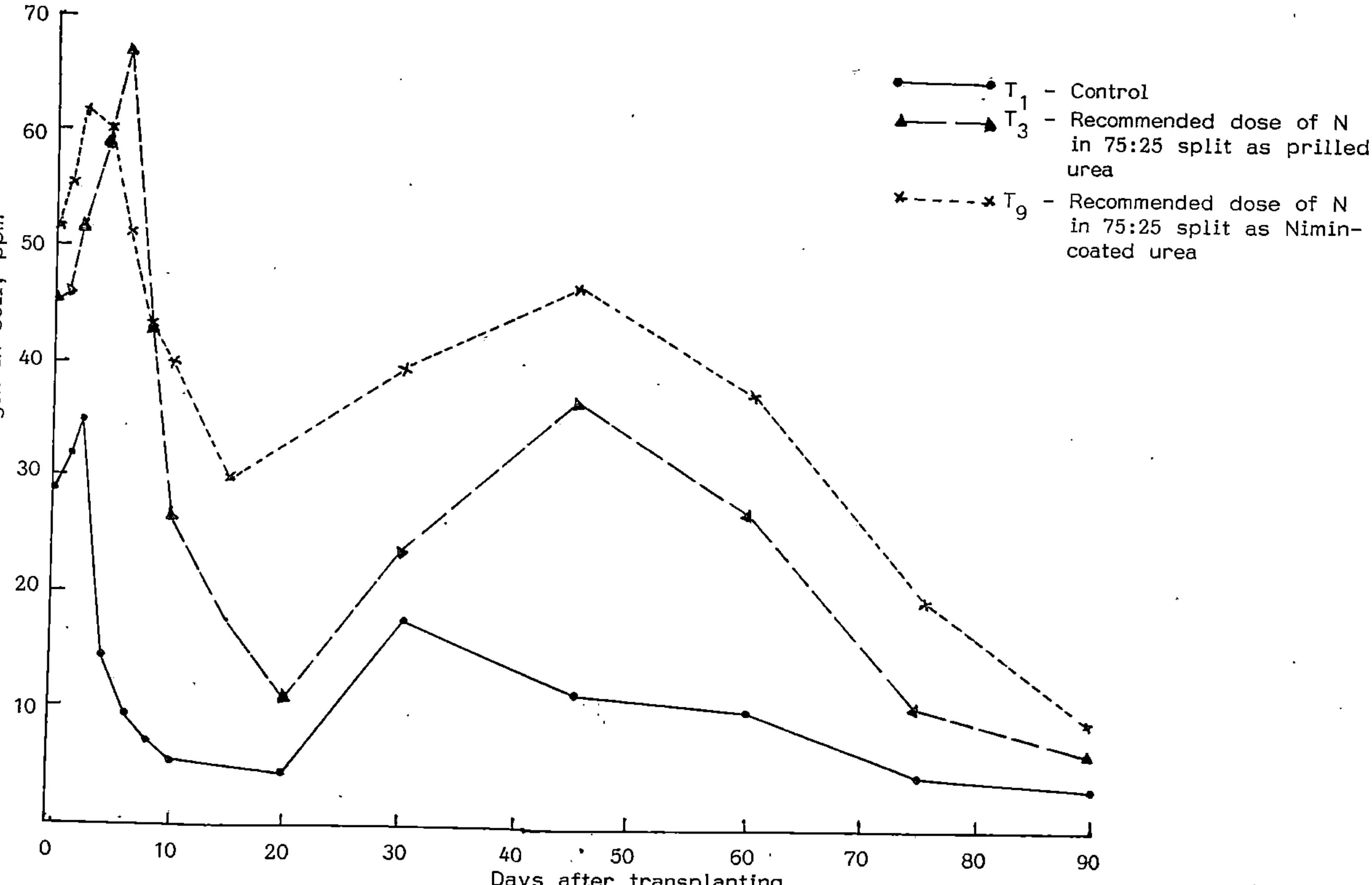


Fig. 5. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (first crop)

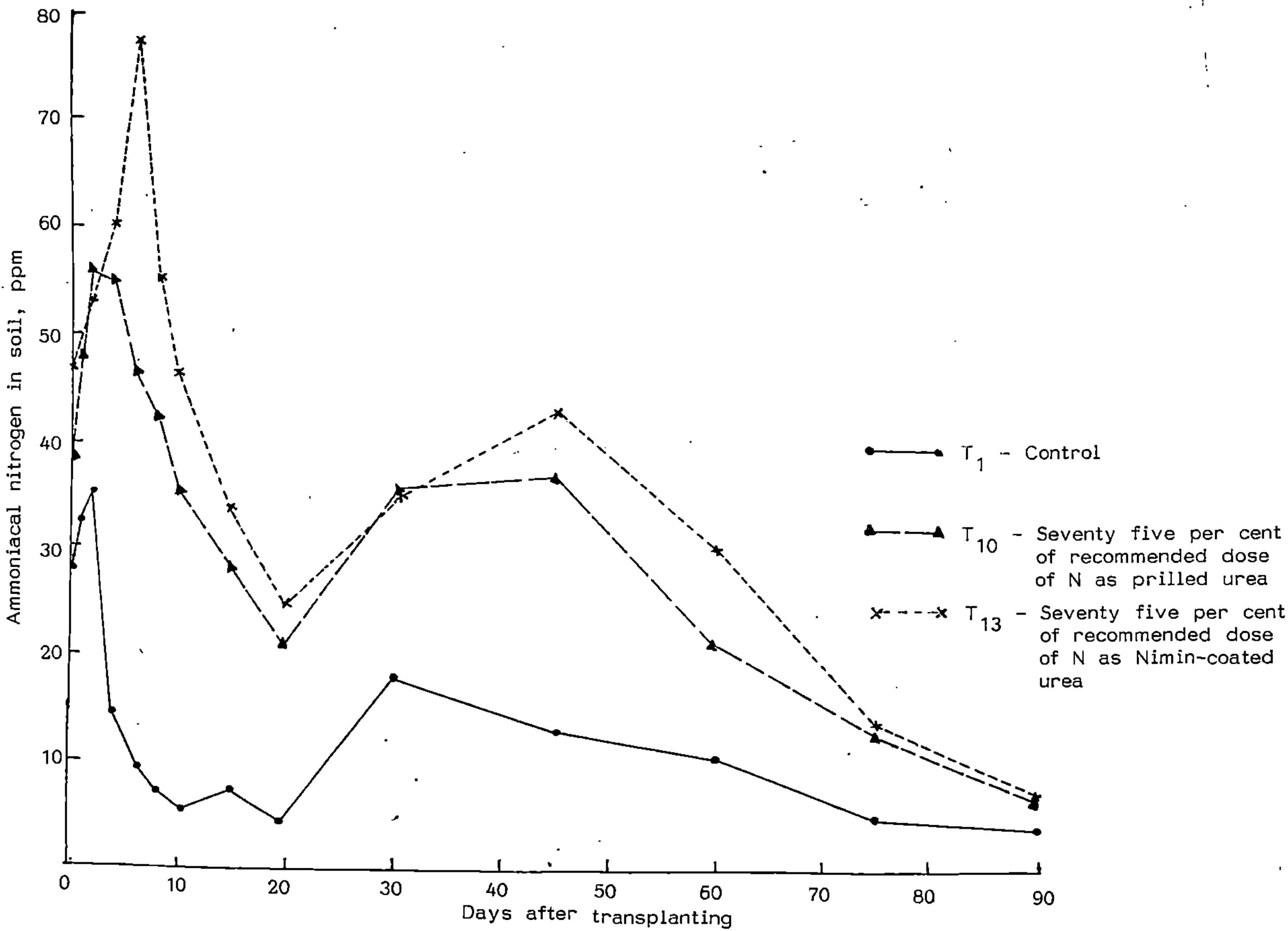


Fig. 6. Ammoniacal nitrogn in soil as influenced by the treatments at different period of crop growth (first crop)

recorded the lowest value at all the intervals. Among the treatments with recommended dose of N in two equal splits (T_2, T_4, T_6 and T_8), Nimin-coated urea recorded highest value at almost all the intervals and it recorded significantly higher values compared to prilled urea except at 6th, 8th and 45th day.

In the case of treatments which have received the recommended dose of N in 75:25 split also (T_3, T_5, T_7 and T_9), Nimin-coated urea retained higher NH_4-N content at 11 intervals and found significantly superior to prilled urea at 9 intervals mainly in the later stages.

Nimin-coated urea recorded the highest value of NH_4-N among the four treatments with 75 per cent of the recommended dose of N (T_{10}, T_{11}, T_{12} and T_{13}) at all the intervals except at the 2nd and 30th day.

Neemcake-coated and neemcake-mixed urea were found to be better than prilled urea when recommended dose of N was applied. There was not much variation between neemcake-coated urea and neemcake-mixed urea in the NH_4-N content of soil.

The results indicated that Nimin-coated urea was more efficient in increasing the NH_4-N content of soil than other treatments. The higher NH_4-N content recorded in the plots receiving Nimin-coated urea especially in the later periods may be due to the retardation of the conversion of NH_4-N to NO_3-N. Similar results have been obtained for the incubation study also. Increased NH_4-N in soil by treating urea with Nimin over untreated urea was reported by Vimala (1991) and Vyas et al. (1991).

There was not much variation in the NH_4-N content of soil due to the application of full and 75 per cent of the recommended dose of N.

In the control plot, the ammonification of the native organic matter present in the soil increased up to a period of two days and thereafter it showed a tendency to decrease up to the 30th day. The slight increase noticed after 30th day may be due to the NH_4-N present in the percolation water from the adjacent plots consequent to top dressing. The NH_4-N content of the soil in general decreased with crop growth barring an increase during the initial periods up to 6 days after transplanting. Corroboratory results were obtained by Anilakumar (1989). The initial increase of NH_4-N in soil may be due to the triggering of mineralisation of both applied and native N and subsequent decrease caused by plant uptake and N losses. The increase in NH_4-N content noticed after 30th day was due to the application of the second dose of fertilizer which again showed a decreasing trend up to 90th day.

2.1.2 Nitrate nitrogen content of soil

The mean values of NO_3-N in the soil samples for the various treatments are presented in Table 10 and Fig.7, 8 & 9.

It was observed that the treatments did not influence the NO_3-N content of the soil significantly at most of the intervals. Among the four treatments with recommended dose of N in two equal doses (T_2, T_4, T_6 and T_8) application of Nimin-coated urea recorded the lowest NO_3-N concentration at all the intervals in the initial periods up to 15th day and this treatment recorded comparatively higher values in the later stages.

When the recommended dose of N was applied in 75:25 splits also the lowest NO_3-N content was recorded by Nimin-coated urea for a longer period up to 60 days and after that this treatments recorded comparatively higher values.

Nimin-coated urea recorded the lowest values up to 20th day in the case of application of 75 per cent of the recommended dose of N. The concentration of NO_3-N increased thereafter and recorded higher values compared to prilled urea at the later intervals. Application of the other two nitrification inhibitors namely neemcake-mixed urea and neemcake-coated urea showed a similar trend of reduced NO_3-N content in the initial periods and increased NO_3-N content in the later stages compared to prilled urea.

In the case of treatment receiving prilled urea, the loss of N as nitrate was relatively high whereas N was retained

Table 10. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (first crop), ppm

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	0.15	0.15	0.22	0.16	0.29	0.23	0.25	0.33	0.22	0.23	0.25	0.18	0.25	0.25
T_2	0.37	0.30	0.30	0.50	0.50	0.61	0.69	0.56	0.52	0.38	0.45	0.68	0.75	0.55
T_3	0.51	0.35	0.45	0.52	0.54	0.61	0.68	0.71	0.40	0.45	0.50	0.50	0.60	0.60
T_4	0.17	0.10	0.25	0.36	0.45	0.52	0.57	0.56	0.45	0.49	0.60	1.00	1.05	1.15
T_5	0.30	0.21	0.23	0.33	0.45	0.52	0.54	0.59	0.38	0.38	0.45	0.65	0.95	1.10
T_6	0.20	0.28	0.22	0.38	0.47	0.42	0.54	0.62	0.36	0.50	0.35	0.65	0.88	1.00
T_7	0.15	0.16	0.17	0.45	0.40	0.49	0.57	0.71	0.40	0.38	0.50	0.65	1.15	1.30
T_8	0.10	0.16	0.13	0.29	0.31	0.26	0.33	0.43	0.40	0.43	0.50	0.45	1.15	1.25
T_9	0.17	0.21	0.15	0.24	0.34	0.37	0.36	0.37	0.29	0.33	0.28	0.40	1.08	1.35
T_{10}	0.25	0.43	0.40	0.47	0.47	0.50	0.47	0.54	0.50	0.35	0.35	0.23	0.55	0.38
T_{11}	0.37	0.20	0.30	0.33	0.33	0.55	0.34	0.51	0.48	0.38	0.35	0.55	0.60	0.60
T_{12}	0.35	0.33	0.30	0.33	0.29	0.45	0.40	0.59	0.47	0.41	0.30	0.58	0.75	0.80
T_{13}	0.15	0.15	0.15	0.20	0.29	0.36	0.31	0.44	0.38	0.38	0.50	0.58	0.89	0.80
CD (0.05)	0.205	NS	NS	0.182	NS	0.185	NS	0.141	NS	NS	NS	0.292	0.344	0.320

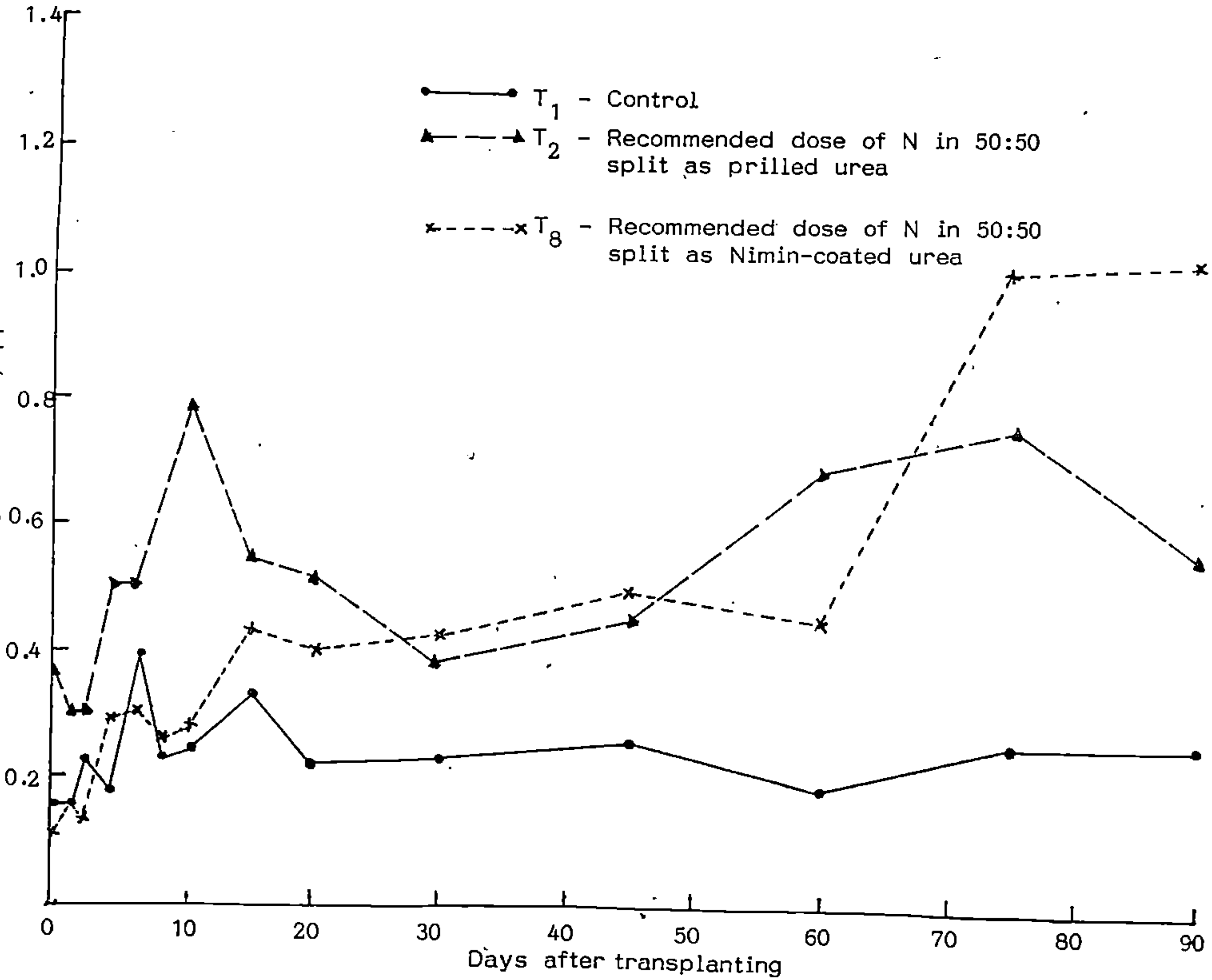


Fig. 7. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (first crop)

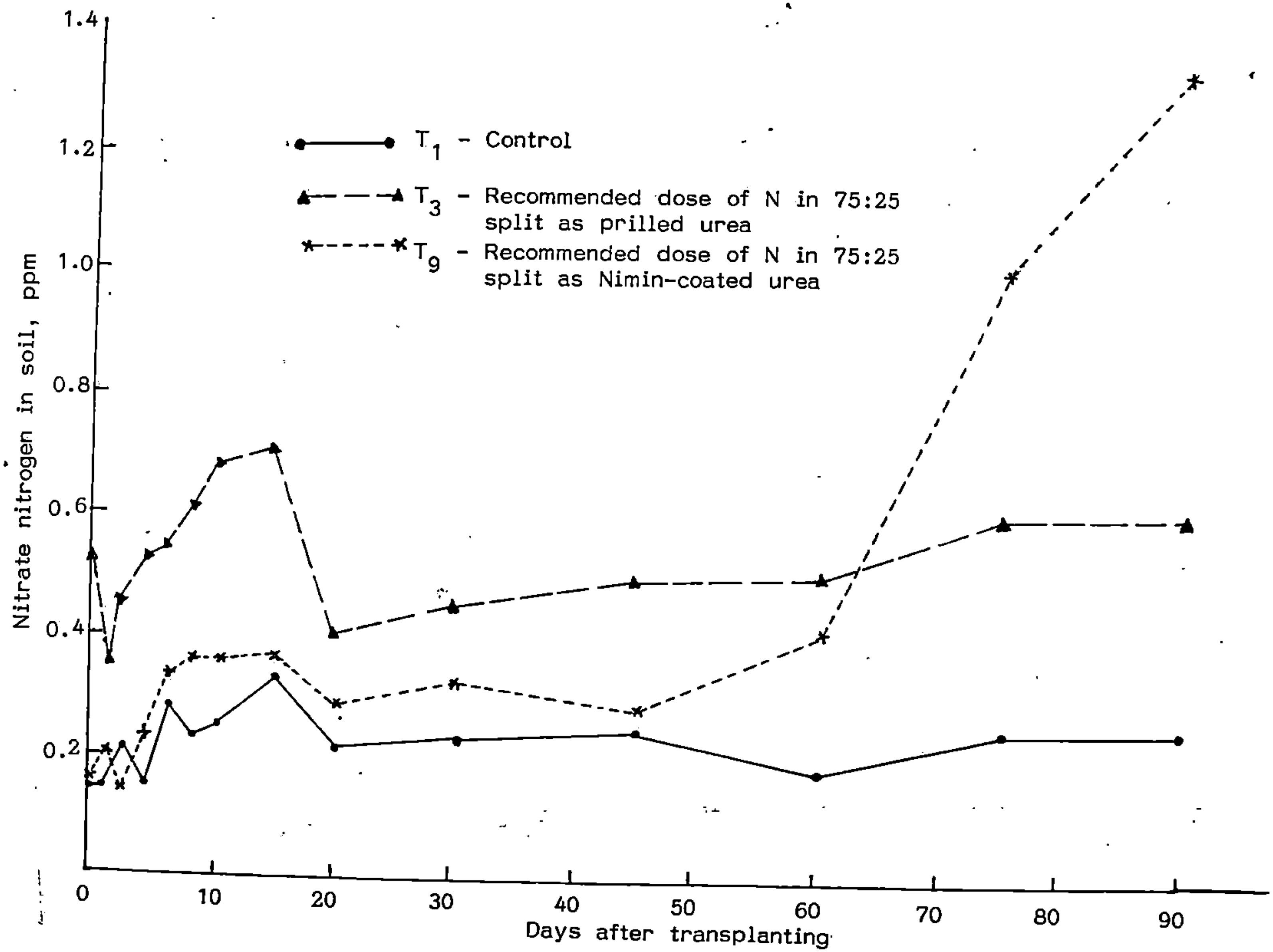


Fig. 8. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (first crop)

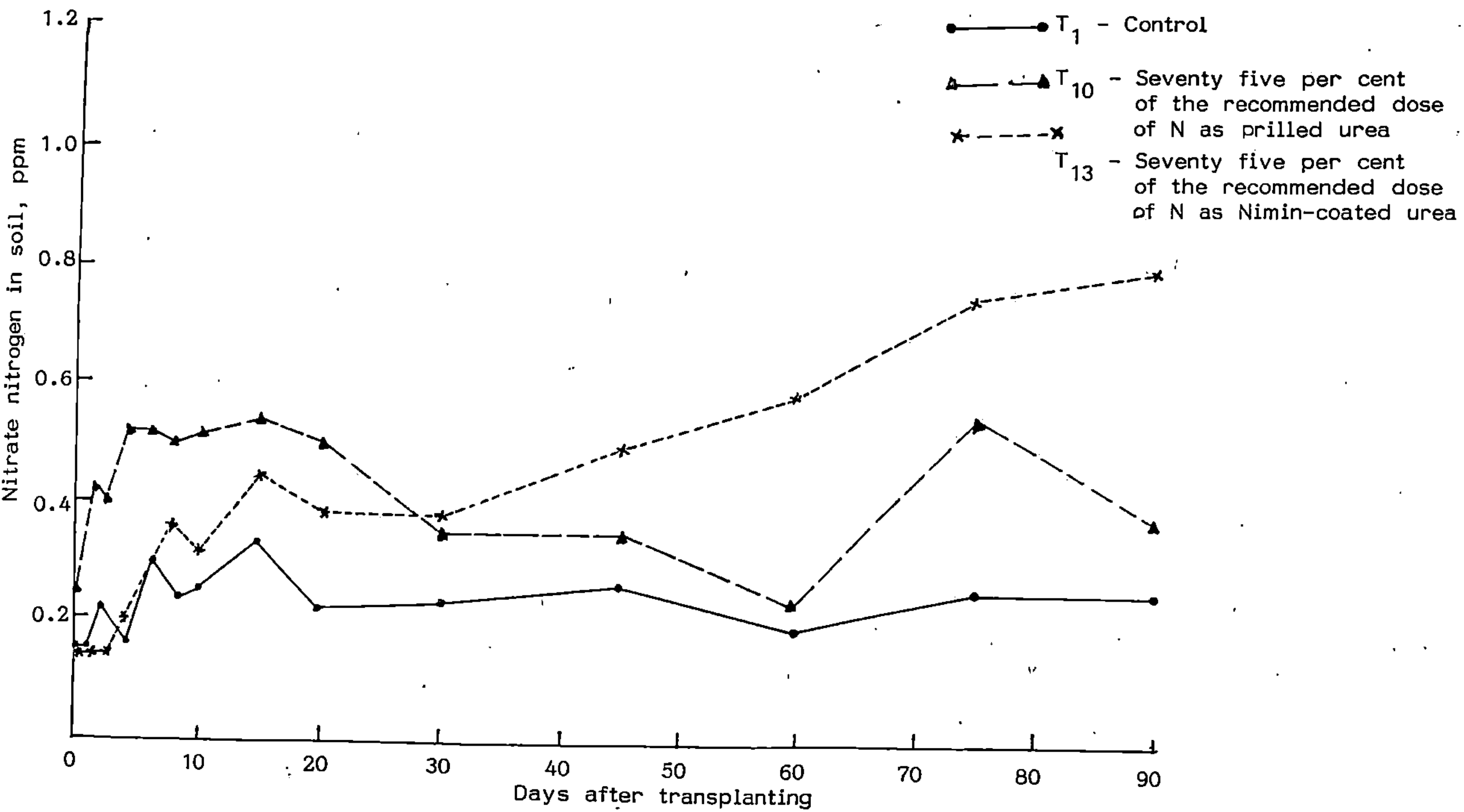


Fig. 9. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (first crop)

as NH_4^+ ions in otner treatment at the early stages of crop growth. The delayed nitrification of N retained as NH_4-N in the latter treatments would have caused the relatively higher content of both ammoniacal and NO_3-N in these plots. Similar results due to the application of Nimin-coated urea have been reported by Vimala (1991) and Vyas et al. (1991).

The inhibition of nitrification by Nimin-coated urea, neemcake-coated urea and neemcake-mixed urea is attributed to the presence of active principles like nimbin, nimbininin, nimbidin and nimbinin (Vyas et al., 1991).

The NO_3-N content of the soil in the treatments with 75 per cent of the recommended dose of N, was found to be lower than that of the treatments with full dose of N at most of the intervals for prilled urea and Nimin-coated urea.

2.1.3 Total nitrogen content of soil

The data on the total nitrogen content of the soil during various periods of estimation are given in Table 11.

The difference in the total N content of soil showed significant difference at 0, 1, 10, 15, 60, 75 and 90 days after transplanting. But no definite trend was noticed in the total N content due to different treatments.

Table 11. Total nitrogen in soil as influenced by the treatments at different period of crop growth (first crop), per cent

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	0.10	0.10	0.10	0.10	0.10	0.09	0.08	0.07	0.07	0.07	0.08	0.08	0.07	0.07
T_2	0.09	0.08	0.10	0.11	0.14	0.11	0.09	0.08	0.08	0.09	0.09	0.10	0.10	0.09
T_3	0.08	0.08	0.09	0.10	0.11	0.12	0.08	0.08	0.08	0.08	0.09	0.10	0.10	0.09
T_4	0.09	0.08	0.09	0.10	0.13	0.12	0.09	0.09	0.09	0.07	0.08	0.08	0.09	0.07
T_5	0.09	0.10	0.09	0.11	0.14	0.11	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.07
T_6	0.10	0.10	0.09	0.13	0.13	0.12	0.11	0.08	0.08	0.08	0.08	0.10	0.10	0.07
T_7	0.09	0.11	0.10	0.10	0.12	0.11	0.09	0.09	0.09	0.08	0.08	0.09	0.10	0.10
T_8	0.08	0.09	0.10	0.11	0.13	0.11	0.10	0.09	0.09	0.08	0.09	0.10	0.11	0.10
T_9	0.09	0.09	0.10	0.11	0.13	0.12	0.11	0.10	0.09	0.08	0.09	0.10	0.10	0.10
T_{10}	0.08	0.07	0.09	0.10	0.13	0.09	0.10	0.08	0.07	0.08	0.08	0.08	0.09	0.10
T_{11}	0.09	0.09	0.11	0.13	0.14	0.12	0.12	0.08	0.08	0.08	0.08	0.08	0.10	0.10
T_{12}	0.09	0.10	0.10	0.11	0.13	0.11	0.10	0.09	0.09	0.07	0.08	0.08	0.08	0.08
T_{13}	0.10	0.10	0.09	0.10	0.13	0.12	0.12	0.09	0.09	0.08	0.09	0.08	0.10	0.08
CD (0.05)	0.020	0.020	NS	NS	NS	NS	0.023	0.016	NS	NS	NS	0.011	0.016	0.020

2.1.4 Soil reaction

Data relating to the pH of the soil are presented in Table 12.

No significant difference was observed in the values of pH recorded for soils, between treatments at any of the intervals. Soil pH gradually increased from an initial value of 5.65 and reached near neutral on 10th day after transplanting for all the treatments and remained without much change up to 60th day. After that the values of pH decreased which may be due the comparatively better oxidised condition of the soil in the later stages. The results obtained are in agreement with the results recorded in the incubation study also.

2.1.5 Biometric observations

Results on the effect of various treatments on the biometric characters such as plant height, number of tillers per m^2 and dry matter yield at maximum tillering, panicle initiation, 50 per cent flowering and at harvest are given in Tables 13, 14 and 15.

2.1.5.1 Height of plant

The difference due to treatment application was not high enough to attain the level of statistical significance at any of the growth stages of crop considered. No specific trend was

Table 12. pH of the soil as influenced by the treatments at different period of crop growth (first crop)

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	6.27	6.17	6.10	6.03	6.37	6.00	6.90	6.80	6.75	6.87	6.80	6.80	6.00	5.95
T_2	6.57	6.03	6.03	6.06	6.70	6.00	7.00	6.90	6.65	6.92	6.80	6.85	6.35	6.10
T_3	6.53	6.20	6.17	6.10	6.87	6.20	6.90	6.90	6.50	6.60	6.85	6.25	6.20	6.05
T_4	6.27	6.30	6.33	6.27	6.70	6.40	7.10	6.80	6.70	6.80	6.90	6.80	6.15	6.00
T_5	6.63	6.47	6.43	6.40	6.50	6.50	6.90	6.90	6.85	7.10	6.90	6.90	6.05	6.00
T_6	6.20	6.43	6.37	6.17	6.50	6.30	6.75	6.75	6.70	6.70	6.75	6.90	6.60	5.95
T_7	6.47	6.03	6.07	6.13	6.60	6.10	7.10	6.85	6.90	6.90	6.90	6.85	6.25	6.05
T_8	6.33	5.93	6.00	6.07	6.33	6.10	6.80	6.80	6.80	6.95	6.90	6.90	6.35	6.15
T_9	6.60	6.10	6.17	6.30	6.57	6.40	6.95	6.80	6.85	6.95	6.85	7.00	6.40	6.20
T_{10}	6.47	6.13	6.02	6.00	6.60	6.30	6.90	6.70	6.75	7.00	6.95	6.90	6.15	5.90
T_{11}	6.26	6.17	6.07	6.15	6.33	6.20	6.95	6.75	6.80	6.85	6.70	7.05	6.25	6.10
T_{12}	6.38	6.17	6.06	6.00	6.27	6.00	6.95	6.90	6.95	6.95	6.70	6.95	6.15	6.00
T_{13}	6.30	6.17	6.13	6.17	6.50	6.30	7.00	6.90	6.90	6.90	6.90	7.00	6.30	6.00

Table 13. Height of plant as influenced by the treatments at different stages of crop growth (first crop), cm

Treatment	Maximum tillering	Panicle initiation	Flowering	Harvest
T_1	51.8	75.7	80.4	80.0
T_2	52.6	77.0	81.0	79.0
T_3	55.9	84.6	86.2	84.0
T_4	52.4	73.5	78.0	77.0
T_5	50.6	76.0	81.4	81.0
T_6	51.0	82.3	84.1	82.0
T_7	51.8	75.9	83.0	81.0
T_8	53.7	83.1	86.9	85.0
T_9	55.8	76.4	80.9	80.0
T_{10}	51.2	75.7	81.3	79.0
T_{11}	56.1	76.3	81.0	78.0
T_{12}	52.9	72.0	79.0	75.0
T_{13}	53.4	73.5	77.8	76.0

noticed due to different treatments. The result obtained in the study is not in agreement with the results reported by Varughese (1988) who has reported significant increase in plant height at different growth stages due to application of urea in combination with neemcake.

2.1.5.2 Number of tillers per m^2

The mean number of tillers per m^2 varied significantly only at the harvest stage. The range at this stage being 211 for control to 289 for recommended dose of N as Nimin-coated urea in 50:50 split. But difference between prilled urea and Nimin-coated urea was not significant. With 75 per cent of the recommended dose of N also, application of Nimin-coated urea recorded the highest tiller count. At this level also the difference between prilled urea and Nimin-coated urea was not significant. Increased number of tillers obtained for this treatment may be due to the comparatively high NH_4-N and NO_3-N content of the soil at the later stages. Increased number of tillers by mixing neemcake with urea over untreated urea was reported by Bains et al. (1971); Oomen et al. (1977) and Subramanian et al. (1979).

2.1.5.3 Dry matter production

Significant difference in the dry matter production was not noticed at any of the growth stages studied due to different

Table 14. Number of tillers per m^2 as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	Flowering	Harvest
T_1	356	245	245	211
T_2	289	245	245	256
T_3	356	255	255	222
T_4	322	244	244	222
T_5	313	233	233	233
T_6	256	248	248	278
T_7	411	245	245	267
T_8	378	245	245	289
T_9	378	222	222	255
T_{10}	341	267	267	233
T_{11}	349	278	267	244
T_{12}	290	244	244	277
T_{13}	378	289	289	278
CD (0.05)	NS	NS	NS	41.387

Table 15. Dry matter production and yield of grain and straw as influenced by the treatments (first crop), kg ha^{-1}

Treatment	Dry matter production			Grain yield	Straw yield
	At maximum tillering	At panicle initiation	At 50 per cent flowering		
T_1	1136.7	4143.3	6270.0	2053.1	2894.5
T_2	1136.7	4363.3	7406.7	2237.9	3123.6
T_3	1375.0	5243.3	8506.7	2258.4	3328.0
T_4	1550.0	4363.3	7480.0	2322.6	3380.6
T_5	1430.0	4656.7	7920.0	2376.5	3516.4
T_6	1254.0	4913.3	8415.0	1978.7	3301.7
T_7	1789.3	4510.0	7076.7	2384.2	3022.1
T_8	1411.7	4455.0	6966.7	2439.6	2997.6
T_9	1283.3	4143.3	7351.7	2540.7	3860.2
T_{10}	1455.7	4986.7	7260.0	2384.2	3197.0
T_{11}	1320.0	3721.7	6710.0	2656.2	2918.1
T_{12}	1155.0	3886.7	6893.3	2756.0	3279.0
T_{13}	1320.0	4253.3	7186.7	2810.2	3799.9

forms and levels of urea application. The lack of response to the application of nitrogen reveals that the plants are provided with sufficient level of nitrogen in soil to meet their requirement. In this connection it may be noted that the amount of available N in the soil was 285 kg ha^{-1}. Grain yield recorded for different treatments showed a variation from 1978.7 to 2810.2 kg ha^{-1}. Though the difference due to treatments was not significant Nimin-coated urea recorded maximum grain yield both for full and 75 per cent of the recommended dose of N. Neemcake-mixed urea and neemcake-coated urea also recorded higher yield compared to prilled urea in all cases except when full dose of N was applied in 50:50 split. The difference between these two treatments did not show any definite trend at different levels and split doses. While a few workers reported the positive response of rice to application of neemcake-mixed urea (Varughese, 1988), most of the studies conducted in Kerala revealed the lack of influence of neemcake on growth and yield of rice (KAU, 1978; Devi et al., 1980 and Anilakumar, 1989).

2.1.6 Content and uptake of nutrients

2.1.6.1 Nitrogen content and uptake

Influence of various treatments on the N content and uptake is presented in Tables 16 and 17. Though there was significant variation in the nitrogen content of plants at all the growth stages, no uniform trend due to different forms and levels of

Table 16. Nitrogen per cent in plant as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	Flowering	Grain	Straw at harvest
T_1	1.49	0.89	0.78	0.73	1.08
T_2	1.58	1.07	1.02	0.82	1.37
T_3	1.73	0.90	1.17	0.87	1.37
T_4	1.61	0.90	0.99	0.95	1.61
T_5	1.73	0.72	1.08	0.92	1.31
T_6	1.46	1.07	0.96	0.92	1.56
T_7	1.46	0.90	0.90	0.95	1.37
T_8	1.52	1.08	1.08	1.09	1.61
T_9	1.67	0.91	0.96	1.09	1.31
T_{10}	1.46	0.89	0.90	0.81	1.25
T_{11}	1.64	0.90	0.90	0.87	1.14
T_{12}	1.46	0.90	0.96	0.87	1.37
T_{13}	1.64	0.78	1.02	0.87	1.31
CD (0.05)	0.177	0.053	0.151	0.107	0.292

Table 17. Uptake of nitrogen by plant as influenced by the treatments at different stages of crop growth (first crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	16.99	36.89	48.49	15.03	31.44	46.47
T_2	17.97	46.61	74.91	19.45	42.76	52.20
T_3	23.84	47.32	99.04	19.69	45.85	65.53
T_4	25.00	39.35	74.57	22.01	54.53	76.54
T_5	24.67	33.57	85.15	22.07	46.30	68.37
T_6	18.40	52.53	81.12	18.17	51.21	69.38
T_7	26.14	40.41	63.41	22.46	41.71	64.17
T_8	25.91	47.90	74.91	26.52	48.16	74.68
T_9	21.48	37.12	69.78	27.39	50.48	77.87
T_{10}	21.43	44.42	65.05	19.39	39.12	58.52
T_{11}	22.01	33.35	60.12	23.02	33.11	46.14
T_{12}	16.97	35.12	66.10	23.53	45.17	68.70
T_{13}	24.05	33.11	69.06	24.41	49.97	74.38
CD (0.05)	NS	10.020	18.597	6.270	12.800	19.070

nitrogen was noticed in the different growth stages. At maximum tillering, panicle initiation and 50 per cent flowering maximum nitrogen content was recorded by T_5, T_8 and T_3 respectively. At the respective stages control recorded values significantly lower than these treatments.

Among the treatments with different forms of urea application, recommended dose of N as Nimin-coated urea recorded highest value of N per cent in grain for both the types of split applications and it was significant higher than the other treatments. But for the treatments with 75 per cent of the recommended dose of N, there was not much variation between the treatments which have received N as neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea. Neemcake-coated urea and neemcake-mixed urea have also recorded higher N content in grain compared to prilled urea. The increased N per cent due to application of nitrification inhibitors may be due to increased availability of N for plants especially at the later stages.

The difference in the NH_4-N content of soil due to treatments was more pronounced in the later stages of growth of plants and that may be the reasons for the greater variation in the nitrogen content of grain compared to that at the initial growth stages. Increase in the N content in plants due to application of nitrification inhibitors has been reported by many workers (Khan _et al_., 1971; Tyagi and Agarwal, 1989).

Significant difference was obtained in the nitrogen percent of straw also. Control treatment recorded the lowest value of 1.08 per cent and the application of Neemcake-coated urea (T_4) and Nimin-coated urea (T_8) recorded the maximum value of 1.61 per cent. But there was no significant difference, between the four treatments which have received recommended dose of N in 50:50 split and between the treatments which have received N in 75:25 split. All the four treatments with 75 per cent of nitrogen application were also on par. Application of 75 per cent of N has resulted in low N content for most of the treatments at different stages of crop growth compared to application of full dose of N.

The N per cent in plants was maximum when they were young and gradually decreased as the plant grew to maturity. This may be due to the fact that the plants are succulent in their early stages having high proportion of protoplasm relative to structural components like cellulose and lignin and have the capacity to store for future use a larger quantity of soluble N which is of great significance to later grain formation. This decrease in N content with crop growth might also be due to the dilution effect.

Nitrogen uptake progressively increased with the advancement of crop growth. This might be due to the increased dry matter production with growth of plants. Significant variation was noticed in the N uptake at all stages except at the maximum tillering stage. But no regular trend due to treatments was noticed at the different growth stages and this can be attributed to the non-significant variation in the dry matter yield and lack of any uniform trend in the N content of plants due to treatments at various growth stages.

Maximum uptake of N by grain was recorded by the treatment with Nimin when full dose of N was applied in both types of splits and for treatments with 75 per cent of recommended dose of N. Though Nimin-coated urea recorded the highest value among the four treatments which have received 75 per cent of N, all the four treatments were on par. Application of Nimin-coated urea had increased the N content and grain yield and that may be the reason for the higher uptake of N by these treatments. Beneficial effects of Nimin-coated urea in increasing the uptake of N has been reported by Vimala (1991) and Vyas et al (1991).

Uptake of N by the treatments with neemcake-coated urea and neemcake-mixed urea and prilled urea were on par. In the case of straw there was no significant difference between the different forms of urea at both the levels of N application. Highest uptake was recorded by Nimin-coated urea for full dose of N in 75:25 split and 75 per cent of recommended dose of N. When recommended dose of N was applied in two equal doses neem-coated urea recorded the maximum uptake.

2.1.6.2 Phosphorus content and uptake

Data on the effect of various treatments on the content and uptake of P at different stages of crop growth are presented in Tables 18 and 19. The variation due to treatments in the content and uptake of P was significant at all the growth stages, but did not show a uniform trend. Instead inconsistent values were obtained. The highest values of 0.31, 0.28 and 0.24 per cent were recorded by T_6, T_7 and T_{12} at maximum tillering, panicle initiation and 50 per cent flowering respectively. The highest per cent of P in grain was obtained by the application of full dose of N as neemcake-coated urea in 50:50 split (0.34 per cent). Phosphorus content of grain was higher than in the straw and it may be due to the preferential migration of nutrient.

Data pertaining to the uptake of P showed that the difference due to treatments was significant only at the panicle initiation stage and in grain. But no definite trend was noticed as in the case of P content in the plants. The uptake by grain varied from 3.76 kg ha^{-1} to 7.96 kg ha^{-1} and that of straw was from 2.87 kg ha^{-1} to 5.54 kg ha^{-1}.

2.1.6.3 Potassium content and uptake

Data on the content and uptake of K by plants at different growth stages are presented in Tables 20 and 21.

Table 18. Phosphorus per cent in plant as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.27	0.20	0.16	0.21	0.12
T_2	0.28	0.27	0.17	0.25	0.11
T_3	0.29	0.26	0.17	0.30	0.14
T_4	0.28	0.28	0.18	0.34	0.14
T_5	0.29	0.26	0.17	0.24	0.11
T_6	0.31	0.27	0.16	0.19	0.12
T_7	0.29	0.28	0.22	0.24	0.10
T_8	0.26	0.24	0.20	0.21	0.12
T_9	0.29	0.23	0.22	0.21	0.11
T_{10}	0.28	0.20	0.20	0.24	0.17
T_{11}	0.27	0.22	0.22	0.21	0.13
T_{12}	0.28	0.22	0.24	0.23	0.10
T_{13}	0.28	0.21	0.22	0.25	0.12
CD (0.05)	0.055	0.001	0.011	0.025	0.034

Table 19. Uptake of phosphorus as influenced by the treatments at different stages of crop growth (first crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	3.09	12.18	10.09	4.25	3.43	7.69
T_2	3.19	11.79	12.88	5.57	3.52	9.09
T_3	4.02	13.35	17.89	7.70	4.66	12.36
T_4	4.37	12.20	13.51	7.96	4.73	12.69
T_5	4.15	12.03	13.32	5.80	3.88	9.68
T_6	3.89	13.07	13.48	3.76	3.85	7.62
T_7	5.09	12.63	15.32	5.66	2.87	8.53
T_8	3.70	10.75	14.13	5.16	3.58	8.74
T_9	3.71	9.31	16.56	5.47	4.20	9.68
T_{10}	4.02	10.16	14.67	5.80	5.54	11.34
T_{11}	3.57	8.22	14.51	5.68	3.65	9.34
T_{12}	3.25	8.53	16.61	6.42	3.30	9.72
T_{13}	3.67	9.10	15.23	7.14	4.59	11.73
CD (0.05)	NS	2.484	NS	1.703	NS	1.703

Significant variation was noticed in the K content at different growth stages but no uniform trend was noticed between treatments and this can be assigned to the reason that there was no difference between the treatments in the dose of K applied. The highest value at maximum tillering, panicle initiation and 50 per cent flowering were recorded by T_4 (3.08%), T_2 (3.03%) and T_7 (2.78%) respectively. The maximum values of 0.72 per cent in grain and 2.63 per cent in straw were recorded by T_9 and T_3 respectively.

The K per cent in plants was decreased with the advancement of crop growth. This may be due to dilution effect with the increase in dry matter production. The K per cent at harvest was higher in straw than in grain. This may be due to the fact that most of K at the time of maturity are retained in the straw because of the preferential migration of K.

Uptake of potassium by plants showed significant difference at panicle initiation and 50 per cent flowering. The values varied between 83.27 kg ha^{-1} and 148.57 kg ha^{-1} at panicle initiation and from 101.26 kg ha^{-1} to 173.22 kg ha^{-1} at 50 per cent flowering. No definite trend in the uptake of K was noticed at various intervals due to various forms and levels of N. This is quite expected as the uptake is the product of the content and dry matter yield and no definite trend was noticed in the K content due to treatments.

Table 20. Potassium per cent in plant as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw at harvest
T_1	2.75	2.72	1.62	0.28	2.17
T_2	2.92	3.03	1.60	0.30	1.83
T_3	2.90	2.83	1.73	0.53	2.63
T_4	3.08	2.62	1.70	0.28	1.60
T_5	3.02	2.80	1.65	0.45	1.80
T_6	2.77	2.60	1.70	0.27	1.62
T_7	2.70	2.90	2.78	0.62	1.52
T_8	2.83	2.87	2.15	0.28	1.98
T_9	2.93	2.85	2.35	0.72	1.58
T_{10}	2.86	2.15	1.78	0.68	2.10
T_{11}	2.90	2.23	1.83	0.28	1.88
T_{12}	2.90	2.23	1.75	0.57	1.83
T_{13}	2.93	2.28	1.88	0.30	1.72
CD (0.05)	0.077	0.277	0.256	NS	0.250

Table 21. Uptake of potassium by plant as influenced by the treatments at different stages of crop growth (first crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	31.24	112.59	101.26	5.52	62.78	68.30
T_2	31.83	132.18	118.91	6.60	56.90	63.50
T_3	39.88	148.57	147.50	11.93	87.54	99.47
T_4	47.97	112.71	127.16	6.58	54.20	60.78
T_5	43.12	130.39	130.68	10.69	62.44	73.44
T_6	34.67	127.79	144.21	5.23	53.43	58.67
T_7	48.31	131.04	152.44	16.20	45.47	61.67
T_8	39.88	127.91	149.82	6.49	58.79	65.27
T_9	37.64	117.92	173.22	16.77	60.95	77.72
T_{10}	41.53	107.07	129.10	15.13	66.57	81.70
T_{11}	38.28	83.27	122.85	7.54	54.93	62.47
T_{12}	33.49	86.63	124.96	15.39	60.05	75.45
T_{13}	38.70	96.73	135.25	8.44	65.23	73.67
CD (0.05)	NS	30.500	13.624	NS	NS	NS

2.1.6.4 Calcium content and uptake

Influence of various treatments on the content and uptake of Ca is presented in Tables 22 and 23.

The plants were not supplied with any additional Ca. However, Ca content and uptake in plants at different growth stages and in grain and straw at harvest were estimated to evaluate the influence of different forms of urea on the content and uptake of Ca by plants.

Though significant variation was noticed due to different treatments, Ca per cent did not show a uniform trend at different stages of growth considered. The per cent of Ca varied from 0.26 to 0.37, at maximum tillering, 0.22 to 0.50 at panicle initiation and from 0.26 to 0.45 at 50 per cent flowering. In grain it varied from 0.16 to 0.51 and in straw ranged from 0.33 to 0.51.

Uptake of Ca also did not show a uniform trend at different stages of growth, but followed a similar pattern as that of Ca content in plants. Significant variation due to treatments was noticed at the stages of panicle initiation, 50 per cent flowering and in grain. In grain, the uptake ranged between 3.13 to 12.02 kg ha^{-1}. The maximum uptake was recorded by T_{10} which recorded the maximum Ca content. The lowest value of 3.13 kg ha^{-1} was recorded by control and it was mainly

Table 22. Calcium per cent in plant as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.33	0.40	0.29	0.18	0.48
T_2	0.36	0.50	0.26	0.19	0.51
T_3	0.37	0.39	0.33	0.19	0.46
T_4	0.33	0.33	0.45	0.19	0.42
T_5	0.34	0.29	0.38	0.20	0.37
T_6	0.33	0.34	0.42	0.16	0.37
T_7	0.29	0.43	0.33	0.33	0.42
T_8	0.36	0.50	0.42	0.19	0.39
T_9	0.34	0.31	0.36	0.42	0.39
T_{10}	0.26	0.22	0.37	0.51	0.37
T_{11}	0.29	0.37	0.39	0.30	0.43
T_{12}	0.31	0.40	0.42	0.29	0.33
T_{13}	0.31	0.39	0.33	0.21	0.39
CD (0.05)	0.0533	0.0754	0.053	0.0754	0.0754

Table 23. Uptake of calcium by plant as influenced by the treatments at different stages of crop growth (first crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	4.04	16.72	18.37	3.13	13.91	17.54
T_2	4.03	21.63	19.08	4.15	15.84	19.99
T_3	5.10	20.18	27.57	4.50	15.41	19.91
T_4	5.03	14.07	33.34	4.31	14.17	18.48
T_5	4.86	13.47	30.03	4.75	13.14	17.89
T_6	4.06	17.67	34.97	3.19	12.27	15.46
T_7	5.35	19.50	23.00	8.29	12.63	20.93
T_8	4.93	22.12	29.13	4.69	13.01	17.70
T_9	4.37	12.63	26.29	10.52	12.01	22.53
T_{10}	3.72	11.23	28.01	12.02	12.19	24.20
T_{11}	3.91	13.88	26.05	7.96	12.40	20.36
T_{12}	3.56	15.46	28.42	8.08	10.60	18.69
T_{13}	4.07	16.35	23.32	5.87	15.06	20.93
CD (0.05)	NS	5.474	5.760	2.915	NS	2.915

due to the low dry matter production. The uptake of Ca was not found to be significantly affected by different forms and levels of urea. Nitrification inhibitors were not found to be effective in increasing the content and uptake of Ca by plants.

2.1.6.5 Magnesium

Results on the effect of different treatments on the content and uptake of Mg by plants at different stages of crop growth are given in Tables 24 and 25.

The plants were not supplied with any additional Mg. As in the case of other nutrients, Mg level in plants at different stages did not show a uniform trend and inconsistent values were obtained. Magnesium content of plants at maximum tillering, panicle initiation and 50 per cent flowering varied from 0.05 to 0.10, 0.03 to 0.14 and 0.03 to 0.10 per cent respectively.

2.2 Second crop

2.2.1 Ammoniacal nitrogen content of soil

The mean values of NH_4-N content of soil for the various treatments are presented in Table 26 and Fig. 10, 11 and 12.

The variation due to treatments was not significant at most of the initial stages. From 15th day onwards the difference was significant at all the intervals except on the 30th day. Control recorded the lowest value throughout the period of experimentation.

Table 24. Magnesium per cent in plant as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.05	0.03	0.03	0.04	0.03
T_2	0.06	0.03	0.06	0.08	0.03
T_3	0.06	0.08	0.06	0.04	0.04
T_4	0.06	0.13	0.03	0.08	0.03
T_5	0.06	0.13	0.03	0.04	0.03
T_6	0.09	0.07	0.03	0.08	0.05
T_7	0.10	0.03	0.09	0.03	0.04
T_8	0.09	0.03	0.06	0.03	0.04
T_9	0.09	0.04	0.07	0.03	0.03
T_{10}	0.09	0.14	0.05	0.06	0.09
T_{11}	0.07	0.03	0.06	0.03	0.03
T_{12}	0.07	0.03	0.06	0.09	0.08
T_{13}	0.07	0.03	0.10	0.03	0.04
CD (0.05)	0.020	0.020	0.020	0.025	0.016

Table 25. Uptake of magnesium by plant as influenced by the treatments at different stages of crop growth (first crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	0.59	1.33	2.08	0.70	0.80	1.59
T_2	0.70	1.21	4.14	1.69	0.99	2.68
T_3	0.83	4.40	5.15	0.90	1.25	4.82
T_4	0.97	6.90	2.10	1.94	0.94	1.88
T_5	0.87	6.37	2.19	0.95	1.15	2.10
T_6	1.09	3.84	2.68	1.48	1.68	3.16
T_7	1.82	1.45	6.91	0.76	0.84	1.60
T_8	1.23	1.42	3.87	0.68	0.98	1.66
T_9	1.22	1.53	5.07	0.72	1.07	1.78
T_{10}	1.30	5.31	3.69	1.36	2.80	4.16
T_{11}	1.10	1.04	3.77	0.74	0.93	1.67
T_{12}	0.76	1.32	3.97	2.54	2.56	5.11
T_{13}	0.87	1.18	7.64	0.78	1.57	2.35
CD (0.05)	0.506	1.024	1.681	0.680	0.449	0.565

The NH_4-N content of the soil in general increased up to a period of 8 days and then decreased with crop growth. In all the treatments with urea application, NH_4-N content increased up to a period of 15-20 days. A further increase was noticed after 30th day which was due to the application of second dose of fertilizer.

The data revealed that the hydrolysis of urea applied at the time of planting was completed to a large extent within a period of 15-20 days.

Nimin-coated urea recorded higher NH_4-N content than prilled urea at most of the intervals for both types of split application of the recommended dose of N. Application of Nimin-coated urea recorded the highest value when applied at the rate of 75 per cent of the recommended dose of N also. The other treatments with nitrification inhibitors namely neemcake-coated urea and neemcake-mixed urea were also found to have influence in increasing the NH_4-N content at most of the intervals. But Nimin was found to be superior to the other two treatments. For the incubation study and for the first crop, similar trend was noticed.

There was not much variation in the NH_4-N content of soil between the two levels of N application. During the first crop season also similar results were obtained.

Table 26. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (second crop), ppm

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	22.25	24.85	20.94	19.63	19.63	30.11	20.94	14.49	10.47	15.71	11.04	7.15	4.58	3.28
T_2	26.18	43.20	32.72	34.04	43.20	48.43	37.96	45.81	34.03	22.25	35.80	19.63	7.85	5.89
T_3	27.49	41.90	43.20	39.27	41.89	46.48	43.20	37.96	32.72	28.80	37.43	22.25	5.89	6.54
T_4	24.87	37.96	44.51	43.20	35.34	46.47	35.34	43.20	48.43	23.56	40.68	22.25	9.82	13.08
T_5	19.04	43.20	40.58	48.43	37.38	48.43	41.89	49.09	37.96	23.56	34.45	20.94	13.74	11.75
T_6	20.94	36.65	37.97	35.34	39.28	45.16	40.58	45.81	35.34	23.56	37.23	24.21	11.78	12.43
T_7	28.80	28.80	37.97	36.66	32.72	46.47	49.74	45.81	41.89	40.58	35.24	23.56	17.02	16.36
T_8	24.87	45.81	37.96	43.20	45.38	48.43	40.58	52.36	45.81	32.72	45.12	22.90	18.65	22.25
T_9	24.87	36.65	45.81	45.82	41.89	54.98	56.29	45.81	47.12	36.65	39.27	24.21	14.73	14.40
T_{10}	28.80	30.11	32.72	26.18	26.19	48.43	30.11	41.89	44.51	30.11	28.51	20.94	5.89	9.16
T_{11}	28.87	24.87	31.42	41.90	35.34	47.12	41.89	47.12	49.74	26.56	33.52	22.90	4.58	13.74
T_{12}	30.11	36.65	30.11	43.20	34.03	44.51	47.13	41.45	35.34	30.11	35.51	22.25	5.89	11.78
T_{13}	20.94	39.96	41.89	44.51	28.80	49.44	48.43	50.46	51.05	35.34	39.60	22.90	13.54	16.42
CD (0.05)	NS	NS	NS	13.050	NS	8.74	NS	10.226	16.000	NS	9.600	4.963	8.405	4.950

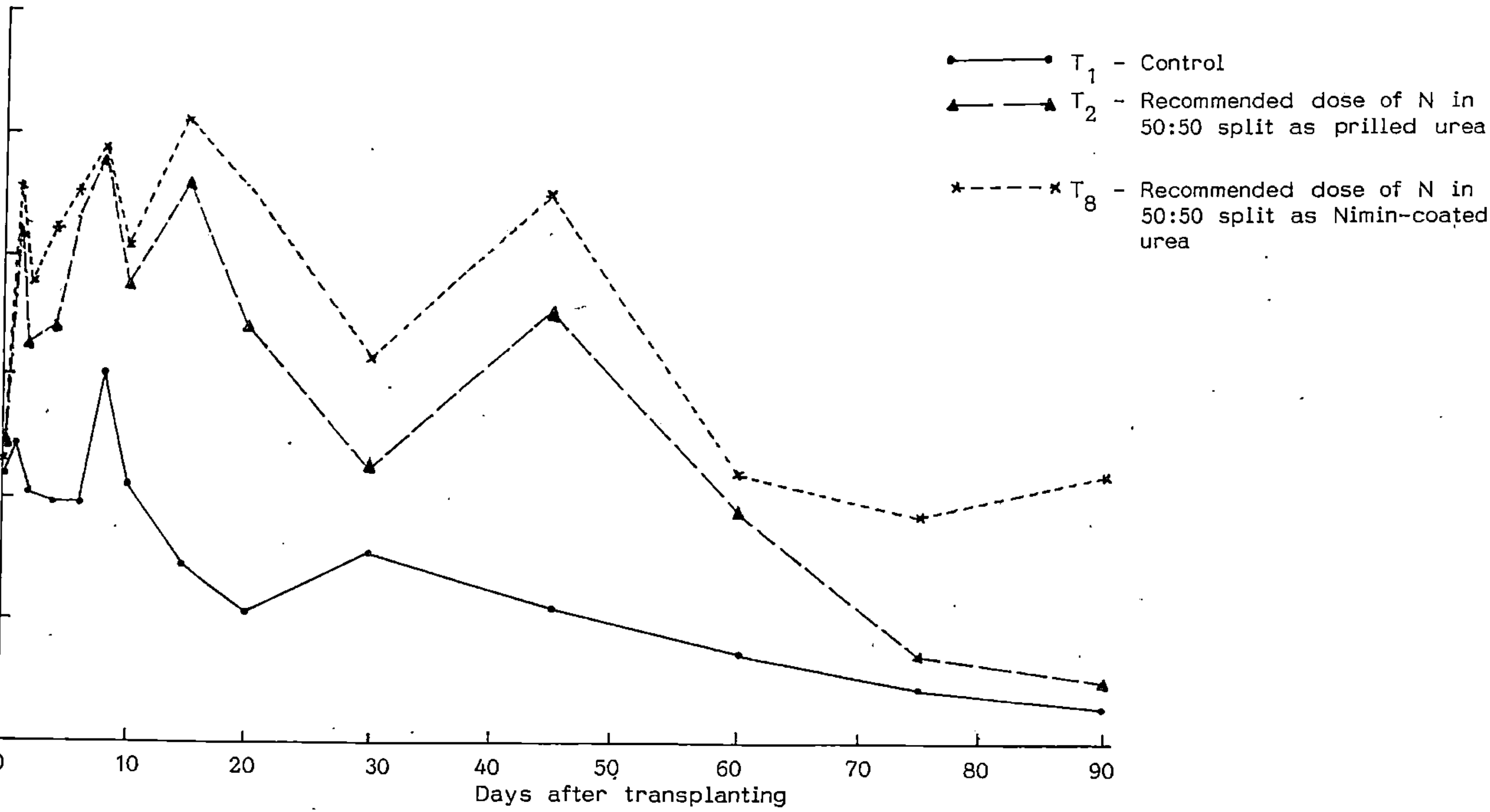


Fig.10. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (second crop)

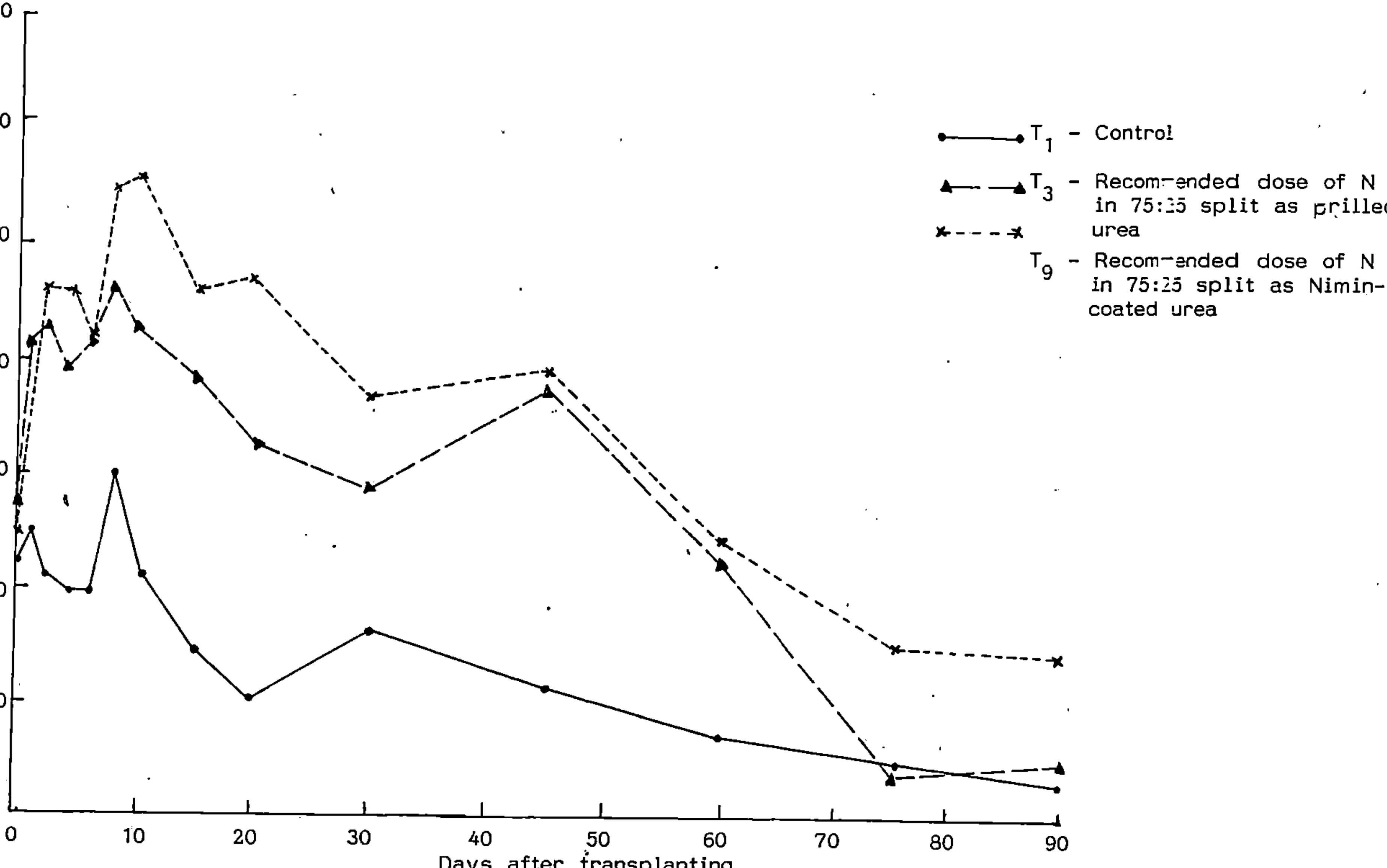


Fig.11. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (second crop)

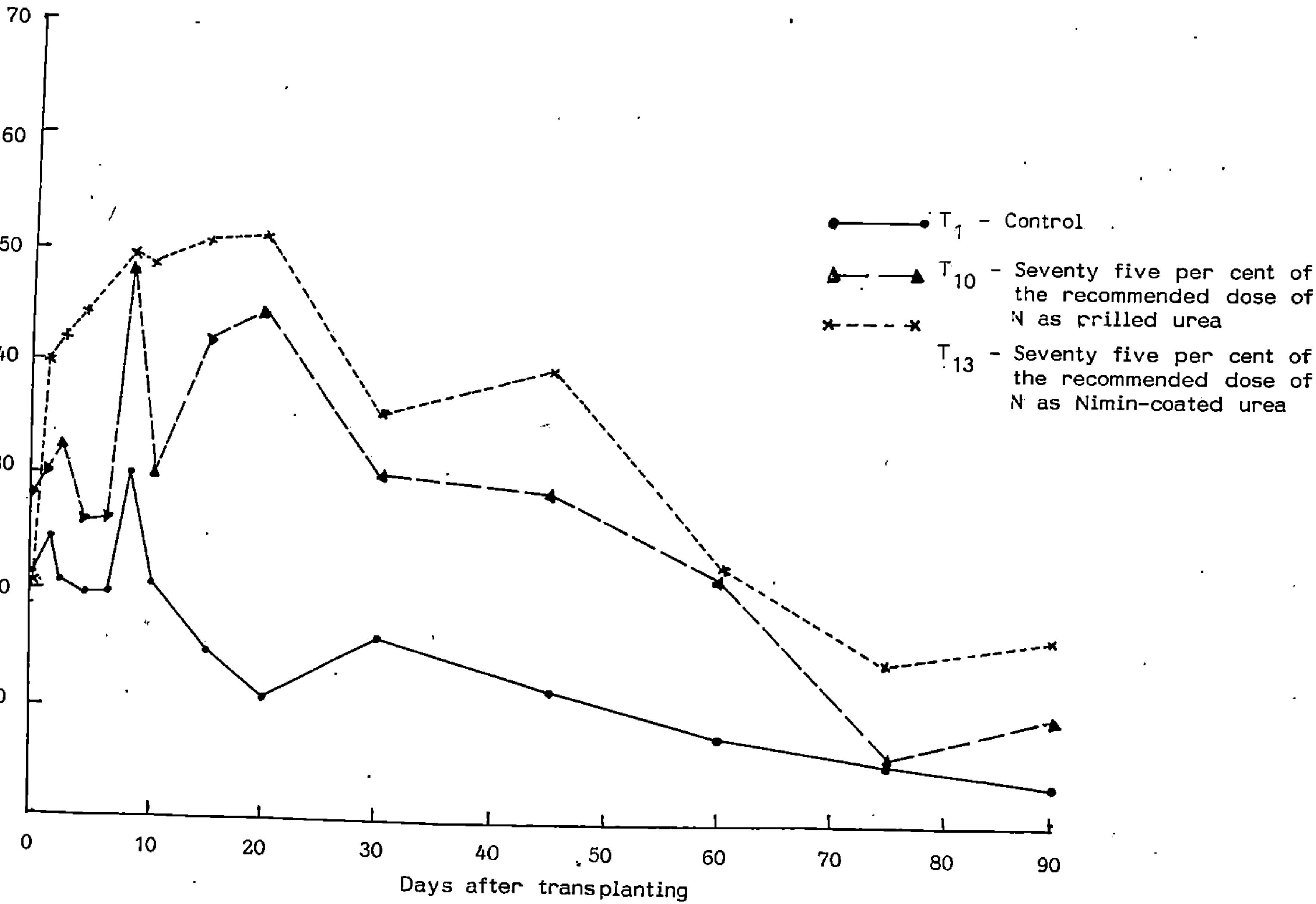


Fig. 12. Ammoniacal nitrogen in soil as influenced by the treatments at different period of crop growth (second crop)

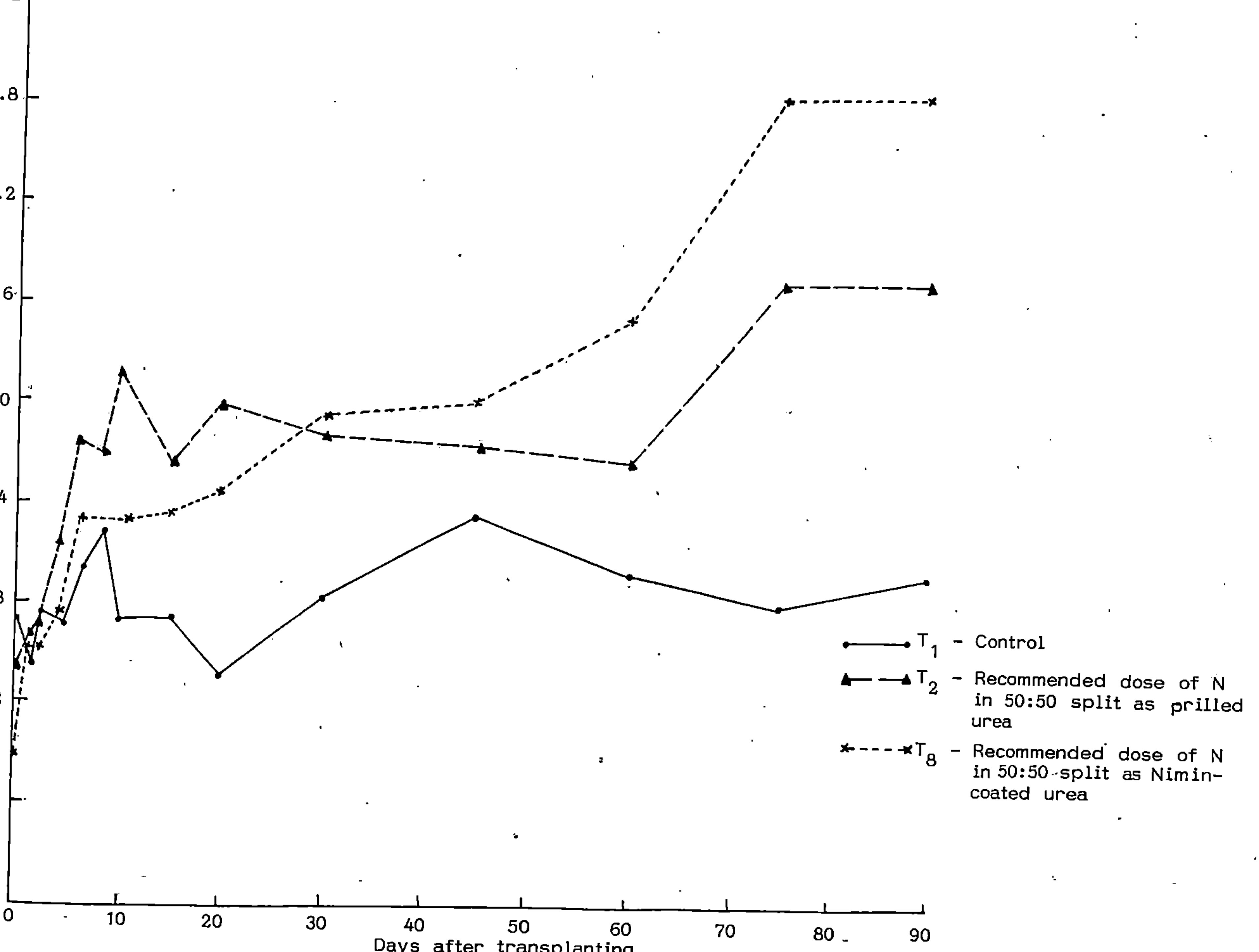
2.2.2 Nitrate nitrogen content of soil

Influence of various treatments on the NO_3-N content of soil is presented in Table 27 and Fig.13, 14 and 15.

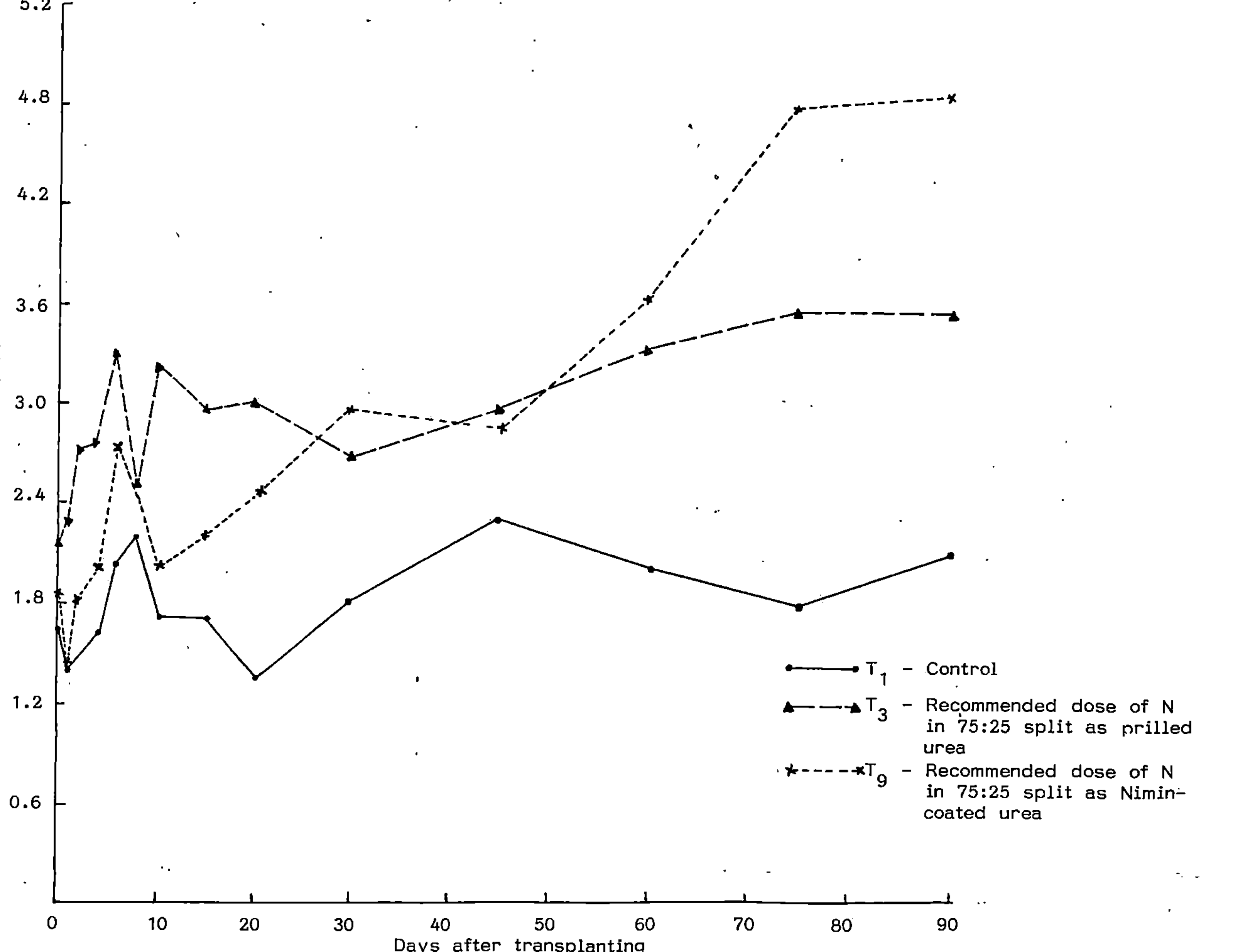
Significant variation due to treatments was noticed only in the later stages of crop growth. The value obtained for NO_3-N content varied from 1.01 to 4.80 ppm. The NO_3-N content of all the treatments showed a trend to increase towards the end of the season and that may be due to the better oxidised condition of the soil at the later periods. The lowest NO_3-N content at almost all the intervals up to 20th day was recorded by Nimin-coated urea and it increased and recorded the highest value at most of the later intervals. Same trend was noticed both for full and 75 per cent of the recommended dose of N. No such trend was noticed with neemcake-mixed or neemcake-coated urea application and the variation between these treatments did not show a uniform trend at different intervals. The lower amount of NO_3-N formed in the initial period for the Nimin treated plots may be due to the inhibition of nitrification. This results in the accumulation of higher amounts of NH_4-N in soil and as the effectiveness of the nitrification inhibitor decreased with time, the NO_3-N content of the soil increased. Not much variation was noticed in the NO_3-N content of soil due to application of N at different levels. Almost similar results were obtained during the first crop season also.

Table 27. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (second crop), ppm

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	1.63	1.43	1.76	1.63	2.02	2.25	2.72	1.72	1.37	1.83	2.33	2.03	1.81	2.09
T_2	1.45	1.72	2.01	2.17	2.80	2.73	3.19	2.63	3.01	2.84	2.77	2.67	3.74	3.74
T_3	2.17	2.30	2.74	2.79	3.34	2.52	3.28	2.99	3.07	2.71	3.00	3.39	3.57	3.57
T_4	2.20	1.64	2.00	2.36	3.19	3.25	2.37	2.26	2.34	3.00	3.08	4.13	4.72	3.43
T_5	1.92	1.98	2.87	3.34	2.86	2.34	2.02	2.14	2.60	3.30	3.67	3.43	3.67	4.61
T_6	1.10	1.86	1.75	2.58	3.93	2.68	2.56	2.48	2.44	2.40	2.83	3.30	4.34	4.13
T_7	1.42	1.76	3.39	2.85	3.49	2.77	2.83	2.89	2.92	3.27	3.63	2.56	3.80	2.85
T_8	1.01	1.53	1.52	1.73	2.30	1.86	2.28	2.33	2.46	2.83	3.00	3.52	4.82	4.84
T_9	1.88	1.49	1.82	2.00	2.77	2.47	2.06	2.20	2.45	2.99	2.88	3.67	4.80	4.85
T_{10}	1.75	2.02	2.52	2.73	2.21	2.47	2.30	2.47	2.90	2.24	2.45	2.57	2.91	2.73
T_{11}	1.92	2.28	1.95	2.25	2.44	2.20	2.15	2.12	2.48	2.27	2.38	3.10	2.97	2.93
T_{12}	1.95	2.43	2.49	1.47	2.19	2.47	2.17	2.10	2.24	2.84	3.21	3.22	3.55	4.00
T_{13}	1.50	1.88	1.57	1.24	1.84	1.89	2.01	2.12	2.10	2.88	3.60	3.20	3.64	4.00
CD (0.05)	NS	NS	NS	NS	NS	0.185	NS	0.141	NS	NS	NS	0.292	0.344	0.32



.8
.2
6
0
4
0
10
20
30
40
50
60
70
80
90
Days after transplanting
T1 - Control
T2 - Recommended dose of N in 50:50 split as prilled urea
T8 - Recommended dose of N in 50:50 split as Nimin-coated urea



5.2
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0
10
20
30
40
50
60
70
80
90
Days after transplanting
T1 - Control
T3 - Recommended dose of N in 75:25 split as prilled urea
T9 - Recommended dose of N in 75:25 split as Nimin-coated urea

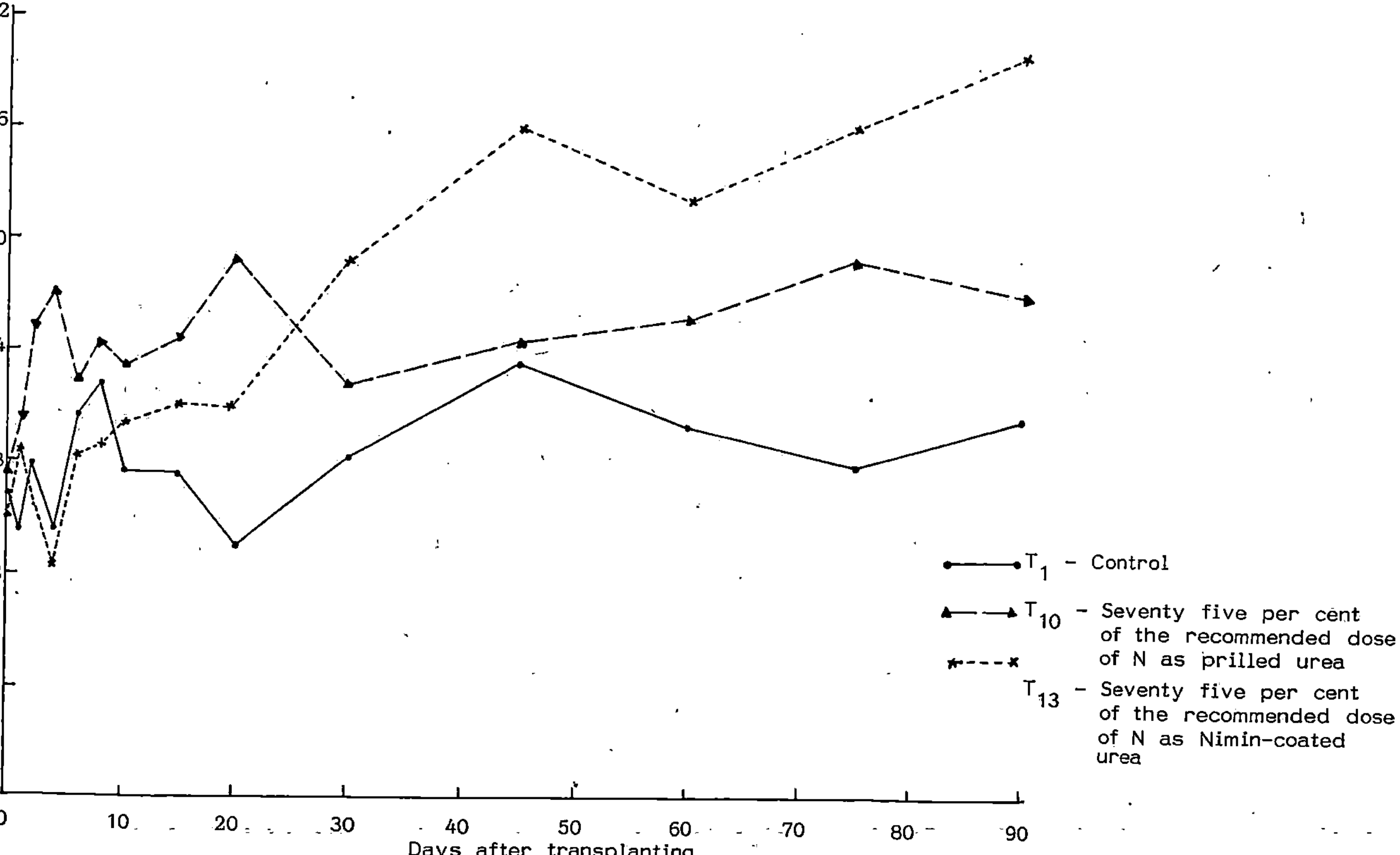


Fig.15. Nitrate nitrogen in soil as influenced by the treatments at different period of crop growth (second crop)

2.2.3 Total N content of soil

Influence of different treatments on the total N content of the soil is given in Table 28.

Though significant difference due to treatments was noticed at most of the intervals, no regular trend was noticed as in the case of incubation study and first crop.

2.2.4 Soil reaction

Result on the effect of different treatments on the soil reaction are given in Table 29.

The values of the pH was increased to near neutral at 10th day after transplanting. The increase in pH is due to the effect of flooding. The pH was stabilised to neutrality up to 75th day and the decreased thereafter. This decrease in pH may be due to the draining of water prior to harvest. Similar trend was noticed in the first crop season also and the reason for this has been discussed earlier.

2.2.5 Biometric observation

Results on the effect of various treatments on height of plant, number of tillers per m^2, dry matter yield of crop at maximum tillering, panicle initiation, 50 per cent flowering and at harvest are presented in Tables 30, 31 and 32.

Table 28. Total nitrogen in soil as influenced by the treatments at different period of crop growth (second crop), per cent

Treatment	Days after planting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.08	0.08	0.08	0.09	0.09
T_2	0.12	0.11	0.13	0.13	0.11	0.11	0.11	0.11	0.11	0.13	0.10	0.09	0.11	0.09
T_3	0.12	0.11	0.10	0.14	0.13	0.09	0.10	0.12	0.11	0.11	0.10	0.10	0.10	0.10
T_4	0.11	0.11	0.10	0.08	0.11	0.13	0.12	0.10	0.08	0.11	0.11	0.11	0.14	0.10
T_5	0.12	0.13	0.09	0.08	0.11	0.11	0.11	0.13	0.11	0.08	0.10	0.12	0.09	0.13
T_6	0.12	0.13	0.11	0.14	0.13	0.13	0.11	0.11	0.12	0.11	0.11	0.12	0.11	0.13
T_7	0.12	0.16	0.10	0.13	0.14	0.10	0.11	0.12	0.08	0.09	0.10	0.12	0.11	0.12
T_8	0.13	0.13	0.14	0.14	0.10	0.10	0.11	0.12	0.13	0.13	0.11	0.13	0.15	0.11
T_9	0.14	0.11	0.11	0.14	0.10	0.09	0.10	0.11	0.13	0.13	0.12	0.11	0.12	0.11
T_{10}	0.11	0.13	0.10	0.08	0.11	0.11	0.10	0.12	0.09	0.09	0.10	0.10	0.09	0.10
T_{11}	0.12	0.10	0.11	0.11	0.11	0.11	0.10	0.12	0.11	0.10	0.11	0.11	0.09	0.11
T_{12}	0.11	0.10	0.11	0.11	0.11	0.13	0.11	0.13	0.12	0.09	0.10	0.11	0.13	0.10
T_{13}	0.13	0.09	0.10	0.13	0.11	0.12	0.11	0.12	0.11	0.11	0.11	0.12	0.12	0.11
(0.05)	0.016	NS	0.022	0.036	NS	NS	NS	0.016	0.022	NS	0.022	0.019	0.029	0.022

Table 29. pH of the soil as influenced by the treatments at different period of crop growth (second crop)

Treatment	Days after transplanting													
	0	1	2	4	6	8	10	15	20	30	45	60	75	90
T_1	6.15	6.10	6.20	6.40	6.45	6.50	6.85	6.85	6.75	6.90	6.85	6.70	6.45	6.00
T_2	6.37	6.30	6.45	6.56	6.65	6.66	6.80	6.90	6.95	6.90	6.95	6.85	6.50	6.20
T_3	6.20	6.25	6.35	6.45	6.56	6.55	6.57	6.95	6.85	6.85	6.90	6.90	6.45	6.25
T_4	6.35	6.40	6.40	6.66	6.60	6.45	6.60	7.00	7.00	7.01	6.95	6.80	6.40	6.25
T_5	6.26	6.50	6.66	6.35	6.86	6.56	6.70	7.05	7.05	6.95	7.01	6.85	6.60	6.05
T_6	6.15	6.47	6.50	6.45	6.55	6.55	7.01	7.00	6.85	7.00	7.00	6.90	6.35	6.00
T_7	6.45	6.45	6.55	6.45	6.67	6.48	6.50	6.95	6.85	7.00	6.90	6.75	6.35	6.11
T_8	6.40	6.44	6.56	6.56	6.66	6.60	6.70	7.11	7.05	7.00	6.90	6.95	6.55	6.35
T_9	6.55	6.25	6.38	6.37	6.35	6.45	6.55	7.00	7.12	7.11	7.01	7.00	6.40	6.40
T_{10}	6.44	6.30	6.45	6.48	6.45	6.50	6.60	6.95	7.01	6.95	7.00	6.78	6.25	6.15
T_{11}	6.25	6.25	6.38	6.45	6.60	6.70	6.75	7.05	6.95	7.00	7.11	6.85	6.15	6.25
T_{12}	6.35	6.40	6.45	6.56	6.65	6.65	6.60	6.85	7.00	6.95	6.85	6.95	6.35	6.15
T_{13}	6.40	6.45	6.50	6.66	6.70	6.75	6.80	6.95	7.00	7.05	7.00	6.85	6.40	6.20

2.2.5.1 Plant height

The mean plant height varied significantly at all the growth stages except at maximum tillering, but no uniform trend was noticed. Results recorded during the first crop season also showed similar trend.

2.2.5.2 Number of tillers

Data on tiller count indicated that there was no significant difference in the number of tillers at any of the growth stages studied. Number of tillers per m^2 varied between 253 to 391 at maximum tillering phase, 271 to 367 at panicle initiation, 247 to 389 at flowering and 238 to 398 at harvest stage.

Different treatments did not exert any influence on the morphological characters of plant as in the first crop season. Lack of response to the applied N may be due to the higher available N content of soil.

2.2.5.3 Dry matter production

Significant difference due to treatments was noticed only in the initial stage of crop growth, maximum tillering and panicle initiation stages. During the first crop season also there was no variation to the extent of statistical significance and the reasons for which have been discussed earlier.

Table 30. Height of plant as influenced by the treatments at different stages of crop growth (second crop), cm

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Harvest
T_1	50.9	53.9	63.9	68.7
T_2	59.7	61.2	64.5	74.5
T_3	60.1	67.2	78.0	77.0
T_4	58.9	60.8	77.7	80.7
T_5	58.3	66.1	80.1	82.3
T_6	59.5	60.1	76.4	77.7
T_7	60.1	62.1	76.8	79.3
T_8	59.7	59.9	79.1	78.7
T_9	63.0	66.4	81.6	82.0
T_{10}	53.1	59.9	79.8	78.0
T_{11}	56.8	59.9	73.8	76.0
T_{12}	54.9	59.9	71.6	73.3
T_{13}	55.7	56.3	74.7	75.3
CD (0.05)	NS	5.69	9.53	7.17

Table 31. Number of tillers per m^2 as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Harvest
T_1	324	271	247	238
T_2	376	367	389	320
T_3	253	320	309	357
T_4	331	336	384	398
T_5	391	329	322	337
T_6	333	320	333	373
T_7	282	282	293	309
T_8	347	327	282	395
T_9	349	354	336	389
T_{10}	253	295	283	332
T_{11}	287	304	338	342
T_{12}	267	271	340	371
T_{13}	284	282	338	358

The control plot has recorded the lowest value at all the growth stages. At maximum tillering stage all the treatments with N application have recorded significantly higher values compared to the control. At panicle initiation stage, all the treatments except prilled urea in which N was applied in 75:25 split (T_3) recorded significantly higher values compared to the control. Compared to prilled urea, neemcake-mixed urea and neemcake-coated urea have recorded higher grain yield for both types of split application of N at the recommended dose, while application of Nimin-coated urea alone has recorded higher values compared to prilled urea at 75 per cent of recommended dose of N.

Nimin-coated urea recorded the highest value of 3016.7 kg ha^{-1} grain yield among the treatments which have received full dose of N in 75:25 split. Maximum value of 2663 kg ha^{-1} was obtained by Nimin-coated urea among treatments which were received 75 per cent of recommended dose of N. When full dose of N was applied in two equal splits, the highest value was recorded by neemcake-mixed urea (2860.7 kg ha^{-1}) and it was closely followed by Nimin-coated urea (2811 kg ha^{-1}). The results thus indicated that Nimin-coated urea is more efficient in increasing the yield compared to prilled urea, neemcake-coated urea and neemcake-mixed urea. The control has recorded the lowest value. During this season also the difference in grain

Table 32. Dry matter production and yield of grain and straw as influenced by the treatments (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	1301.7	2284.3	5276.3	1997.3	1622.0	3619.3
T_2	2431.0	4752.0	6508.3	2433.0	2587.0	5020.0
T_3	2728.0	3333.0	5720.0	2177.3	2200.0	4377.3
T_4	2530.0	3857.3	6838.3	2326.3	2359.7	4686.0
T_5	3465.0	4821.7	6270.0	2793.0	3117.7	5910.7
T_6	2845.3	4601.7	6930.0	2860.7	2562.7	5423.4
T_7	3538.3	5023.3	7333.3	3008.3	2995.7	6004.0
T_8	2786.7	4110.3	7956.7	2811.0	2607.7	5418.7
T_9	3666.7	4400.0	7351.7	3016.7	2583.7	5600.4
T_{10}	3142.3	3831.7	6622.0	2652.6	2349.0	5001.6
T_{11}	2878.3	4216.7	6105.0	2351.0	2150.3	4501.3
T_{12}	3120.3	4587.0	6380.0	2581.3	2460.7	5042.0
T_{13}	2511.7	3982.0	7058.3	2663.0	2111.7	4774.7
CD (0.05)	962.84	1376.1	NS	NS	NS	NS

yield between the treatments which have received full and 75 per cent of the recommended dose of N was not significant.

The treatment differences in straw yield was not large enough to cause statistical significance. Application of different levels and forms of urea have not shown any uniform trend in the straw yield. Here also control recorded the lowest value. Similar results have been obtained during the first crop season also.

2.2.6 Content and uptake of nutrients

2.2.6.1 Nitrogen content and uptake

Influence of various treatments on the content and uptake of N at different growth stages of the crop are presented in Tables 33 and 34.

The results revealed that N per cent in plant was increased by N application at all stages of growth.

The treatments showed significant influence in the N content in plants at all stages of crop growth and in grain and straw but no regular trend was noticed due to treatments at different stages of growth, namely at maximum tillering and panicle initiation and 50 per cent flowering. Nimin-coated urea recorded the highest N content of grain when recommended dose of N applied in two equal splits and when 75 per cent of the

Table 33. Nitrogen per cent in plant as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	1.06	0.93	0.72	0.57	0.46
T_2	1.33	1.25	1.01	0.81	0.60
T_3	1.55	1.43	0.99	0.81	0.68
T_4	1.22	1.43	1.05	0.68	0.76
T_5	1.30	1.43	1.17	1.00	0.68
T_6	1.27	1.31	1.14	0.68	0.71
T_7	1.30	1.11	0.93	0.87	0.90
T_8	1.27	1.49	1.05	0.87	0.81
T_9	1.33	1.28	1.08	0.85	0.95
T_{10}	1.16	1.22	0.93	0.85	0.49
T_{11}	1.27	1.28	1.05	0.81	0.60
T_{12}	1.27	1.31	0.93	0.85	0.52
T_{13}	1.30	1.31	0.99	0.95	0.71
CD (0.05)	0.107	0.107	0.119	0.092	0.107

Table 34. Uptake of nitrogen by plant as influenced by the treatments at different stages of crop growth (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	13.85	21.10	37.82	11.33	7.36	18.69
T_2	32.33	59.39	72.05	19.82	15.39	35.21
T_3	41.64	47.62	56.55	18.66	14.83	33.99
T_4	28.74	55.30	71.75	15.60	17.89	33.49
T_5	45.11	69.53	72.70	28.16	19.22	47.34
T_6	36.08	60.27	78.62	17.49	18.00	35.49
T_7	46.49	55.18	58.47	26.16	26.25	53.11
T_8	35.21	61.26	82.63	24.47	21.34	45.81
T_9	48.73	56.31	79.05	25.39	24.59	49.90
T_{10}	36.80	46.88	61.36	23.80	11.46	35.26
T_{11}	36.49	54.21	64.00	19.12	13.02	32.14
T_{12}	39.95	59.68	59.12	21.59	12.68	34.27
T_{13}	32.03	51.86	70.39	25.14	14.75	39.88
CD (0.05)	13.412	17.042	NS	7.044	6.230	6.637

recommended dose of N was applied. When the recommended dose of N was applied in 75:25 split, neemcake-coated urea recorded the highest value. Neemcake-coated urea and neemcake-mixed urea have not showed a uniform trend compared to prilled urea at different levels and type of split application of N. During the first crop season also application of Nimin-coated urea showed a favourable influence in increasing the N content of grain. In the case of straw also, Nimin-coated urea recorded the highest value at both the levels of N application.

Uptake of N as influenced by the different treatments varied significantly at all intervals except at 50 per cent flowering. But no specific trend was obtained due to treatments at different growth stages. Control recorded the lowest uptake of N at all the growth stages. Though the difference between the Nimin-coated urea and prilled urea was not significant, Nimin-coated urea has recorded the maximum uptake when the recommended dose of N was applied in two equal splits (T_8) and with 75 per cent of N application (T_{13}). Neemcake-mixed urea has recorded the highest uptake in the split 75:25 of the recommended dose of N. Uptake of N by grain followed allmost the same trend as that of the N content of plants.

In the case of straw also almost the similar trend was noticed. The difference between Nimin-coated urea and prilled urea was significant in both types of split application with recommended dose of N. Nimin-coated urea has recorded comparatively high dry matter yield and N content and this resulted in increased uptake. During the first crop season also almost the same trend was noticed. In general, nitrogen applied through Nimin-coated urea enhanced the N uptake over uncoated urea. Greater availability of N throughout the crop growth and lower loss of N might have enhanced the N uptake.

2.6.2 Phosphorus content and uptake

Data on the influence of various treatments in the content and uptake of P are given in Tables 35 and 36.

Significant difference was noticed in the P content at all stages of crop growth, but no specific trend due to treatments was observed. This indicates that the different levels and forms of N has not influenced the P content in plants significantly. Similar trend was obtained during the previous crop also.

There was significant difference in the P uptake also at maximum tillering, panicle initiation stage and in grain and straw. As in the case of P content no uniform pattern of uptake was noticed due to different levels and forms of N. The highest total P uptake, 9.75 kg ha^{-1} was recorded by T_7 closely followed

Table 35. Phosphorus per cent in plant as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.16	0.22	0.20	0.18	0.14
T_2	0.17	0.23	0.21	0.18	0.15
T_3	0.21	0.24	0.22	0.18	0.13
T_4	0.17	0.26	0.21	0.16	0.13
T_5	0.17	0.23	0.21	0.17	0.14
T_6	0.19	0.23	0.19	0.21	0.16
T_7	0.17	0.26	0.20	0.19	0.14
T_8	0.20	0.26	0.21	0.16	0.16
T_9	0.21	0.26	0.20	0.14	0.13
T_{10}	0.20	0.24	0.20	0.18	0.13
T_{11}	0.19	0.24	0.20	0.17	0.12
T_{12}	0.21	0.24	0.22	0.20	0.12
T_{13}	0.23	0.26	0.21	0.19	0.18
CD (0.05)	0.110	0.015	0.011	0.007	0.003

Table 36. Uptake of phosphorus by plant as influenced by the treatments at different stages of crop growth (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	2.06	5.00	10.72	3.63	2.17	5.80
T_2	4.18	10.72	15.69	4.25	3.75	8.00
T_3	6.45	8.13	12.40	4.04	2.76	6.80
T_4	4.30	10.03	14.41	3.98	3.07	7.65
T_5	6.00	11.29	13.03	4.78	3.77	8.55
T_6	5.38	10.57	13.14	5.74	4.00	9.74
T_7	6.04	13.13	14.51	5.73	4.02	9.75
T_8	5.61	10.69	16.60	4.37	4.12	8.49
T_9	7.71	11.14	14.56	4.22	3.33	7.55
T_{10}	6.25	9.16	13.24	5.20	2.96	8.16
T_{11}	5.43	10.28	11.88	3.88	2.50	6.38
T_{12}	6.55	11.05	13.67	5.11	2.94	8.05
T_{13}	5.69	10.27	14.03	5.01	3.82	8.83
CD (0.05)	1.946	3.460	NS	1.327	1.132	1.229

by T_6 (9.74 kg ha^{-1}). The lowest uptake recorded by control mainly due to its low dry matter yield. The results obtained during the first crop season also followed similar pattern as in this crop season.

2.6.3 Potassium content and uptake

Data on the influence of various treatments on the content and uptake of K at different growth stages of the crop are given in Tables 37 and 38.

Significant variation was noticed in the K content at maximum tillering, panicle initiation and 50 per cent flowering, but no regular trend was noticed due to treatments and this may be due to the application of uniform dose of K for the crop.

In the case of uptake of K, significant difference was noticed at maximum tillering and in grain and straw at harvest. As in the case of N and P, the lowest value was recorded by the control at all stages. It is because of the lowest dry matter yield for control at these stages and uptake is the product of dry matter and content. It was noted that although N application increased K uptake, different forms and levels of N did not exert any specific influence on uptake of K by grain and straw. Similar trend was noticed in the first crop season also.

Table 37. Potassium per cent in plant as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	1.43	1.85	1.36	0.28	2.35
T_2	1.68	1.72	1.50	0.50	2.60
T_3	2.28	1.85	1.17	0.37	2.12
T_4	1.58	1.75	1.05	0.30	1.95
T_5	1.57	1.76	1.45	0.35	2.17
T_6	1.97	1.70	1.22	0.32	1.70
T_7	1.58	1.70	1.42	0.27	1.90
T_8	1.80	1.88	1.60	0.32	2.28
T_9	1.80	1.82	1.25	0.29	2.20
T_{10}	2.00	1.68	1.40	0.28	2.05
T_{11}	1.92	1.65	1.48	0.23	1.90
T_{12}	1.87	1.72	1.20	0.28	1.88
T_{13}	1.85	1.95	1.38	0.33	1.95
CD (0.05)	0.174	0.123	0.11	0.120	0.150

Table 38. Uptake of potassium by plant as influenced by the treatments at different stages of crop growth (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	18.70	42.21	71.96	5.63	37.99	43.62
T_2	40.91	81.43	97.97	12.20	66.91	79.11
T_3	61.91	61.47	66.82	7.99	46.50	54.49
T_4	40.01	67.56	71.22	6.78	45.95	57.73
T_5	54.30	84.57	90.56	9.97	61.03	71.01
T_6	55.91	78.18	84.06	9.04	43.45	52.49
T_7	55.72	85.32	104.22	7.99	57.01	65.00
T_8	50.00	77.53	127.99	8.98	59.51	68.50
T_9	65.98	79.93	92.39	7.56	56.87	64.44
T_{10}	63.49	64.63	91.98	8.02	48.18	56.80
T_{11}	55.07	70.00	90.66	5.41	41.03	46.43
T_{12}	57.78	78.27	76.86	7.28	46.67	53.95
T_{13}	46.42	77.90	98.64	8.87	41.91	50.78
CD (0.05)	19.026	NS	NS	2.880	17.200	10.040

2.6.4 Calcium content and uptake

Influence of various treatments on the content and uptake of Ca is presented in Tables 39 and 40.

It was noted that the application of N increased the Ca content in plants as indicated by the higher levels of Ca in plants received N application over control at all stages of growth. Significant difference was obtained due to different treatments at all stages but no uniform trend due to application of different forms and levels of N was noticed.

Uptake of Ca by straw showed significant difference at maximum tillering, panicle initiation and harvest. All the treatments with N have recorded higher values of total uptake by grain and straw compared to control. During the first crop season also almost similar results were obtained.

2.6.5 Magnesium content and uptake

Data on the influence of different treatments on the content and uptake of Mg by plants at different growth stages is presented in Tables 41 and 42.

Data on Mg per cent in plants show that eventhough significant differences were obtained between treatments at all intervals, the values were found to be inconsistent.

Table 39. Calcium per cent in plant as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.26	0.33	0.38	0.16	0.43
T_2	0.37	0.43	0.55	0.19	0.61
T_3	0.48	0.45	0.50	0.16	0.55
T_4	0.41	0.45	0.46	0.21	0.61
T_5	0.27	0.43	0.46	0.13	0.58
T_6	0.37	0.41	0.43	0.22	0.67
T_7	0.36	0.43	0.44	0.18	0.57
T_8	0.49	0.14	0.49	0.20	0.56
T_9	0.44	0.41	0.45	0.15	0.66
T_{10}	0.46	0.36	0.39	0.18	0.57
T_{11}	0.46	0.43	0.42	0.15	0.57
T_{12}	0.46	0.46	0.43	0.16	0.57
T_{13}	0.50	0.42	0.43	0.26	0.72
CD (0.05)	0.055	0.055	0.055	0.055	0.055

Table 40. Uptake of calcium by plant as influenced by the treatments at different stages of crop growth (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	3.40	7.58	20.00	5.02	6.89	11.90
T_2	9.04	20.67	35.64	4.60	15.71	20.30
T_3	13.24	14.93	28.69	3.43	12.07	15.50
T_4	10.36	17.33	31.14	4.62	14.43	19.05
T_5	9.41	20.93	33.42	3.64	16.25	19.89
T_6	10.51	19.00	29.91	6.20	17.19	23.38
T_7	12.80	21.13	32.78	5.37	17.03	22.40
T_8	13.60	18.13	38.61	5.65	14.53	20.17
T_9	16.13	18.00	33.25	4.45	16.96	21.41
T_{10}	14.73	13.93	25.63	5.04	13.45	18.50
T_{11}	13.06	18.30	25.47	3.49	12.19	15.68
T_{12}	14.50	21.47	27.15	4.02	14.19	18.21
T_{13}	12.47	16.63	30.83	6.89	15.28	22.18
CD (0.05)	4.670	7.264	NS	NS	5.25	6.25

Table 41. Magnesium per cent in plant as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw
T_1	0.05	0.05	0.03	0.07	0.07
T_2	0.05	0.03	0.05	0.05	0.06
T_3	0.07	0.07	0.03	0.06	0.08
T_4	0.02	0.05	0.05	0.06	0.05
T_5	0.08	0.06	0.06	0.05	0.06
T_6	0.08	0.04	0.04	0.04	0.06
T_7	0.09	0.07	0.04	0.05	0.08
T_8	0.04	0.07	0.04	0.05	0.08
T_9	0.06	0.07	0.06	0.03	0.06
T_{10}	0.03	0.05	0.05	0.03	0.03
T_{11}	0.04	0.07	0.08	0.05	0.06
T_{12}	0.04	0.05	0.06	0.07	0.07
T_{13}	0.04	0.08	0.04	0.05	0.03
CD (0.05)	0.028	0.025	0.025	0.020	0.025

Table 42. Uptake of magnesium by plant as influenced by the treatments at different stages of crop growth (second crop), kg ha^{-1}

Treatment	Maximum tillering	Panicle initiation	50 per cent flowering	Grain	Straw	Total
T_1	0.62	1.07	1.69	1.49	1.19	2.68
T_2	1.36	1.57	3.30	1.08	1.65	2.74
T_3	2.04	1.98	1.87	1.21	1.83	3.05
T_4	0.58	1.80	3.45	1.32	1.20	2.51
T_5	2.90	2.75	3.58	1.26	1.53	2.79
T_6	2.21	1.77	2.59	1.20	1.43	2.63
T_7	3.07	3.29	2.71	1.65	2.34	3.99
T_8	1.11	3.01	2.95	1.42	1.94	3.36
T_9	2.21	3.24	4.06	0.98	1.43	2.41
T_{10}	1.53	1.95	3.16	0.92	0.76	1.68
T_{11}	1.13	2.91	4.80	1.16	1.30	2.46
T_{12}	1.23	2.58	3.64	1.92	1.49	3.41
T_{13}	0.92	3.22	2.55	1.34	0.71	2.05
CD (0.05)	0.904	1.440	NS	0.440	0.794	0.617

Magnesium uptake also followed a similar trend as that of Mg content. The results indicated that application of different forms and levels of urea did not influence the contents and uptake of Mg by plants. Similar results were obtained during the first crop season also.

Summary

SUMMARY

A study was conducted to evaluate the different methods to improve the N use efficiency of urea in rice which consisted of an incubation study and a field experiment during the first and second crop seasons of 1991. The results revealed that:

1. Significant difference in the NH_4-N content was obtained at most of the intervals of incubation study. In the initial period definite trend was not noticed due to treatments, but Nimin-coated urea recorded higher values from 15th day onwards.

2. The proportion of NO_3-N formed compared to total N was quite low. Nimin-coated urea recorded lower concentration of NO_3-N in the initial period of incubation and higher values were obtained for treatment with prilled urea.

3. Ammoniacal nitrogen content of soil solution was gradually decreased with period of incubation and reached minimum value by the end of the period of incubation. Control recorded lowest value throughout the period and there was not much variation between the other treatments.

4. Nitrate nitrogen content of the soil solution in the incubation study was found to be higher than that of the soil. Among the four treatments with N application, the lowest value was recorded by Nimin-coated urea at most of the intervals.

5. Definite trend due to treatments was not noticed in the total N content of soil at different periods of incubation.

6. Significant difference was not noticed in the pH of the soil and soil solution in the incubation study.

7. In the case of field experiment, Nimin-coated urea recorded highest value of NH_4-N at most of the intervals for both full and 75 per cent of the recommended dose of N during the first crop season. During the second crop season variation due to treatments was not significant in the initial period. Nimin-coated urea recorded higher NH_4-N than prilled urea at most of the intervals from 15th day after transplanting for both full and 75 per cent of the recommended dose of N.

8. As in the case of incubation study, NO_3-N formed was quite low in the field experiment during both the seasons. Nimin-coated urea recorded the lowest value of NO_3-N especially in the initial period for both full and 75 per cent of the recommended dose of N. The concentration of NO_3-N in the plots received Nimin-coated urea increased towards the end of the period of study during both the seasons.

9. The difference due to treatments was not high enough to attain the level of statistical significance for the biometric characters such as plant height, number of tillers and dry matter production during different growth stages and yield of grain and straw at harvest in the first and second crops.

10. Nitrogen per cent in plant was increased by N application. But regular trend in the content and uptake of N was not noticed due to different treatments at different stages of growth in both the first and second crop seasons.

11. The content and uptake of P, K, Ca and Mg were influenced significantly due to treatments in the first and second crops. But the values were inconsistant and no uniform trend was obtained.

Nimin was found to increase the efficiency of urea by increasing the ammoniacal nitrogen content in soil.

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* Originals not seen

Appendix

Appendix-I

Weather data (weekly average) during the cropping period
(from 1-7-1991 to 28-1-1992)

Standard week No.	Month and date	Total rainfall, mm	No. of rainy days	Temperature		Relative humidity (%)		Sunshine hours
				Maximum °C	Minimum °C	Forenoon	Afternoon	
1	2	3	4	5	6	7	8	9
27	Jul. 1-8	161.4	7	29.3	22.8	93	78	2.8
28	Jul. 9-15	179.4	7	28.4	23.2	94	79	2.1
29	Jul. 16-22	140.9	7	29.5	22.7	94	77	2.4
30	Jul. 23-29	361.6	7	29.3	22.6	92	79	3.2
31	Jul. 30-Aug. 5	160.8	7	29.0	23.3	95	84	1.9
32	Aug. 6-12	65.2	6	29.5	23.1	95	79	2.3
33	Aug. 13-19	313.9	7	27.8	22.0	95	84	1.8
34	Aug. 20-26	53.0	6	29.1	22.3	96	79	3.5
35	Aug. 27-Sept. 2	12.5	3	30.4	23.3	94	66	6.5
36	Sept. 3-9	0.0	0	31.4	23.2	90	59	9.1
37	Sept. 10-16	6.4	2	31.6	24.6	90	65	6.1
38	Sept. 17-23	18.3	4	31.5	22.4	92	59	6.8
39	Sept. 24-30	36.8	5	31.7	24.0	90	70	6.5
40	Octo. 1-7	11.4	3	31.2	23.5	92	77	4.1
41	Octo. 8-14	97.3	4	30.6	23.2	91	75	4.3

Contd.

Appendix-1. Continued

1	2	3	4	5	6	7	8	9
42	Octo. 15-21	57.6	4	32.1	23.0	87	66	6.4
43	Octo. 22-28	40.0	5	30.8	23.1	87	72	3.9
44	Octo. 29-Nov. 4	75.4	3	29.8	23.0	96	76	3.0
45	Nov. 5-11	105.0	6	32.1	22.5	89	62	7.4
46	Nov. 12-18	53.4	3	31.4	22.8	94	69	5.0
47	Nov. 19-25	0.5	1	31.0	24.4	76	58	7.7
48	Nov. 26-Dec. 2	0.0	0	31.9	20.9	79	58	8.6
49	Dec. 3-9	0.0	0	31.3	21.4	78	45	9.7
50	Dec. 10-16	0.0	0	30.9	23.5	69	56	8.0
51	Dec. 17-23	0.0	0	31.9	23.2	75	49	7.9
52	Dec. 24-30	0.0	0	33.2	19.9	91	45	8.6
1	Jan. 1-7	0.0	0	32.4	21.8	80	39	7.0
2	Jan. 8-14	0.0	0	32.1	20.6	66	35	9.3
3	Jan. 15-21	0.0	0	32.4	22.1	72	40	9.4
4	Jan. 22-28	0.0	0	33.2	19.8	60	28	9.7

Plates

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Plate 1. A general view of the field experiment (first crop)

Plate. 2. A general view of the field experiment (second crop)

EVALUATION OF METHODS TO IMPROVE THE NITROGEN USE EFFICIENCY OF UREA IN RICE

By

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree of

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ABSTRACT

An investigation was carried out to evaluate the various methods recommended by different agencies to increase the N use efficiency of urea in rice. The study consisted of an incubation study and a field experiment during two crop seasons, first and second crop seasons in 1991 using rice variety Jyothi.

The incubation study was conducted at College of Horticulture, Vellanikkara, Trichur. There were five treatments for the incubation study which were control and recommended dose of N as prilled urea, neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea. The experiment was laid out in Completely Randomised Design. The 13 treatments for field experiments consisted of control, recommended dose of N in two types of splits (50:50 and 75:25) as prilled urea, neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea and 75 per cent of the recommended dose of N in 50:50 split as prilled urea, neemcake-coated urea, neemcake-mixed urea and Nimin-coated urea.

The field experiment was conducted at Agricultural Research Station, Mannuthy under Kerala Agricultural University. The soil for the incubation study was collected from the location where field experiment was carried out. The soil was sandy clay loam in texture, acidic and non saline.

Ammoniacal nitrogen content of the soil in incubation study, increased upto a period of 20 days in all the treatments. The treatments showed significant difference in the NH_4-N content at most of the later intervals. In the initial period no definite trend due to treatments was observed but from 15th day onwards Nimin-coated urea recorded highest value at all the intervals. Neemcake-coated urea and neemcake-mixed urea have also recorded higher content of NH_4-N than prilled urea but the difference was statistically not significant. At all the intervals control recorded lowest value.

The proportion of NO_3-N formed compared to total nitrogen was quite low. Significant difference in the NO_3-N content of soil due to treatment application was noticed from 8th day of incubation.

Significant difference due to different treatment application was not obtained for total N content of the soil and pH of soil and soil solution at different periods of incubation.

Ammoniacal nitrogen content of the soil solution was high during the initial periods of incubation both for control and treatments, and gradually decreased and reached minimum value by the end of the period of incubation. The control recorded lowest value throughout the period of incubation and there was not much variation between the other treatments.

The NO_3-N content of the soil solution was found to be high than that of the soil. The control recorded lowest value at most of the intervals and among the four treatments with N application, the lowest value was recorded by Nimin-coated urea at most of the intervals.

In the field experiment significant difference was noticed in the NH_4-N content of the soil throughout the period of study in first crop season. At all the intervals control recorded lowest value. Nimin-coated urea recorded highest value at most of the intervals for both full and 75 per cent of the recommended dose of N. Neemcake-coated and neemcake-mixed urea were also found to be better than prilled when full dose of N was applied. But such difference was not noticed when 75 per cent of the recommended dose of N was applied.

In the second crop season, variation due to treatments was not significant in the initial periods. Nimin-coated urea recorded higher NH_4-N content than prilled urea at most of the intervals from 15th day after transplanting both for full and 75 per cent of the recommended dose of N. Neemcake-coated urea and neemcake-mixed urea were also found to have influence in increasing the NH_4-N content at most of the intervals.

Nimin-coated urea recorded lowest NO_3-N concentration at all the intervals in the initial period in the first crop season and in the later stages this treatment recorded comparatively higher values, both for treatments with full and 75 per cent of recommended dose of N. As in the case of incubation study proportion of NO_3-N formed was quite low. Similar trend was obtained during second crop season also.

No uniform trend was obtained in the total N content of soil at different intervals due to treatments in both the seasons. Significant difference in soil pH was also not noticed.

The difference due to treatment application was not high enough to attain the level of statistical significance for the major biometric characters of the plant during both the crop seasons. Though the difference due to treatments was not significant on grain yield, Nimin-coated urea recorded maximum grain yield both for full and 75 per cent of the recommended dose of N during both the crop seasons.

Nitrogen content in plant was increased by N application. Nimin-coated urea showed a favourable influence in increasing the N content of grain during both the crop seasons. In general application of Nimin enhanced the uptake of N by grain and straw during both the seasons.

Significant variation was obtained in the content and uptake of P, K, Ca and Mg at various stages of crop growth during both the seasons. ~~But no uniform trend due to treatments was observed.~~