DYNAMICS OF NUTRIENT RELEASE AND TRANSFORMATIONS FROM SLOW RELEASE FERTILISERS IN ACID RICE SOILS

By

P.T. NISHA

THESIS

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Faculty of Agriculture
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Department of Soil Science and Agricultural Chemistry
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Kerala, India

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Dr.P.K. SUSHAMA
Associate Professor
Dept. of Soil Science &
Agricultural Chemistry
College of Horticulture

Vellanikkara
11 - 8-95

CERTIFICATE

Certified that the thesis entitled **"Dynamics of nutrient release and transformations from slow release fertilisers in acid rice soils"** is a record of research work done independently by **Smt.P.T. Nisha** 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.

P.K.SUSHAMA
Chairperson, Advisory Committee

CERTIFICATE

We, the undersigned members of the advisory committee of **Smt.P.T.Nisha** a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled "**Dynamics of nutrient release and transformations from slow release fertilisers in acid rice soils**" may be submitted by Smt.P.T.Nisha in partial fulfilment of the requirement for the degree.

P.K.Sushama
Associate Professor
Department of Soil Science and
Agricultural Chemistry
College of Horticulture
Vellanikkara
(Chairperson)

A.I.Jose
Professor and Head
Department of Soil Science and
Agricultural Chemistry
College of Horticulture
Vellanikkara
(Member)

N.P.Chinnamma
Professor
Department of Soil Science and
Agricultural Chemistry
College of Horticulture
Vellanikkara
(Member)

P.V.Prabhakaran
Professor and Head
Dept. of Agricultural Statistics
College of Horticulture
Vellanikkara
(Member)

EXTERNAL EXAMINER

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LIST OF ABBREVIATIONS USED IN THE STUDY

SLNF	- Slow release nitrogen fertilizer
C	- Control
NF	- N_0 fertilizer
UF	- Urea formaldehyde
NP tab	- NP tablet
NPK tab	- NPK tablet
GCU	- Gypsum coated urea
UAS	- Blended urea ammonium sulphate
MAP	- Magnesium ammonium phosphate

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Introduction

INTRODUCTION

Effective fertiliser use is the key factor to maximise agricultural production. Nitrogen is the pivotal element in plant nutrition which is considered as universally deficient in soils and it is the costliest one too. The recovery of applied nitrogen by rice plant seldom exceeds 40 per cent (Craswell and Datta, 1980) because of poor cation exchange capacity, heavy rainfall and continuous submergence which are the characteristics edapho climatological factors associated with the acid rice soils of Kerala. Thus, the loss of fertiliser N is one of the major contraints in rice production for which the option of slow release nitrogen fertilisers is a widely accepted remedy.

Slow release nitrogen fertilisers (SLNF) have built-in properties to release their nutrients at a slow pace. The N release from SLNF source usually matches with the N uptake by plant due to the extended span of N availability. This will result in less leaching denitrification and ammonia volatalization and therefore result in efficient utilisation by the crop.

There are many ways to develop SLNF which include the synthesis of chemical compounds with inherently slow rates of dissolution. The amount of surface area exposed determines the rates of dissolution. The rate of release of nutrients from pelletted fertilisers is therefore a function of the amount of exposed surface area and particle size (Prasad *et al.*, 1971). Fertilisers like NP tablet, NPK tablet and magnesium ammonium phosphate express the slow release mechanism on this principle. The slow release of urea formaldehyde on the other hand is determined by its low solubility and resistance to microbial decomposition.

The mechanism where the release of nutrients from the coated fertilisers like gypsum coated urea is achieved through the increased internal pressure due to the entry of water vapour degradation of coatings through microbial and abrasive actions and controlled movement of dissolved salt through the coating. Fertilisers in the blended form such as urea ammonium sulphate also possess slow release effect.

Performance of many of the newly introduced SLNF materials in different acid rice soils of Kerala has not been explored. Also, in many of field situations, recommended practices of split dose application of nitrogen is not possible because of the continuous submergence. Application of SLNF materials can be a better solution under such conditions. Moreover, the use of SLNF sources is considered as a better technique to bring down environmental pollution from high concentration of soluble chemical fertilisers and consequent eutrophication. Detailed understanding of the various mechanisms of N release from the SLNF may help to formulate effective techniques for plugging N losses and therefore, the present study was undertaken with the following objectives.

1. To investigate the pattern of release and transformations of N and other major nutrients from test SLNF like urea formaldehyde NP tablet, NPK tablet, gypsum coated urea, blended urea ammonium sulphate and magnesium ammonium phosphate against the no fertiliser treatment and conventional urea application.
2. To evaluate the efficiency of the above slow release fertilisers, in relation to yield and plant uptake of nutrients by rice.

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Review of Literature

REVIEW OF LITERATURE

Nitrogen losses by nitrification and leaching under waterlogged conditions in which wet land rice is grown will be as high as 60-70 per cent of the applied nitrogen. The efficiency of N uptake by the crop can be increased mainly by reducing N losses from the soil-crop root system and by regulating the nutrient supply by the use of slow release N fertilizers. A brief review of the research work pertaining to all these aspects is presented below.

1 Losses of N from soil

Volatalization of ammoniacal-N, leaching and run off of nitrate-N and denitrification were suspected to be the main processes through which loss of N from soil occurs (Kresge and Satchell, 1960; Reddy and Patrick, 1980; Criag and Wollum, 1982; Ellington, 1986). High losses of N under conditions of alternate wetting and drying had been reported by many workers (Prasad and Rajale, 1972; Reddy and patrick, 1975; Tisdale *et al*. 1985). Loss of N through biological and chemical immobilization was studied by Craswell and Vlek (1979).

1.1 Through ammonia volatalization

Various studies indicated that there was loss through ammonia volatalization even in acid soils though the magnitude was quite small (Blasco and Cornfield, 1966; Duplessis and Kroontje, 1964; Macrae and Ancajas, 1970; Volk, 1959). The nature of N source also influenced ammonia losses (Macrae and Ancajas, 1970; Matocha, 1976; Ventura and Yoshida, 1977). The loss was found to be more with

1.3 Due to leaching and surface run off

Almeida (1965) reported that substantial quantities of N was lost by way of leaching from ammonium sulphate. Moe *et al.* (1967) observed that losses of N occurred when the soil conditions favoured high rates of run off. Pande and Adak (1971) reported that in paddy soils the losses due to leaching could be from 45 to 60 per cent of the basal application but these losses were reduced to 11 to 33 per cent by split application of nitrogen. Drainage studies in heavily manured rice fields revealed that during the monsoon season the extent of N loss from a lowland rice field through leaching was 42 kg N ha^{-1} (Chakravorthy *et al.*, 1973). Studies carried out in Japan estimated an average loss of about 20 kg N ha^{-1} every year through leaching from rice fields (Yatazawa, 1977). Padmaja and Koshy (1978) reported that a maximum run off of 70 per cent N occurred if the surface water was drained on the same day of fertiliser application. Haunold (1986) found that leaching loss was on an average 10 per cent of the fertiliser applied.

1.4 Fixation by soil clay minerals and immobilization

Fertiliser N entering the inorganic N pool was subjected to biological interchange with soil organic fraction (Saito and Watanabe, 1978). Ammonium fixation and immobilization was found to be another channel of N loss (Broadbent, 1979).

2 Improving efficiency of urea

Gould *et al.* (1986) reported that urea efficiency could be increased by the modification of physical form, split application and modification of chemical nature of the fertiliser to reduce its rate of N release.

2.1 Modification of physical form

The N loss could be minimised by increasing granule size of fertilisers (Prasad *et al.*, 1970) and by coating urea with nitrification inhibitors (Reddy and Prasad, 1975). The placement of urea in mud ball and paper packets produced higher yield than basal application of urea (KAU, 1979). The minimum risk of loss and maximum agronomic efficiency of urea super granules for rice was reported by Savant and Livingston (1988). The apparent recovery and N use efficiency were higher for large granule urea than those for prilled urea in low land rice (Sahu and Misra, 1989). Kumar *et al.* (1990) reported urea super-granules as one of the sources of N that improved the efficiency in rice crop with minimum risk of loss. From another study with clayey loam soil, it was inferred that rice responded better to granular N than prilled urea and placement of N as urea super-granules in the root-zone gave the best results for growth, yield performance and nutrient use efficiency in rice under irrigated conditions (Subbaiah and Pillai, 1993).

2.2 Split application

Sulphur coated urea in three split dressings gave the highest paddy yield in an experiment during monsoon season for upland irrigated rice (Singh and Kumar, 1980). In another trial conducted with sandy loam and clayey loam soil, split application of slow release urea materials gave higher yields (Ramasamy *et al.*, 1987). Split application of granular urea was found to be efficient in terms of rice yield and N recovery (Rao, 1987) and for reducing ammonia volatalization (KAU, 1987). The same mode of application also gave maximum grain yield compared to full basal application in rice (Datta *et al.*, 1990 and Moletti *et al.*, 1990).

2.3 Modification to reduce rate of release

The objective of developing slow release fertiliser was to release N at a rate to meet the requirement of crop at different growth stages. Nitrogen from magnesium ammonium phosphate was reported to become available at a rate greater than would be expected from the solubility of the compounds (Prasad *et al.*, 1971). Abraham *et al.* (1975) observed that neemcake increased the efficiency of urea applied to rice. Experiments conducted at Pattambi, Kerala showed that sulphur coated urea increased N response and grain yield in rice (KAU, 1979). Application of neemcake coated urea resulted in higher NH_4-N content in soil than other N carriers (Subbaiah and Kothandaraman, 1980; Sankaran and Biddappa, 1980). Neem coated or blended urea was reported to be superior to ordinary urea in terms of yield component and N recovery (Reddy and Shinde, 1981). The nitrogen uptake, N recovery % and grain per unit input of N were increased in rice by the application of gypsum or rock phosphate coated urea (Moorthy, 1982). Misra and Khan (1985) reported that gypsum coated urea reduced the ammonia volatilization loss. Evaluation of gypsum coated urea and rock phosphate coated urea along with other modified materials revealed that the results were not promising in terms of yield and N recovery (Singh *et al.*, 1986).

3 Transformation from slow release nitrogen fertilisers

Urease activity in soil was known to vary with location, depth, season and forms of nitrogenous fertilisers used (Bhavanandan and Fernando, 1970). Prasad

(1982) showed the suitability of various slow release N fertilisers to rice which utilised both ammonia and nitrate sources. Under constant moisture conditions 25-40 per cent of the N from slow release N fertilisers changed into nitrate form (Kaplunova and Aronshtein (1983). Moawad *et al.* (1984) found that nitrification, nitrite accumulation and gaseous loss of N as ammonia were retarded by the use of urea derivatives. Yadav and Srivasthava (1987) showed reduced rates of ammonification and nitrification of slow release N fertilisers as compared with urea in the incubation trial. In a study by Sannigrahi and Mandal (1987) it was noted that the release of urea-N was rapid in the case of ureaform followed by IBDU and CDU. Christianson *et al.* (1988) recorded that solubility, the ureaform was less susceptible to volatalization than urea due to its reduced solubility.

4 Nutrient release from slow release N fertilisers

The studies of Bopaiah and Biddapa (1987) revealed that ureaform recorded low exchangeable ammonium and urease activity than neemcake coated urea, neemcake blended urea, urea blended with neemcake and coaltar coated urea. Ureaform released ammoniacal, nitrate and urea-N for more than 105 days in acid soils of Kerala, whereas the nitrate-N only up to 45 days. Based on a field experiment, Awasthe and Misra (1987) concluded that mineralisation of urea in the soil was delayed by neemcake and dicyandiamide (didin) coated urea. Placement of urea briquettes at 10 cm depth in the flooded soil maintained a higher level of NH_4^+-N in soil during the period of active N absorption by rice. Urea briquettes outyielded all other N sources and showed the highest N use efficiency and apparent recovery of applied N.

5 Slow release N fertilisers in reducing the N losses from soil

5.1 Ammonia volatilization

In a trial conducted at Pattambi, Kerala it was observed that urea mud-ball and urea super-granule recorded minimum volatalization loss and maximum grain yield (KAU, 1987). Field trials conducted using latosols of Pattambi, Kerala during virippu and mundakan season revealed maximum leaching loss with full basal application of urea and minimum with rock phosphate coated urea. But maximum volatalization loss was in the case of neem coated urea and minimum for urea split application(Anon, 1987). Laboratory incubation studies by Sannigrahi and Mandal (1988) recorded the lowest N loss by ammonia volatalization from crotonylidine diurea after 70 days of incubation. Volatalization loss from ureaform and isobutylidine urea was also much lower. In a study to assess N loss by ammonia volatalization from submerged rice soils of Kerala (Anilakumar, 1989), suitable N carriers capable of reducing the N loss were identified. They were in the order, sulphur coated urea > urea mudball > gypsum coated urea > rock phosphate coated urea > coaltar coated urea = neem coated urea = ammonium sulphate > ammonium chloride > urea:coconut pith:soil = urea basal. Kanani *et al.* (1994) in a study with amended urea fertilisers, such as formulations of solutions, physical dry blend and tablets, it was noted that amending induced 46-85 per cent reduction in ammonia loss compared with unamended urea. For tablet and physical dry blend formulations placement in bands reduced ammonia loss compared with surface application.

5.2 Denitrification

In an incubation study on laterite and kari soil types of Kerala. Thomas (1981) observed that the higher efficiency of urea super-granule over prilled urea was due to its higher diffusion as urea and ammonium to different soil layers, less nitrate accumulation and lower rate of nitrification. Blending urea with this cake imparted both nitrification inhibiting and slow release effects to the same. In the laterite soils ureaform was found effective as a sustained N release fertiliser up to 4 years by single application (Vijayachandran and Devi, 1982). John (1987) conducted a study in karapadom soil to study the mineralisation pattern of different sources of nitrogen. The higher inhibiting effect of nitrifying organisms had been reported with neemcake blended urea and neemcake coated urea as compared to lac coated urea, sulfur coated urea and karanja cake blended urea (KCBU).

5.3 Leaching and run off

The maximum loss of N through leaching occurred between 12 and 24 hours after the application of fertilisers and there was very little loss after 72 hours (Krishnakumari, 1968). Sandy soil recorded the maximum loss and clayey soil the least. Sannigrahi and Mandal (1984) in a study on slow release N fertilisers reported higher leaching loss of N as inorganic-N and as urea-N in isobutylidene, crotonylidene and urea formaldehyde treatments than under lac coated urea and urea treatments. Leaching losses of N was in the decreasing order of urea formaldehyde, crotonylydine diurea, isobutylidenediurea, urea, lac coated urea under waterlogged paddy cultivation (Sannigrahi and Mandal, 1991). The cumulative leaching losses of N from coated urea, urea super-granule and urea were much lower under submergence than due to intermittent watering. The heavy leaching losses of N took place up to the 2nd day of application under submergence conditions and up to the 6th day under intermittent moisture conditions (Mahajan and Tripathi, 1991).

6 Slow release N fertilisers in increasing growth and yield of rice

Oomen *et al.* (1977) reported the higher efficiency of various slow release N fertilisers in increasing growth, yield and yield attributes. Sharma and Prasad (1980) found that N recovery and grain yield were more with slow release N fertilisers. Prasad and Prasad (1980) reported the suitability of sulphur coated urea and neem coated urea over urea for higher yield in rice. Using the laterite soil of the Agricultural Research Station, Mannuthy, the effect of blending urea with four different oil cakes namely marotti, punna, karingotta and neem was evaluated by Devi *et al.* (1980) and no beneficial effect was reported. Reddy *et al.* (1980) revealed that application of 80 kg N ha^{-1} as sulphur coated urea gave paddy yield similar to those obtained with 100 kg N ha^{-1} as urea, applied in three split dressings. Krishnappa *et al.* (1986) conducted a detailed study in coastal laterite soils of Karnataka to evaluate the effect of prilled urea, lac coated urea, neemcake blended urea, urea super-granule and sulphur coated urea at different levels for rice and all slow release nitrogen fertilisers performed better than prilled urea at all N levels, with sulphur coated urea giving the highest yield. Relative efficiency of some new urea based fertiliser for growing wet land rice was studied by Singh and Katyal (1987) and it was found that sulphur coated urea produced significantly more rice grain than urea super-granule. Srivasthava *et al.* (1987) in a study for comparing the efficiency of sulphur coated urea, urea super-granule and split application of prilled urea it was found that maximum grain yield was obtained with sulphur coated urea followed by urea super-granule. But Kundu (1989) reported that application of 100 kg N ha^{-1} as urea super granule gave the highest yield, followed by sulphur coated urea. In an experiment conducted with sandy loam soil of Karamana (Mathew, 1987) reported that sulphur coated urea, urease inhibited urea and urea super- granule were superior compared to neem coated urea, rock phosphate coated urea and prilled urea to increase grain yield.

7 Nitrogen use efficiency in rice

Rajale and Prasad (1974); Patro *et al.* (1975) and Nair and Tomy (1978) reported that slow-release N fertilisers were more efficient than traditional N fertilisers in increasing the yield of rice. Prasad (1979) reported the high fertiliser use efficiency of slow release N fertilisers where continuous standing water did not permit timely top dressing of N. Sharma and Prasad (1980) found that urea coated with neemcake and N serve proved 148-150 per cent as effective as urea, whereas sulphur coated urea was 116 per cent as effective as urea. Bandopadhyaya and Biswas (1982) found that sulphur coated urea and lac coated urea were the most effective N-sources for the coastal saline rice soils of Bengal. In the light textured soils of Punjab, sulphur coated urea and lac coated urea are the most effective sources than split doses of urea (Rama *et al.*, 1984). The superiority of urea briquettes, urea mudball and neemcake coated urea over other forms of urea could be attributed to slow release of N, maintenance of higher concentration of ammonia in the rhizosphere, nitrification inhibition and subsequent loss of nitrate through percolation, leaching and denitrification etc. (Sahu and Pal, 1987). The relative efficiency of ordinary urea in splits, granulated urea at planting, and sulphur coated urea at planting were 111.4, 102.3 and 100.8 per cent respectively as compared to ordinary urea at planting. The residual effect of wheat was obtained only with sulphur coated urea in loamy soil (Yadav and Verma, 1985)..Singh and Yadav (1985) while recommending ways of increasing nitrogen use efficiency in low land rice, highlighted the use of rock phosphate and gypsum coated urea. Agronomic efficiency of deep placed USG for rice was revealed by Savant and Livingston (1988). Duraisamy and Palaniappan (1989) reported higher N recovery percentage and response ratio for neem coated urea followed by urea gypsum-21 in both the season for low land rice.

The study conducted with slow release N fertilisers by Sannigrahi and Mandal (1991) under waterlogged paddy cultivation revealed that the percentage recovery of applied N by rice decreased in the order; lac coated urea > isobutylidene diurea > urea > urea formaldehyde > crotonylidene diurea and decreased N losses in the order urea formaldehyde > crotonylidene diurea > isobutylidene diurea > urea > lac coated urea. Mishra *et al.* (1994) reported N uptake by rice using different N sources in the order; karanja cake coated urea > rock phosphate coated urea > neem cake coated urea > lac coated urea for transplanted rice.

Materials and Methods

MATERIALS AND METHODS

The present study was aimed to investigate the pattern of release and transformation of major plant nutrients from slow release fertilisers and to evaluate the efficiency of slow release fertilisers in relation to yield and plant uptake of nutrients by rice. With this view, an incubation study and a pot culture experiment were conducted during 1992-94.

1 The incubation study

A laboratory experiment was conducted at the College of Horticulture, Vellanikkara, Thrissur in a completely randomised design with three replications. The treatments were

Notation	Treatment
C	Control (urea, superphosphate and muriate of potash)
NF	Absolute control - no fertiliser
UF	Urea formaldehyde
NP tab	NP tablets
NPK tab	NPK tablets
GCU	Gypsum coated urea
UAS	Blended urea ammonium sulphate
MAP	Magnesium ammonium phosphate

The slow release fertilizers used were supplied by the R & D Division of FACT. Four important soil types of Kerala viz. acid laterite, Kuttanad alluvium, coastal sandy and acid sulphate (kari) were selected for the incubation study. The location and the important physico-chemical properties of the soil are given in Table 1.

Table 1. General characteristics of the selected soil types

Soil type	Location	Textural class	Field capacity %	pH	CEC cmol(+) kg^{-1}	Organic carbon %	Available P kg ha^{-1}	Available K kg ha^{-1}
1. Laterite	Mannuthy	Loamy sand	20.50	4.7	6.34	0.38	35.6	138.0
2. Kari	Karumadi	Sandy loam	25.71	3.4	9.96	3.96	6.0	660.0
3. Kuttanad alluvium	Moncompu	Clayey	22.05	4.3	5.63	1.86	12.2	192.0
4. Coastal sand	Kayamkulam	Sandy	16.05	4.8	4.20	0.82	55.2	172.8

Surface soil collected at 0-15 cm depth was used for the incubation study. The soil was air dried and ground with a wooden mallet. One kg each of soil samples was transferred to incubation bottles. Fertilisers were applied in full so as to satisfy the 90:45:45 kg ha^{-1} recommendation (KAU, 1989). They were maintained at field capacity for a period of six months by periodical additions of calculated quantities of distilled water. All the details regarding the quantity of different fertiliser application is provided in Appendix I. Soil samples were collected at monthly intervals and analysed for pH, ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), available P and available K.

1.1 Important characteristics of nitrogen carriers used

Urea: This is a high analysis fertiliser containing 46% N. Urea formaldehyde: Urea formaldehyde materials are the reaction products of urea and formaldehyde containing at least 35% N largely insoluble but in slowly available form. NP tablets: Contains 26% N and 4% P. NPK tablets: Contains 16% N, 8% P, 8% K. Gypsum coated urea: A coated product of urea with gypsum containing around 37% N, 12% calcium and 3.9% sulphur. Urea ammonium sulphate: A blend of urea and ammonium sulphate of grade 32:12 (N:S) containing urea-N and NH_4^+-N with sulphur as secondary nutrient. Magnesium ammonium phosphate: This product contains N (7%) and P_2O_5 (32%) as primary nutrients. Magnesium (10%) is available as secondary nutrient. The source of NP tab is urea and amophos whereas for NPK tab it is urea, amophos and muriate of potash.

2 Pot culture experiment

A pot culture study was conducted during puncha season, at the College of Horticulture, Vellanikkara, situated at 10°32' N latitude and 76°10'E longitude at an altitude of 22.25 m above mean sea level.

2.1 Climate and soil

Typical humid tropical climate was experienced by the area. The soil was collected from the wet lands of the Agricultural Research Station, Mannuthy.

2.2 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.

2.3 Treatment details

All the eight treatments of the incubation study were used for this experiment, with the same design.

2.4 Cultivation details

The experiment was conducted in earthern pots fitted with leaching outlets. Powdered and air dried soil (15 kg) was placed in each pot and puddled thoroughly. The pots were left waterlogged for 7 days to allow free leaching of water. Seedlings of rice variety Jyothi (21 days old) were transplanted at the rate of four seedling per pot.

2.5 Fertiliser application

Requisite quantities of nitrogen fertilisers and single superphosphate were applied as basal in one split only as detailed in Appendix I. Muriate of potash and urea, wherever needed, were applied in two splits half as basal and half one week before panicle initiation. Thus fertilisers were applied as per package recommendation (KAU, 1989).

2.6 Irrigation

Up to crop maturity 3-4 cm of standing water was maintained uniformly in the pots.

2.7 After cultivation

Weeding and plant protection operations were carried out as and when required.

2.8 Observations

2.8.1 Growth parameters

a. Plant height: Height was recorded from the base of the plant to the tip of the longest leaf.

b. Number of tillers: The number of tillers in each hill of each replication was counted at periodic intervals till harvest and the mean for a pot was noted.

c. Dry matter production: The plants were oven dried at $70 \pm 2^{\circ}C$ and total dry weight expressed as g pot^{-1}.

2.8.2 Yield parameters

a. Grain yield: The weight of grains in each replication was recorded and expressed as g pot^{-1}.

b. Straw yield: The weight of straw in each replication was recorded and expressed as g pot^{-1}.

3 Laboratory studies

3.1 Collection of soil samples

Soil samples were collected at 25 (maximum tillering), 40 (panicle initiation) and 90 (harvest) days after planting.

3.2 Collection of leachate

Leachates were collected at weekly intervals throughout the crop growth.

3.3 Collection of plant samples

Plant samples were collected at 25, 40 and 90 days after planting.

3.4 Soil analysis

pH: Soil water suspension (1:2.5) was used to determine the pH of soil in all treatments. The pH reading was taken using Elico pH meter (Jackson, 1958).

NH_4-N and NO_3-N: To 10 g soil, 100 ml of 2 M KCl solution was added and extracted for 1 h. It was filtered through Whatman No.42 filter paper and the extract was used for analysis. Ammoniacal nitrogen content was estimated by macrokjeldhal distillation and nitrate nitrogen by adding Devarda's alloy to the Kjeldhal's flask (Jackson, 1958).

Available P: Ascorbic blue colour method after the extraction with Bray No.I and estimated using photo electric colorimeter (Watenabe and Olsen, 1965).

Available K: Using neutral normal ammonium acetate as extractant and measurement by flame photometer (Jackson, 1958).

3.5 Leachate analysis

The leachates collected were analysed for total inorganic nitrogen following the steam distillation procedure as described by Black (1965), the total phosphorus was estimated by chlorostannous reduced sulfomolybdic acid blue colour method and total potassium using flame photometric method (Jackson, 1958).

3.6 Preparation of plant sample

The plant samples collected were oven dried at 80°C till it attained constant weight. The dried samples were ground into powder in a mechanical grinder. The powdered plant samples were analysed.

3.7 Analysis of plant samples

The total nitrogen in the plant sample was estimated by microkjeldhal method total P colorimetrically by vanodomolybdate method and total K using flamephotometric method (Jackson, 1958).

4 Uptake of nutrients

The N, P and K contents of the plant were multiplied with their respective dry matter yields to get the uptake values. It was expressed in mg pot^{-1}.

5 Nitrogen use efficiency

The biological nitrogen use efficiency (N response) and chemical nitrogen use efficiency (apparent N recovery) were computed by using the following formulae

$$\text{(a) N response} = \frac{\text{Grain yield in treatment} - \text{Grain yield in control}}{\text{Quantity of N applied}}$$

$$\text{(b) Apparent N recovery} = \frac{\text{N uptake in treatment} - \text{N uptake in control}}{\text{Quantity of N applied}} \times 100$$

6 Statistical analysis

The data generated from the incubation studies and pot culture studies were subjected to statistical analysis using analysis of variance technique (Panse and Sukhatme, 1985).

Results and Discussion

RESULTS AND DISCUSSION

The results obtained from the incubation study and the pot culture trial are discussed in this chapter.

1 Incubation study

The main objective of the incubation study was to assess the release of NH_4-N and NO_3-N as influenced by different treatments at varying intervals of incubation for 180 days. The changes in soil pH, available P and available K were also monitored. Since the soils with distinct physico-chemical properties respond differently to the N application, laterite, kari, kuttanad alluvium and coastal sandy soils were made use for the study.

1.1 Laterite soil

1.1.1 Soil reaction

The influence of various N-source on the soil reaction at different periods of incubation are presented in Table 2. The pH values ranged from 4.95 to 5.57 which were recorded by the treatments and NP tab at 120th and 30th day of incubation respectively.

The pooled effect of all the trea nts on soil pH was presented in Fig.1. There was a continuous decrease in the of the soil from 30th to 120th day of incubation, then remained almost stati later slightly raised at 180th day of incubation. Usually the pH of the soi ased due to submergence. But no such increase was noticed in this experi s the soil samples were maintained not

Table 2. Soil reaction at different periods of incubation : Laterite soil (pH values)

Treatments	Period (days)					
	30	60	90	120	150	180
C	5.55	5.47	5.12	4.95	5.07	5.10
NF	5.42	5.35	5.10	5.00	5.07	5.10
UF	5.55	5.55	5.15	5.05	4.97	5.20
NP tab	5.57	5.40	5.17	5.13	5.07	5.05
NPK tab	5.45	5.43	5.20	5.10	5.05	5.15
GCU	5.55	5.45	5.18	5.02	5.07	5.03
UAS	5.45	5.43	5.10	4.95	4.98	5.00
MAP	5.53	5.45	5.17	5.08	5.02	5.10
SEm±	0.04	0.04	0.05	0.12	0.05	0.06
CD (0.05)	0.08	0.08	NS	NS	NS	NS

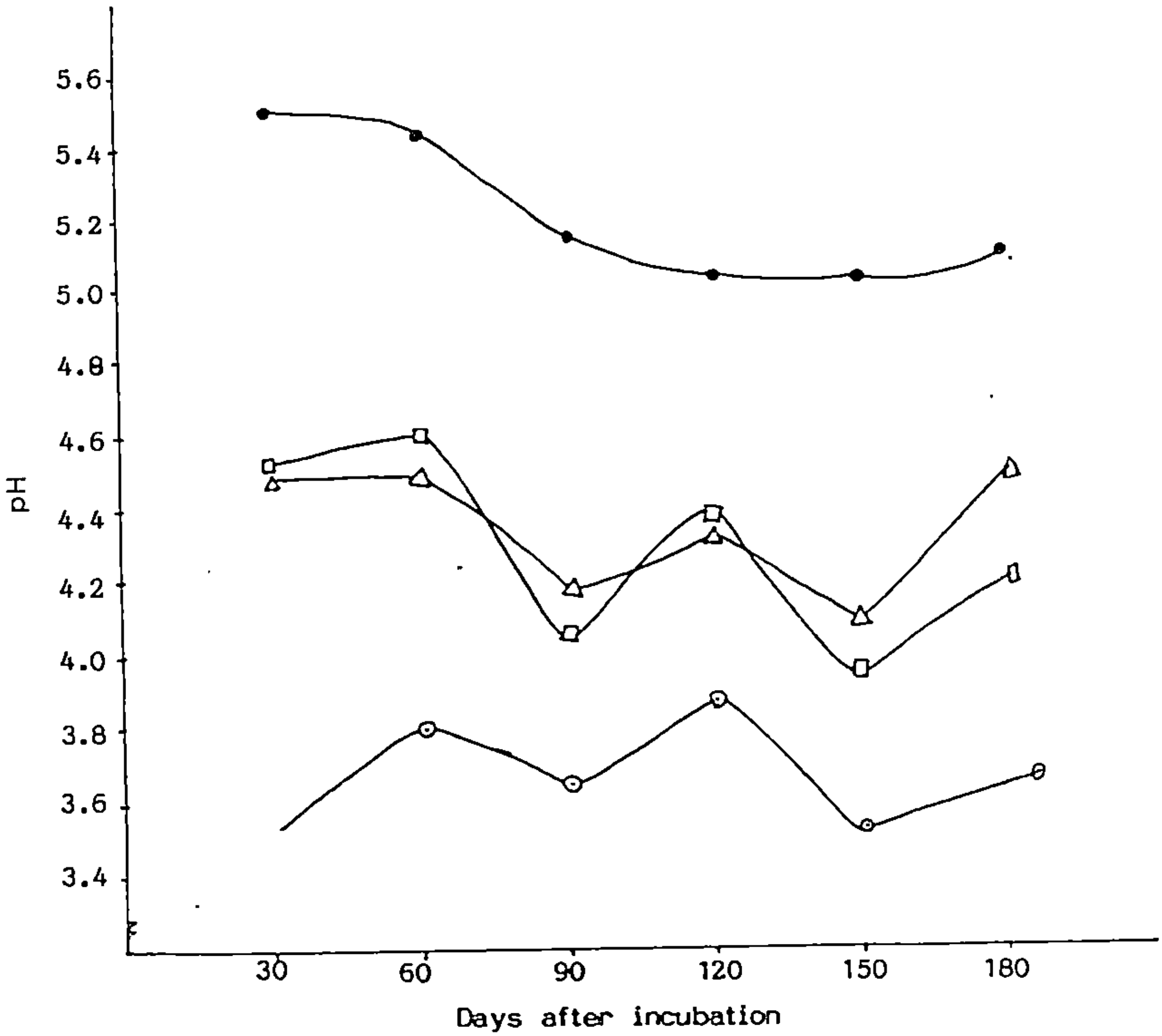

Fig.1. pH change of the soils as influenced by periods of incubation

● Laterite   △ Coastal sandy

□ Kuttanad alluvium   ⊙ Kari

under submerged condition but at field capacity. That may be the reason for the lack of increase in pH during the initial periods of incubation. But as the interval prolonged, the release of H^+ ion by nitrification may be reduced to a minimum and that may the reason for the increasing pH by 180th day of incubation.

The influence of different treatments on soil reaction was found to be significant for 30th and 60th days of incubation. The NF treatment recorded the least value for soil pH on 30th, 60th and 90th days after incubation. The NP tablet recorded the highest value for soil pH at 30th and 120th days of incubation whereas the UF registered the highest value at 60th day of incubation.

Though there was significant differences in the pH of the soil due to different treatments, the differences came to be nonsignificant in the later stages, indicating the result that application of nitrogenous fertilisers will not change the soil reaction appreciably. Similar results have been reported by Padmam (1992).

1.1.2 NH_4-N release

The data on NH_4-N content of the soil at different periods of incubation as influenced by different treatments are presented in Table 3. The highest value of 52.5 ppm was recorded by NPK tablets and the lowest value of 3.73 ppm by the NF treatment at 150th and 180th day of incubation.

Irrespective of the treatments, the release of NH_4-N remained without much variation up to 90th day and then suddenly dropped at 120th day (Fig. 2). Though there was a slight increase at 150th day, the NH_4-N decreased to a minimum value at 180th day of incubation. In general, the NH_4-N release was maximum at 90th day and minimum at 180th day of incubation. This may be due to triggering

Table 3. Ammoniacal nitrogen content (ppm) of soil at different periods of incubation : Laterite soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	35.10	35.35	51.10	30.10	48.53	17.27
NF	18.90	14.70	22.40	11.90	18.20	3.73
UF	21.00	31.55	30.80	28.47	20.07	7.47
NP tab	35.47	51.80	30.10	15.40	18.67	6.53
NPK tab	46.70	44.10	42.00	28.70	52.50	24.50
GCU	34.53	23.45	36.40	18.67	23.10	7.70
UAS	45.15	33.37	35.00	25.20	27.30	17.50
MAP	38.50	42.00	42.70	16.80	21.70	11.90
SEm±	3.41	0.93	1.65	1.69	4.02	1.42
CD (0.05)	7.23	1.96	3.50	3.57	8.52	3.01

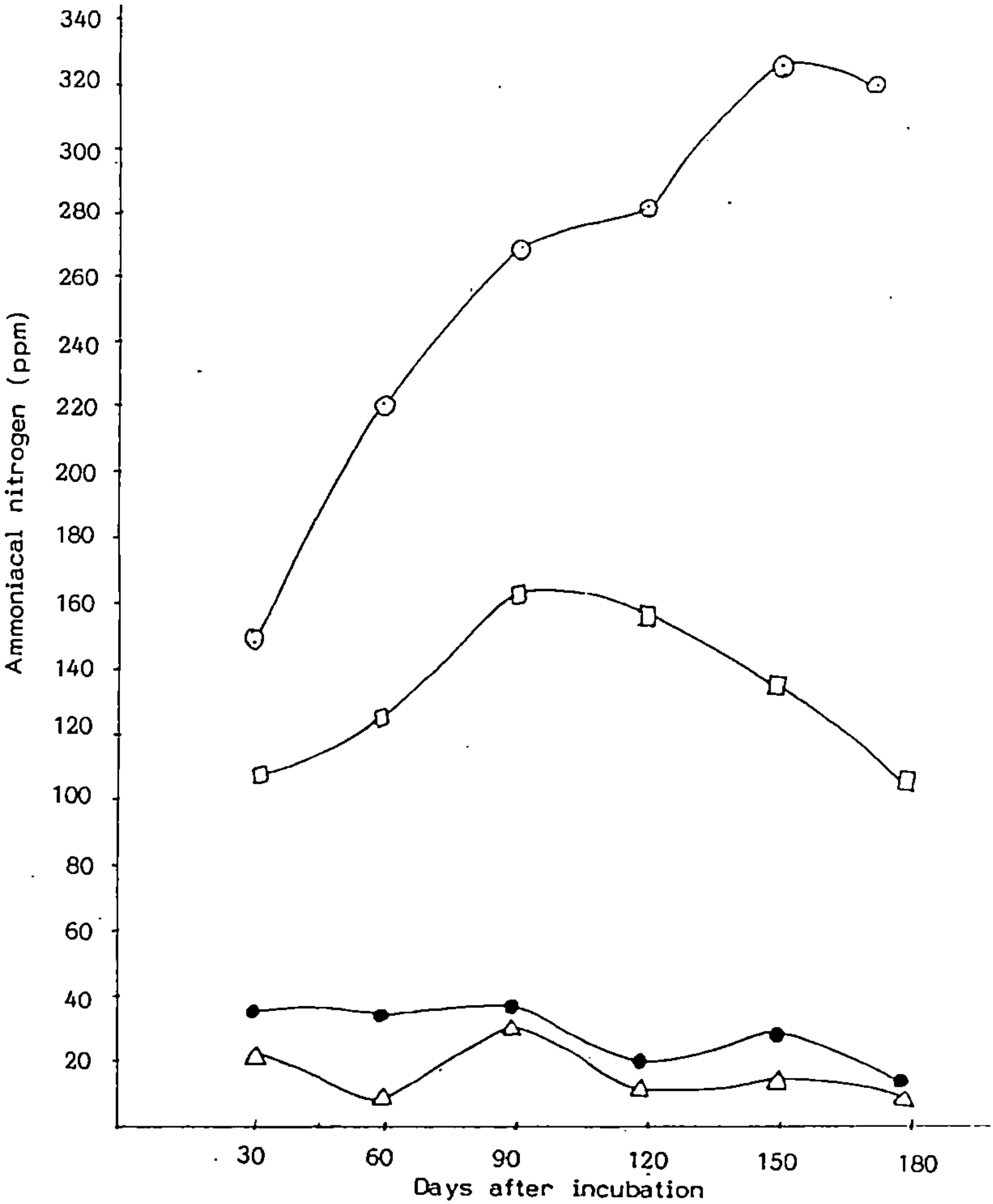

Fig.2. Ammoniacal nitrogen release from different soils as influenced by periods of incubation

● Laterite
Δ Coastal sandy
□ Kuttanad alluvium
⊙ Kari

of mineralisation of both applied and native N in the initial stages and consequent reduction in the rate of ammonification. Similar results were reported by CRRI (1983).

The effect of treatments on the release of NH_4-N was found to be significant at all the stages of incubation and the NF treatment registered the lowest value at all intervals. On 30th day, the treatment UF was on par with NF and all the other treatments were significantly superior to the same.

On both 60th and 90th day of incubation, all the other treatments recorded higher values compared to the NF treatment. As the periods of incubation advanced to 120 days, the NF treatment became on par with NP tablet. When the interval increased further, the NF treatment came to be on par with UF, NP tab, GCU, and MAP at 150th day of incubation. When the period of incubation increased upto 180 days, there was no significant difference between NF and NP tab. In contrast to NP tablet, the NPK tablet recorded higher values of NH_4-N at almost all the stages of incubation. The dissolution rate of NPK tablet was found to be higher than that of NP tablet. On 30th, 120th, 150th and 180th days of incubation, it was found to be the highest releaser of NH_4-N. The treatments like UAS and MAP were also recorded higher amounts of NH_4-N in soil as compared to other treatments, GCU, UF and NP.

1.1.3 NO_3-N release

The NO_3-N content of the soil as influenced by different stages of incubation and treatments are presented in table 4. The lowest value (6.07 ppm) and the highest value (73.5 ppm) was recorded by MAP at 180th and 90th day of incubation respectively.

Table 4. Nitrate nitrogen content of soil (ppm) at different periods of incubation
Laterite soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	33.60	37.10	54.60	49.00	17.50	14.70
NF	22.05	32.20	42.10	35.00	39.20	13.30
UF	24.50	44.45	62.53	60.20	31.50	15.87
MP tab	36.40	46.55	46.90	23.10	39.2	7.47
NPK tab	13.65	25.20	49.70	51.10	31.50	7.93
GCU	21.00	38.85	67.90	26.60	23.80	15.40
UAS	33.13	43.87	68.13	42.00	27.3	14.93
MAP	29.87	52.50	73.50	21.00	35.00	6.07
SEm±	2.02	2.12	4.15	1.78	2.55	1.41
CD (0.05)	4.29	4.49	8.79	3.78	5.42	2.99

From the Fig. 3, it was clear that there was continuous increase in NO_3-N content of soil up to 90th day and then drastically reduced to a minimum at 180th day of incubation. One of the main reasons in the reduction of NO_3-N at the later intervals may be due to the low NH_4-N content of the soil. The maximum value was registered at 90th day of incubation (42.10 ppm) and at this stage the native N content of NF treatment raised from a value of 22.05 ppm that was recorded at 30th day. From this, it can be inferred that the rate of nitrification was higher up to 90th day.

There was significant variation among treatments at all the stages of incubation. The NPK tablet registered significantly low values for NO_3-N content of soil at 30th and 60th day of incubation. At 90th day of incubation, the NF treatment recorded the lowest value of 42.1 ppm for NO_3-N in soil. At 120th day, it was found to be superior to the treatments GCU, NP and MAP. The maximum release of NO_3-N was from NF at 150th day which was on par with NP and MAP. At 180th day, it was again found to be on par with UF, GCU, UAS and control. At this stage the lowest release was from MAP which was closely followed by NP and NPK tablets.

Though the release of NH_4-N was maximum for NPK tab the release of NO_3-N was found to be comparatively less. The case was just the reverse for the treatment UF where the release of NO_3-N was more as compared to that of NPK tablet. On comparison with other treatments MAP recorded higher NO_3-N in the initial periods of incubation. The high nitrifiability of MAP was reported by Prasad *et al.*, 1971 also.

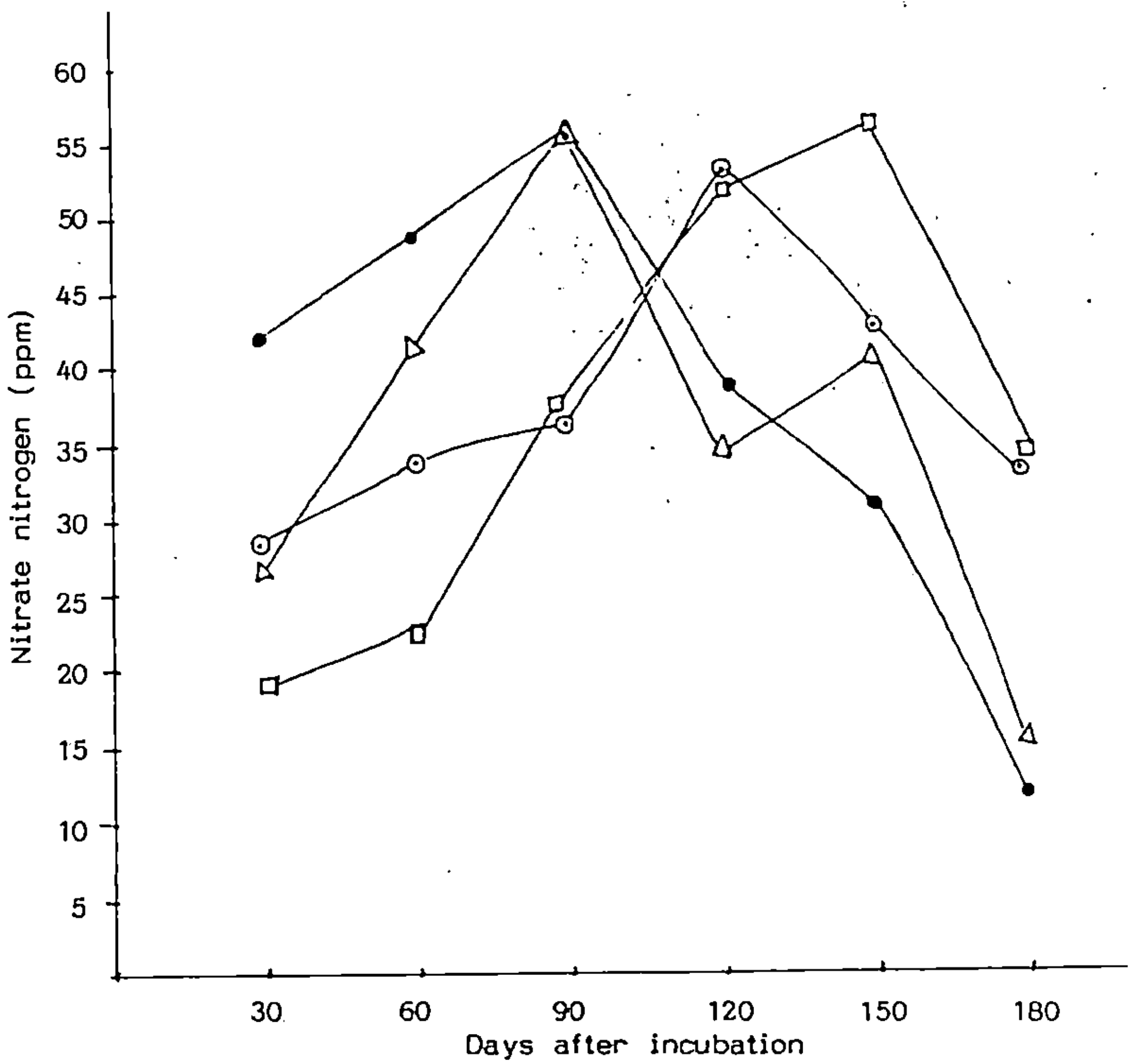

Fig.3. Nitrate nitrogen release from different soils as influenced by periods of incubation

● Laterite

△ Coastal sandy

□ Kuttanad alluvium

⊙ Kari

1.1.4 Total release of NH_4-N and NO_3-N

Though the values of NH_4-N and NO_3-N are not additive for the consecutive days of incubation, inorder to compare the performance of different fertilizers, the values were added and depicted in Fig.4.

In the case of NH_4-N and NO_3-N, maximum release was by NPK tab and UF respectively. The release of both forms of N was found to be in the least amounts for NF and NPK tab. Apart from the NPK tab, the ammonification was found to be high for the control treatment where recommended levels of N was applied as prilled urea. For all the other treatments including NPK tab, the nitrification was found to be higher than the NF treatment. The treatment UAS also recorded a significantly higher rate of nitrification compared to control. It may also be noted that the NPK tablet which has recorded the higher amounts of NH_4-N, has a lower nitrification rate compared to control.

1.1.5 Available P

The table 5 represents the data on available P content of the laterite soil at different periods of incubation as influenced by the different treatments. The values ranged from 33.66 to 72.45 kg ha^{-1} recorded by NF and UAS at 150th and 90th day of incubation respectively.

Significant treatment differences were also observed at all the intervals with NF treatment registering the lowest. The treatment UAS recorded the maximum values at all the intervals except at 180th day of incubation. The treatment NPK tablet recorded lower values which was on par with NF. The P from NPK

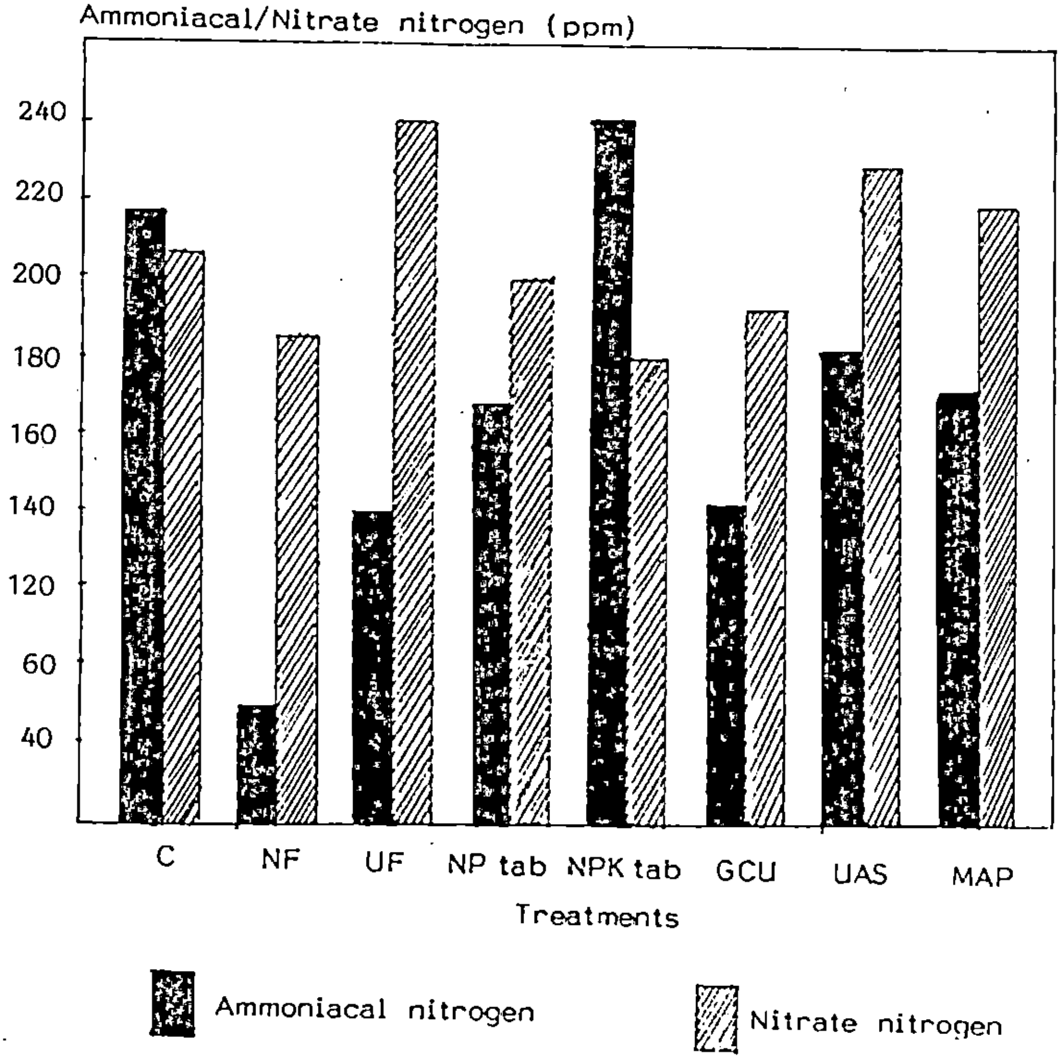

Fig.4. Total release of Ammoniacal and Nitrate nitrogen of laterite soil as influenced by the treatments

C - Control
NF - No fertilizer
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum caoated urea
UAS - Urea ammonium sulphate
MAP - Magnesium ammonium phosphate

Table 5. Available phosphorus content (kg ha^{-1}) of soil at different periods of incubation : Laterite soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	39.44	46.19	58.38	39.46	40.00	48.96
NF	36.76	38.36	50.47	34.48	33.66	36.64
UF	41.82	45.04	59.11	41.86	40.10	41.30
NP tab	40.08	46.08	57.01	39.19	33.91	41.48
NPK tab	37.89	38.70	52.57	35.90	34.28	38.46
GCU	43.63	43.88	52.23	44.07	35.98	44.71
UAS	49.75	54.30	72.45	48.40	45.70	44.54
MAP	41.75	45.86	63.42	46.14	42.43	43.24
SEm±	1.06	1.07	0.87	0.80	0.93	1.20
CD (0.05)	2.25	2.28	1.84	1.70	1.97	2.54

tablet form may not be immediately solubilised. The higher available P status of treatments under NP tablet may be due to the additional supply of P as single super phosphate (SSP). All the fertiliser treatments except NPK tablet and MAP were supplied with SSP at the recommended level. However the dominance of UAS for the high contents of available P may be accounted for its presence of SO_4^{2-} anions which might have released PO_4^{2-} from the fixation sites (Tisdale *et al.*, 1985).

No regular trend was noticed due to the application of treatments in the availability of P. The treatment NF has also recorded comparatively higher available P content in soil which indicates that a major part of the available P is obtained from the native source.

1.1.6 Available K

The results of available K content of soil at different stages of incubation are presented in Table 6. The values varied from 95.2 to 212.8 kg ha^{-1} which were registered by the treatments NF and UF at 90th and 30th day of incubation respectively.

In general the release of available K was maximum on 30th day. At other intervals the treatments recorded lower values. The higher values of available K on 30th day may be due to the immediate release of the same from the applied potassic fertiliser and soil.

Treatment differences were also observed at all the intervals of incubation. For all the treatments except NPK tablet, muriate of potash was applied in common. In the case of NPK tablet, the release was high during 30th day and it was at minimum during 150th and 180th day of incubation. The treatment NF was found

Table 6. Available potassium content (kg ha^{-1}) of soil at different periods of incubation : Laterite soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	203.20	144.80	146.40	189.60	139.20	139.20
NF	144.80	98.00	95.20	114.40	96.80	98.40
UF	212.80	143.20	144.00	148.80	144.00	152.80
NP tab	158.40	151.20	146.40	145.60	142.40	148.80
NPK tab	196.80	141.60	195.20	148.80	128.80	116.00
GCU	175.20	127.20	143.20	148.80	144.00	120.80
UAS	159.20	164.00	130.40	208.80	150.40	142.40
MAP	171.20	167.20	133.60	200.00	143.20	144.80
SEm±	6.14	6.76	5.03	4.75	3.44	5.26
CD (0.05)	13.02	14.33	10.65	10.06	7.29	11.15

to be significantly inferior to all other treatments for the available K contents of the soil at all the intervals of incubation.

1.2 Kari soil

1.2.1 Soil reaction

The values of soil reaction as influenced by sampling intervals and treatments are presented in Table 7. The minimum value of 3.33 and maximum value of 3.82 was recorded at 150th and 60th day of incubation.

Though there was influence for the different treatments on the pH of the soil which increased from 30th to 60th day, then gradually decreased from 60th to 90th day again increased at 120th, decreased at 150th and finally raised at 180th day of sampling (Fig. 1). The highly variable trend in pH of the soil was due to the inherent low pH of the soil.

The influence of different treatments on variations in soil pH was found to be nonsignificant at all the stages of sampling. As the rate of nitrification was slow, the nitrogenous fertilisers may not have influenced the soil reaction.

1.2.2 NH_4-N content

The NH_4-N content of the soil as influenced by the different periods of incubation and treatments are presented in Table 8. The values varied from 115.5 to 431.2 ppm which were recorded by the NF and NPK tab respectively. On examination of the data, it was found that the maximum value was recorded on 150th day and minimum on 30th day of incubation. A gradual increase was found up to 150th

Table 7. Soil reaction at different periods of incubation : Kari soil (pH values)

Treatment	Period (days)					
	30	60	90	120	150	180
C	3.52	3.82	3.65	3.40	3.37	3.62
NF	3.48	3.77	3.60	3.42	3.35	3.65
UF	3.57	3.80	3.65	3.48	3.42	3.63
NP tab	3.57	3.82	3.65	3.40	3.35	3.63
NPK tab	3.55	3.80	3.65	3.38	3.35	3.60
GCU	3.50	3.78	3.70	3.50	3.40	3.67
UAS	3.53	3.77	3.67	3.45	3.43	3.60
MAP	3.55	3.80	3.80	3.50	3.33	3.65
SEm±	0.04	0.04	0.05	0.05	0.04	0.05
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 8. Ammoniacal nitrogen content (ppm) of soil at different periods of incubation
Kari soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	137.20	258.30	273.00	292.13	305.20	313.60
NF	115.50	152.60	245.07	220.27	266.00	251.07
UF	132.27	174.07	257.60	259.70	297.27	324.80
NP tab	170.80	190.40	242.90	264.60	297.50	319.67
NPK tab	191.80	228.00	260.40	288.40	431.20	332.73
GCU	163.10	228.40	254.80	303.80	342.30	319.90
UAS	143.50	261.80	309.40	308.70	346.73	375.20
MAP	133.70	265.60	307.30	311.50	331.80	324.53
SEm±	5.02	10.67	10.63	5.83	10.28	4.67
CD (0.05)	10.65	2.61	2.53	12.36	21.80	9.90

day and then a slight decrease in NH_4-N content was noticed at 180th day of incubation (Fig. 2). The increase in NH_4-N content with time may be due to native organic matter decomposition as well as from the slow release of N from different N-sources.

The treatment effects were found to be significant at all the stages of incubation. On 30th day all treatments were significantly higher than NF. Maximum value of 191.80 ppm was recorded by NPK tab and minimum value of 115.50 ppm by UF.

On 60th day MAP recorded the highest value (265.6 ppm) and all treatments except UF were significantly greater than NF. The treatments MAP, UAS and C were found to be on par Ammoniacal-N release was not much affected by the treatments on 90th day. Significant effects were recorded by MAP, UAS and C and others were on par with NF.

All the treatments were significant on 120th day with MAP recording the highest value (311.5 ppm) and NF recording the minimum value (220.27 ppm). It was found that MAP, GCU and UAS were on par for the NH_4-N contents in soil.

On 150th day NPK tab recorded maximum value of 431.2 ppm and all the treatments significantly influenced the NH_4-N released from the soil. The treatments MAP, UAS and GCU were on par.

Significant effect of all treatments were also recorded on 180th day with UAS and NF recording the maximum and minimum values respectively.

1.2.3 NO_3-N content

The NO_3-N content of the soil as influenced by different stages of incubation and treatments are presented in Table 9. The values varied from 16.8 to 77.93 ppm recorded by MAP and NP tab at 60th and 150th day.

The NO_3-N content remained almost static up to 90th day, higher values were recorded on 120th and 150th day and again decreased on 150th and 180th day (Fig. 3). On the first two stages nitrification was very low. Comparatively better treatment effects were noticed on 150th day with all the treatment except C and UF were significant over NF.

On 30th day the treatment UAS and NF were found to be on par and others were significantly lower than them while on 60th day UF, NP tab, and GCU were on par with NF with other treatments recording values significantly lower than NF. The treatments GCU, UAS and NPK tab were significantly higher NO_3-N release on 90th day, UF recorded significantly lower value than NF and other treatments were on par with NF. On the 120th day significant effect was recorded by NPK tab and GCU only and NP tab was on par with NF. Other treatments remained inferior to NF. The treatments except C remained significant on 150th day and NP tab recorded highest value. On 180th day the highest value was recorded by the treatment MAP followed by UAS, urea and GCU. The treament NP tab was significantly lower than NF.

From the above results it can be concluded that ammonification was not reduced by acidity, but nitrification was very low in kari soil. Since nitrobactor could not thrive under acid conditions, nitrification might have reduced in this soil

Table 9. Nitrate nitrogen content (ppm) of soil at different periods of incubation
Kari soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	25.20	33.60	33.60	39.20	18.20	43.40
NF	39.90	43.40	32.67	53.90	21.70	25.43
UF	35.00	45.50	23.80	35.00	26.13	21.00
NP tab	32.90	41.30	32.90	57.87	77.93	18.67
NPK tab	34.3	23.27	42.70	77.00	28.00	28.70
GCU	27.30	38.27	40.60	66.03	44.80	37.10
UAS	39.90	25.20	42.00	44.80	61.70	44.10
MAP	25.67	16.80	32.90	44.10	58.10	45.73
SEm±	1.83	3.53	2.29	3.43	2.67	2.49
CD (0.05)	3.88	7.48	4.85	7.26	5.65	5.28

similar to that of kuttanad alluvium. This is in confirmity with the opinion of Goswami and Sahrawat (1982).

1.2.4 Total release of NH_4-N and NO_3-N

Among the treatments, the release of NH_4-N was found to be the highest for UAS, NPK tab and MAP. The release was minimum for NF treatment. But the NO_3-N was found in comparatively more in GCU. In other treatments, the release of NO_3-N was almost at the same amounts (Fig. 5).

1.2.5 Available P

Data on available P are presented in Table 10.

Among the sampling intervals the lowest values were recorded on 90th day and the highest on 60th day. The values varied from 0.37 to 11.95 kg ha^{-1}.

Significant effects on available P contents of soil as influenced by different treatments were also observed at all the intervals of incubation. On 30th and 60th day of incubation all the treatments maintained superiority NF on P contents of the soil. On 90th, 120th and 180th days, the NF treatment was not found to be significantly inferior to other treatments but on 150th day GCU and UAS recorded lower values compared to NF.

1.2.6 Available K

Data on available K content of the soil are presented in Table 11. The available K contents were found gradually increasing up to 120th day, a slight

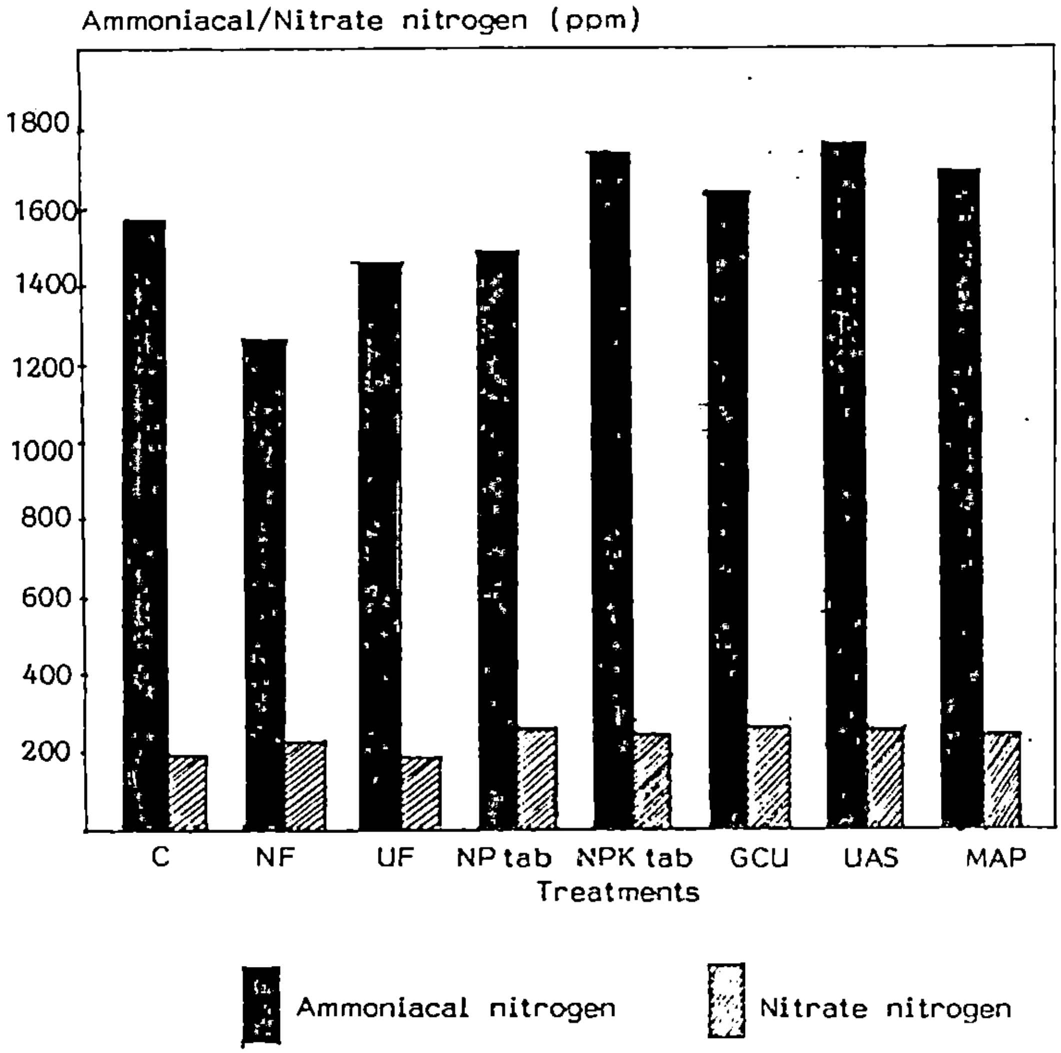

Fig.5. Total release of Ammoniacal and Nitrate nitrogen of kari soil as influenced by treatments

C	- Control	NPK tab	- NPK tablet
NF	- No fertilizer	GCU	- Gypsum coated urea
UF	- Urea formaldehyde	UAS	- Urea ammonium sulphate
NP tab	- NP tablet	MAP	- Magnesium ammonium phosphate

Table 10. Available phosphorus content (kg ha^{-1}) of soil at different periods of incubation : Kari soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	4.50	9.02	0.57	3.85	5.92	3.43
NF	2.87	6.72	0.37	2.98	2.82	2.82
UF	5.23	8.25	0.72	3.82	3.37	5.35
NP tab	5.34	7.97	2.54	4.53	7.27	4.61
NPK tab	3.72	8.36	0.40	3.78	5.09	6.43
GCU	11.95	8.25	0.84	3.25	2.29	5.41
UAS	4.80	9.75	2.22	3.71	2.30	6.52
MAP	3.92	9.41	2.69	5.40	2.87	7.32
SEm±	0.16	0.52	0.12	0.27	0.51	0.52
CD (0.05)	0.59	1.10	0.26	0.57	1.09	1.10

Table 11. Available potassium content (kg ha^{-1}) of soil at different periods of incubation : Kari soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	780.0	760.0	840.0	840.0	960.0	780.0
NF	620.0	660.0	720.0	720.0	640.0	700.0
UF	720.0	960.0	860.0	760.0	680.0	880.0
NP tab	780.0	860.0	880.0	960.0	720.0	1160.0
NPK tab	740.0	800.0	880.0	900.0	760.0	840.0
GCU	780.0	840.0	820.0	1140.0	740.0	1000.0
UAS	760.0	960.0	840.0	900.0	680.0	780.0
MAP	740.0	840.0	820.0	1080.0	780.0	900.0
SEm±	52.9	54.7	37.4	46.9	37.4	46.9
CD (0.05)	NS	116.1	79.3	99.4	79.3	99.4

decrease was noticed on 150th day and again increased on 180th day of sampling for all treatments except C in which case the K content increased up to 150th day.

The treatment effects were significant at all intervals except 30th day. At the other stages of incubation the different treatments did not show any decreasing or increasing order in the available K content. But the NF treatment always registered the lower values of available K content in the kari soil.

1.3 Kuttanad alluvium

1.3.1 Soil reaction

The values on soil reaction as influenced by different treatments at different periods of sampling are presented in Table 12. The pH values ranged with a low value of 3.87 and a high value of 4.7 at 150th and 90th day of incubation respectively.

Throughout the period of incubation, there was no definite trend in the pH values of Kuttanad alluvium (Fig. 1). The trend was almost similar to that of kari soil. In the NF treatment there was a continuous decrease in values of pH from 30th to 120th day of incubation. This may be due to the high content of ferric and manganic compounds present in this soil that might have undergone reduction.

On 30th and 60th day of incubation, the effect of treatments had no significant influence on variations in soil pH. Both the treatments GCU and MAP registered high pH value that was closely followed by UAS and UF on 90 th day. At 150th day of incubation, all the treatments except GCU were found to be significantly lower than NF.

Table 12. Soil reaction at different periods of incubation : Kuttanad alluvium (pH values)

Treatment	Period (days)					
	30	60	90	120	150	180
C	4.47	4.62	4.55	4.37	3.90	4.17
NF	4.47	4.55	4.55	4.37	4.08	4.15
UF	4.55	4.65	4.63	4.40	3.93	4.25
NP tab	4.48	4.63	4.57	5.35	3.87	4.22
NPK tab	4.50	4.58	4.62	4.33	3.90	4.17
GCU	4.55	4.60	4.70	4.35	4.02	4.20
UAS	4.58	4.63	4.67	4.45	3.95	4.25
MAP	4.55	4.63	4.70	4.42	3.97	4.23
SEm±	0.05	0.04	0.04	0.05	0.05	0.06
CD (0.05)	NS	NS	0.08	0.10	0.10	0.13

1.3.2 NH_4-N release

The data on the release of NH_4-N at different stages of incubation as influenced by different treatments are presented in Table 13. The values ranged from 73.5 to 202.3 ppm that was recorded by the NF and MAP at 180th and 120th day of incubation respectively.

On perusal of the data it is clear that NH_4-N continuously increased upto 90th day and then gradually decreased to 180th day (Fig. 2). The increase at 90th day indicated the slow nitrification rate in the initial periods which later improved on subsequent periods of incubation.

At all the intervals of incubation, the treatment effects were found to be significant irrespective of the periods of incubation. The NF treatment always registered the least value. The highest content in NH_4-N was registered by the control treatment at 30th day of incubation. On 60th day, it was found to be on par with UF and MAP. At the stages of 90th and 120th day of incubation, MAP dominated the other treatments where as the treatment C registered the maximum on 150th day. The NPK treatment was found to be significantly superior to all the other treatments on 180th day. Though the NPK treatment released more NH_4-N from the laterite soil during the different periods of incubation, the effect of the same treatment was comparatively less for kuttanad alluvium. The treatment MAP recorded highest release compared to other treatments.

1.3.3 NO_3-N release

The data pertaining to the release of NO_3-N at different periods of

Table 13. Ammoniacal nitrogen content (ppm) at different periods of incubation Kuttanad alluvium

Treatment	Period (days)					
	30	60	90	120	150	180
C	130.67	154.93	170.10	170.10	144.67	114.10
NF	89.13	118.07	133.93	114.80	116.20	73.50
UF	92.87	165.67	141.87	129.50	131.20	88.20
NP tab	106.40	122.73	138.60	126.93	128.70	83.07
NPK tab	106.80	142.33	171.50	145.60	133.93	132.07
GCU	100.80	144.20	181.30	178.50	143.50	121.10
UAS	118.30	144.20	166.13	190.40	142.80	112.00
MAP	101.50	150.27	196.70	202.30	141.87	119.70
SEm±	2.81	14.61	4.10	6.97	4.72	3.82
CD (0.05)	5.96	30.97	8.69	14.77	10.01	8.11

incubation as influenced by various N-sources are presented in Table 14. On perusal of the data, it was found that there was maximum release (85.87 ppm) at 150th day by the control treatment and the minimum (11.9 ppm) at 60th day by the NPK treatment tablet.

The NO_3-N content of the soil continuously increased from 30th to 150th day of incubation and then suddenly dropped at 180th day (Fig. 3). The less release of NH_4-N at the last period of incubation may be the reason for the drastic reduction in NO_3-N of the soil. From the results, it was observed that the nitrification occured at a slow rate, indicating higher values on later periods of incubation and lower values on earlier periods. Corrobarative findings of Goswami and Sahrawat (1982), indicated that nitrification was slow in soils with pH less than 5.0. For the kuttanad alluvium, the original soil pH was 4.3 (Table 1).

The treatment effects was found to be significant at all the stage of incubation. At 30th day, the NF treatment did not differed with other treatments UAS, NPK tab and GCU for the release of NO_3-N. At this stage, the MAP was found to be significantly superior to other treatments for the release of NO_3-N. At 60th day, UAS was significantly superior over other treatments, though the treatments UF and NPK were on par with the NF. On 90th day, the lowest value (30.80 ppm) was recorded by NF and the highest (43.23 ppm) by NPK tab. The treatment UAS recorded higher value at 120th day of incubation. But at 150th day, the control treatment was found to be the highest releaser of NO_3-N. On 30th, 60th and 150th days of incubation, the MAP treatment faired well in the release of NO_3-N as compared to other treatments. The high NO_3-N content in MAP treatments may be due to its high nitrifiability.

Table 14. Nitrate nitrogen content (ppm) of soil at different periods of incubation
Kuttanad alluvium

Treatment	Period (days)					
	30	60	90	120	150	180
C	18.90	21.70	35.02	51.80	85.87	16.10
NF	16.10	16.10	30.80	41.53	26.60	18.20
UF	26.00	14.00	35.00	32.67	42.00	14.93
NP tab	24.50	22.40	36.40	45.73	28.70	23.90
NPK tab	14.70	11.90	43.23	49.00	64.87	24.50
GCU	14.70	25.20	35.47	62.06	59.50	26.60
UAS	16.80	38.50	32.20	83.53	61.60	24.73
MAP	31.50	25.90	40.60	49.70	76.30	25.90
SEm±	1.15	2.07	3.21	3.18	3.78	1.42
CD (0.05)	2.43	4.39	6.81	6.74	8.01	3.02

1.3.4 Total release of NH_4-N and NO_3-N

In all the treatments, mineralisation was found to be very less (Fig. 6) with the least content of both forms of N in NF treatment than kari soil. The total NH_4-N release was maximum for MAP which was followed by control, GCU and UAS where as NO_3-N was high in UAS followed by control and MAP. For all the treatments, the total release of NH_4-N was found to be more than that of NO_3-N. These observations further supports the finding that nitrification process takes place in kuttanad alluvium soils at a slow rate as compared to laterite and sandy soils. The slow nitrification rate of kuttanad alluvium was recorded by John (1987) also.

1.3.5 Available P

Data pertaining to available P content of kuttanad alluvium are presented in Table 15. The available P content ranged from 3.50 to 23.38 kg ha^{-1}.

On incubation, the available P content of the soil increased from 30th to 60th day and then remained almost static, although there was a slight decrease at 150th day of incubation for all treatments except control. The increase in 'P' availability on 60th day and decrease on 150th day was due to consequent variations in soil native P, as indicated by the treatment NF. The rise in soil pH at 60th day and fall at 150th day of incubation might have clearly influenced this trend.

The treatments influenced the available P content of the soil with UAS recording the maximum values on 30th, 60th, 180th days of incubation. The NF treatment recorded the minimum values on 60th, 90th and 180th days of incubation.

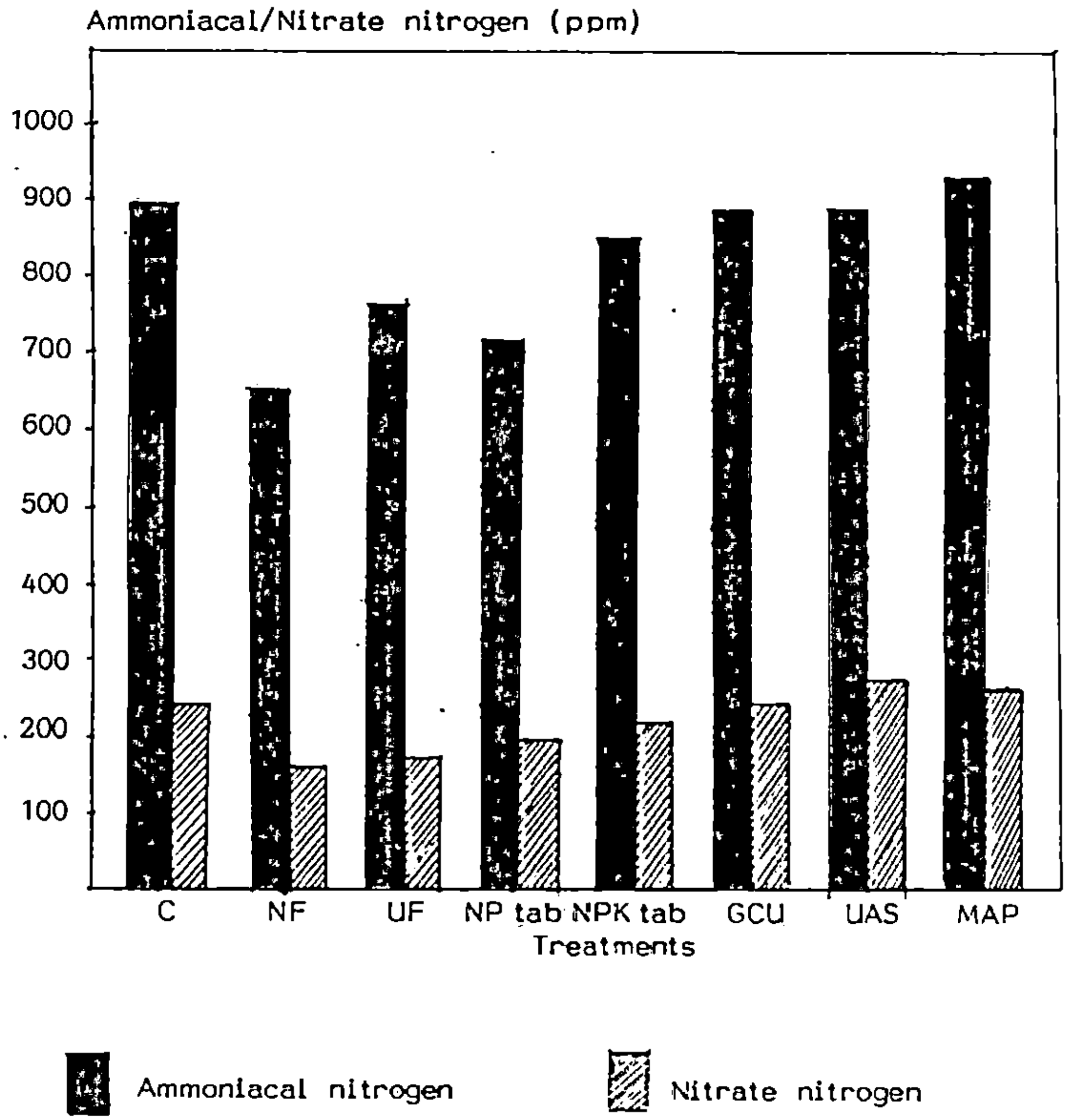

Fig.6. Total release of Ammoniacal and Nitrate nitrogen of kuttanad alluvium soil as influenced by the treatments

C - Control
NF - No fertilizer
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum coated urea
UAS - Urea ammonium sulphate
MAP - Magnesium ammonium phosphate

Table 15. Available phosphorus content (kg ha^{-1}) of soil at different periods of incubation : Kuttanad alluvium

Treatment	Period (days)					
	30	60	90	120	150	180
C	11.68	17.63	10.07	11.58	10.86	11.70
NF	6.62	17.24	7.58	11.82	6.42	8.31
UF	11.31	17.94	9.62	10.57	4.24	10.55
NP tab	7.84	18.34	10.39	10.70	6.53	11.59
NPK tab	6.24	18.15	3.50	10.70	6.42	10.33
GCU	8.26	19.86	11.52	10.67	9.06	11.30
UAS	12.50	23.38	11.89	9.91	8.78	17.64
MAP	10.41	20.75	12.06	10.37	6.02	14.23
SEm±	0.70	0.83	0.78	1.25	0.64	0.71
CD (0.05)	1.48	1.75	1.66	2.66	1.35	1.50

The treatment MAP registered the highest value on 90th day and the control on 150th day.

With regards to the P containing N-sources like MAP, NP and NPK tablets, the net release of 'P' was found to be less. There was much influence for the native soil P and the 'P' applied in the form of soluble SSP on the available P content of the soil as recorded by different treatments.

1.3.6 Available K

Table 16 represents the values on available K content of soil at different periods of incubation as influenced by the treatments. The values varied from 167.2 to 224.8 kg ha^{-1} which were recorded by the treatments NF and GCU at 120th and 60th day of incubation respectively.

With respect to different intervals of incubation, the values of available K remained almost at a static level. However, there was a sudden increase and decrease in 'K' contents of the soil at 60th and 150th day of incubation respectively. The same trend of release pattern was also indicated by treatment, NF. From this we can conclude that the variations in native soil K content influenced the net release of available K in the soil. Among the different sources of N, only NPK tablet contained K and the other treatments were supplied with soluble K fertiliser.

1.4 Sandy soil

1.4.1 Soil reaction

Soil reaction as influenced by different treatments at various intervals of incubation are presented in Table 17.

Table 16. Available potassium content (kg ha^{-1}) of soil at different periods of incubation : Kuttanad alluvium

Treatment	Period (days)					
	30	60	90	120	150	180
C	192.8	216.0	201.6	205.6	177.6	218.4
NF	168.0	172.0	169.6	167.2	173.6	167.2
UF	180.8	180.8	179.2	215.2	195.2	168.8
NP tab	195.2	220.8	192.8	181.6	182.4	168.8
NPK tab	183.2	205.6	176.0	206.4	179.2	204.8
GCU	180.0	224.8	194.4	209.6	203.2	192.0
UAS	182.4	215.2	218.4	197.6	189.6	175.2
MAP	186.4	224.0	200.8	214.4	185.6	176.8
SEm±	6.7	5.1	4.8	4.6	7.4	4.7
CD (0.05)	14.3	10.8	10.1	9.7	15.8	9.9

Table 17. Soil reaction at different periods of incubation : Sandy soil (pH values)

Treatment	Period (days)					
	30	60	90	120	150	180
C	4.38	4.45	4.18	4.25	4.08	4.43
NF	4.52	4.62	4.37	4.35	4.22	4.48
UF	4.40	4.43	4.13	4.30	4.05	4.53
NP tab	4.55	4.55	4.18	4.32	4.08	4.50
NPK tab	4.45	4.45	4.15	4.28	4.10	4.53
GCU	4.53	4.42	4.15	4.30	4.05	4.43
UAS	4.55	4.47	4.18	4.35	4.07	4.52
MAP	4.42	4.45	4.18	4.38	4.07	4.52
SEm±	0.05	0.04	0.04	0.05	0.05	0.05
CD (0.05)	0.10	0.08	0.08	NS	0.10	NS

The values of pH remained almost static at the initial periods of incubation up to 60th day (Fig. 1). The values ranged from 4.05 to 4.62 at 150th and 60th day respectively. There was an increase in pH value at 60th day of incubation (4.62) which was steadily decreased to 150th day (4.22) and then increased (4.48) for the treatment NF.

Significant change of pH was noticed at all intervals except at 120th day and 180th day. The treatments GCU and UAS recorded significant decrease in values of pH at 60th, 90th and 150th days. On 30th day MAP, UF and C were significantly lower while others were on par with NF. On 120th day and 180th day all treatments were on par with NF. The variation in pH for the different treatments was found to be almost uniform for other stages of incubation. Since most of the fertilisers are acid forming there was decrease in pH at most of the stages of incubation.

1.4.2 NH_4-N content

Data pertaining to NH_4-N content of the soil are presented in Table 18.

The NH_4-N content decreased from 30th day to 60th day, then a sudden increase was noticed on 90th day which decreased by the 120th day. On the 180th day of incubation the values of NH_4-N content of the soil were found to be the lowest. However, the peak values of NH_4-N was recorded at 90th day of incubation and later, it remained almost static (Fig. 2). The inherent high pH of the soil itself might have influenced the rate of mineralisation of added N compounds in the soil.

Table 18. Ammoniacal nitrogen content (ppm) of soil at different periods of incubation
Sandy soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	31.27	5.03	39.9	11.90	18.67	9.33
NF	8.00	1.40	25.9	2.80	9.10	3.73
UF	11.27	7.70	22.87	9.80	15.40	7.93
NP tab	9.80	8.17	25.90	14.47	9.80	9.10
NPK tab	22.87	12.55	52.50	23.10	20.07	13.30
GCU	31.50	16.80	38.27	19.13	10.73	10.40
UAS	18.20	7.35	33.13	9.80	8.40	14.80
MAP	38.50	8.75	42.00	21.70	22.40	13.90
SEm±	2.03	1.38	1.56	1.27	1.86	2.22
CD (0.05)	4.29	2.92	3.32	2.70	3.95	4.70

Significant treatment differences were observed at all the intervals of incubation. The treatments MAP and NPK tab recorded comparatively higher values at all intervals.

On the 30th day maximum value was recorded by MAP (38.5 ppm) followed by GCU and C, but the treatments UF and NP tab were on par with NF (8 ppm). On the 60th day the maximum value was recorded by GCU (16.8 ppm) followed by NPK tab and MAP and the lowest by NF (1.4 ppm). The treatments UF, UAS and C were on par. The highest value of 52.50 ppm by NPK tab and lowest value of 22.87 ppm by UF was recorded on 90th day. On 120th day NPK tab and MAP were superior over other treatments. On the 150th day, the treatments UAS, GCU and NP tab were on par with NF with MAP recording the highest NH_4-N content.

On the 180th day the treatments were significantly higher than NF, but the treatments were not significantly different from each other. The treatments MAP, UAS and NPK were on par with each other.

As in the case of laterite soil, sandy soil also recorded peak values of NH_4-N at 90th day and that may be due to decrease in pH value. The higher release of NH_4-N from MAP and NPK and lower release from UF and NP tab may be due to the variation in the release characteristics of the nitrogen sources. The fast rate of mineralisation in the case of MAP, the resistance to microbial decomposition in the case of UF and the different dissolution rates of tablets might have resulted in the differential release of NH_4-N. It can be also inferred that NH_4-N content is greatly influenced by the native NH_4-N as well as soil organic matter decomposition.

Regarding the total release of NH_4-N, the MAP and NPK treatments released more NH_4-N in soil. This was closely followed by GCU and control. The NO_3-N content was minimum for the NF treatment. The treatments UF and UAS also registered lower values for the release of NH_4-N in the soil.

1.4.3 NO_3-N content

The data pertaining the NO_3-N content are presented in Table 19.

The NO_3-N content remained without much change up to 90th day, then showed a trend to decrease after 90th day. Finally the NO_3-N recorded the lowest values on 180th day (Fig. 3).

The least content of NO_3-N was recorded by NF treatment at first three stages of incubation. Throughout the incubation period MAP maintained higher values of NO_3-N. Just like NH_4-N, the NO_3-N release was found to be the highest at 90th day of incubation. The minimum and maximum values of 4.67 and 76.07 ppm was recorded by NPK tab and MAP respectively.

The highest value of 54.6 ppm and the lowest values of 28.6 ppm was recorded by MAP and NF on 30th day. The treatment UF was on par with NF, other treatments being significantly superior to NF.

Though there was significant variation among the different treatments on NO_3-N contents of the soil, the treatment NPK tab was found to be on par with NF. On 60th day all the other treatments were on par with each other on both day.

Table 19. Nitrate nitrogen content (ppm) of soil at different periods of incubation
Sandy soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	50.87	46.2	67.20	22.33	72.33	23.10
NF	28.60	29.17	29.87	37.33	26.60	9.80
UF	31.15	48.07	36.87	58.33	37.33	19.13
NP tab	44.30	47.60	36.87	58.33	29.40	28.70
NPK tab	38.50	36.17	52.27	42.93	42.93	4.67
GCU	44.10	67.90	61.60	28.47	35.93	11.67
UAS	41.30	50.87	60.67	30.33	23.80	6.53
MAP	54.60	59.27	76.07	55.53	54.60	15.77
SEm±	4.35	6.59	2.59	5.06	5.83	2.11
CD (0.05)	9.21	13.96	5.48	10.73	12.36	4.47

On 90th day the highest value of 76.07 ppm was recorded by MAP and the lowest value of 29.87 ppm was recorded by NF.

The consequent intervals of 120th, 150th and 180th days recorded lesser release of NO_3-N from the soil as compared to other stages of incubation. Significant increase in NO_3-N content was recorded by UF, NP tab and MAP alone where as C was significantly lower than NF on 120th day. The treatment NPK tab, UAS and GCU remained on par with NF. On 150th day significant nitrification effect with the release of more NO_3-N in soil was recorded by the treatments, NPK tab, C and MAP while others were on par with NF.

On 180th day significant effect on NO_3-N content was produced by the treatments MAP, UF, C and NP tab while others were on par with NF.

The lower values of NH_4-N and NO_3-N in sandy soil may be due to slow rate of mineralisation and lower values of native N content. The light textured sandy soil with inherent low CEC and organic carbon content was found to be inefficient in retaining the mineralised form of ammonia (Anilakumar, 1989).

1.4.4 Total release of NH_4-N and NO_3-N

As compared to other soils the nitrification was maximum for sandy soil. In all the applied treatments and in NF treatment, the rate of release of NH_4-N was comparatively less and the maximum was recorded by MAP and minimum by NF. Total NO_3-N was found to be in higher amounts for MAP, closely followed by control (Fig. 7). The release for either forms of N was found to be minimum for NF treatments.

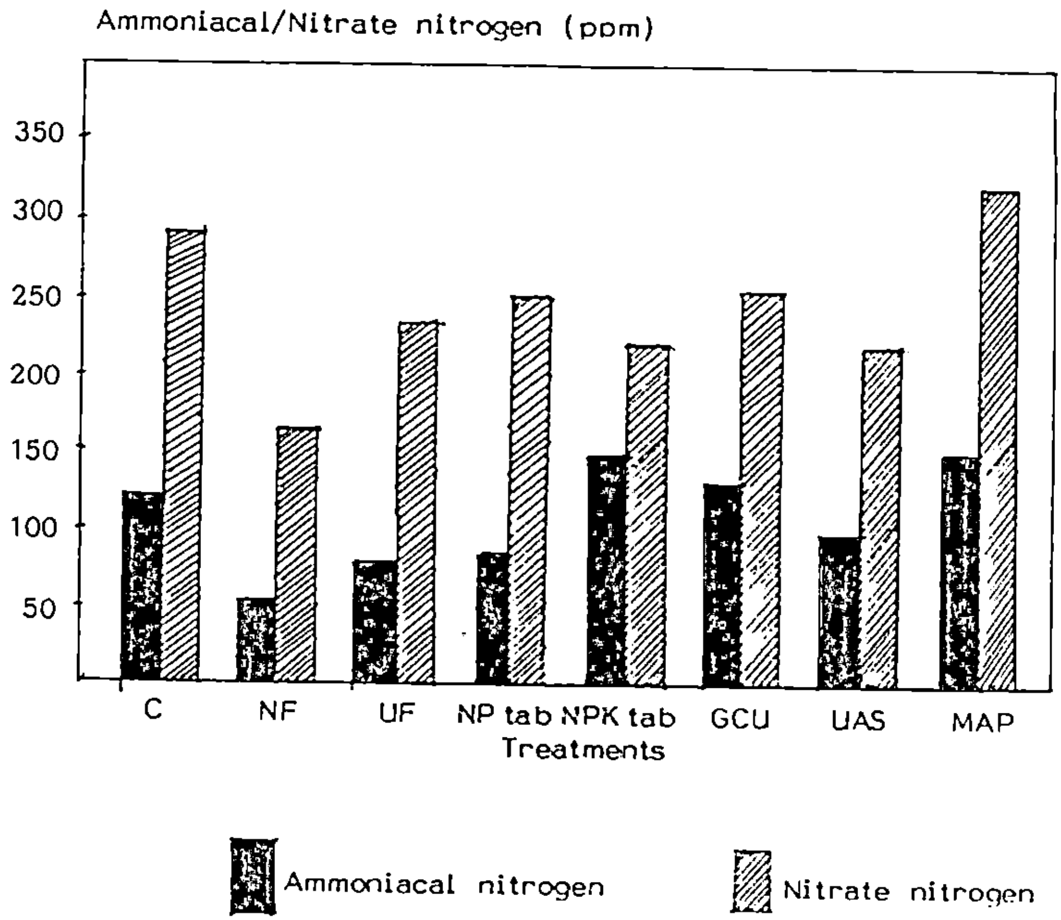

Fig.7. Total release of Ammoniacal and Nitrate nitrogen of coastal sandy soil as influenced by the treatments

C - Control
NF - No fertilizer
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum coated urea
UAS - Urea ammonium sulphate
MAP - Magnesium ammonium phosphate

1.4.5 Available P

Table 20 represents available P content of soil at different stages of incubation as influenced by the different treatments.

The values varied from 40.19 to 115.19 kg ha^{-1}. The values were static on 30th and 60th days. Later, the available P increased on 180th day. The original content of available P in the soil was recorded as 55.2 kg ha^{-1} which was subjected to the mineralisation process. Apart from the treatments NF, NP tab and NPK tab, other treatments were supplied with P using SSP. So by the application of P containing fertilisers, the available P content of the soil might have improved.

Significant effect of treatments were recorded with UAS registering the highest value and NF the lowest value. The treatment NPK tab recorded values on par with NF at all the intervals of incubation. Other treatments were significantly different from NF at all intervals except on 60th day. Where the treatments C and NPK tab were on par with NF. Regarding the NPK tablets, the dissolution of P was found to be lowest for the sandy soil also. The high 'P' status of UAS treated soil may be due to the acidifying nature of the same on native soil P sources.

1.4.6 Available K

The data on available K content of soil at different periods of incubation are presented in Table 21.

On average the values varied from 148.8 to 296.8 kg/ha recorded by NF and UAS treamtnets at 30th and 180th days of incubation respectively.

Table 20. Available phosphorus content (kg ha^{-1}) of soil at different periods of incubation : Sandy soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	76.03	74.17	73.82	74.73	75.67	75.98
NF	60.81	68.98	61.11	40.19	60.95	65.68
UF	83.74	82.83	73.45	72.17	69.54	74.64
NP tab	93.22	83.13	80.27	65.98	63.58	80.05
NPK tab	64.01	71.30	61.17	60.06	62.26	75.38
GCU	88.94	97.32	74.66	75.54	67.85	78.88
UAS	115.19	109.39	83.09	107.54	82.04	103.99
MAP	87.35	77.58	97.60	85.06	71.37	92.75
SEm±	2.87	3.54	1.67	3.23	1.16	1.47
CD (0.05)	6.09	7.51	3.53	6.85	2.45	3.10

Table 21. Available potassium content (kg ha^{-1}) of soil at different periods of incubation : Sandy soil

Treatment	Period (days)					
	30	60	90	120	150	180
C	203.2	218.4	214.4	192.0	212.8	200.0
NF	148.8	169.6	169.8	179.2	170.4	167.2
UF	181.6	193.6	207.2	208.8	178.4	196.8
NP tab	191.2	196.8	192.0	201.6	176.0	192.0
NPK tab	189.6	213.6	208.8	203.2	192.0	176.0
GCU	192.8	193.6	192.0	186.4	203.2	176.0
UAS	191.2	218.4	204.8	190.4	201.6	296.8
MAP	189.6	224.0	196.0	193.6	199.2	220.8
SEm±	7.2	5.3	6.47	4.4	4.2	6.1
CD (0.05)	15.2	11.2	13.5	9.4	8.9	12.9

There was no considerable increase or decrease in the available K content of the soil due to incubation. In the light textured sandy soil, the exchange reactions are poor. Since all the treatments except NPK tablets were supplied with MOP, there was no significant variation between treatments.

Treatment effects were also noticed, with NF always registering the lowest value where as the highest values were recorded by MAP on 60th and 180th day of incubation and the treatment C at 30, 90, 150th days of incubation.

2. Pot culture study

The experiment was conducted with the objectives to find out the effect of different slow release N fertilisers on yield and plant uptake of major nutrients by the rice crop and to study the leachate loss of the nutrients. The results obtained in the pot culture study are presented and discussed as follows:

2.1 Effect of application of slow release N fertilisers on growth and yield of the crop

2.1.1 Plant height

Data on plant height at different growth stages are presented in Table 22. In general, the plant height varied from 51.0 to 57.3 cm at maximum tillering stage and 57.7 to 64.7 cm at panicle initiation stage. Significant variation was noticed on plant height at all the stages studied and the treatment MAP always recorded the highest value followed by the treatments C, UAS and UF. But the effect of NP tab, NPK tab and GCU on plant height was on par with that of NF treatment. The superiority of MAP treatment over others may be accounted to its steady release of N throughout the crop growth as discussed in section 1.1.2 and the less leaching loss

Table 22. Plant height (cm), number of tillers and dry matter yield (g pot^{-1}) as influenced by the treatments

Treatment	Maximum tillering			Panicle initiation		
	Plant height (cm)	No. of tillers	Dry matter yield g pot^{-1}	Plant height (cm)	No. of tillers	Dry matter production g pot^{-1}
C	57.00	5.00	3.20	62.70	5.30	8.00
NF	51.00	4.30	2.40	57.70	4.30	6.00
UF	56.70	4.30	3.60	61.70	5.00	8.80
NP tab	55.30	3.70	2.80	61.30	4.00	7.20
NPK tab	52.70	3.70	2.80	59.00	4.70	6.80
GCU	53.00	4.30	3.20	61.00	5.30	7.60
UAS	56.30	4.70	4.00	64.70	6.30	9.60
MAP	57.30	5.00	4.00	64.70	6.30	9.20
SEm±	1.82	0.65	0.11	1.98	0.65	0.13
CD (0.05)	3.85	NS	0.23	4.19	1.37	0.29

of N from the same. The low response of the crop to NP tab, NPK tab and UF may be due to their less solubility. So these fertilisers could not meet the crop requirements for nitrogen.

2.1.2 Number of tillers

Table 22 presents the data on number of tillers at critical stages of crop growth. On an average 4.4 tillers/plant at maximum tillering and 4.8 tillers/plant at panicle initiation were recorded. The treatments could not influence the tiller production at the maximum tillering stage. But almost the same trend, expressed by the treatments on plant height, is clear from the data. At panicle initiation MAP and UAS were found to be significantly superior over the other treatments. The effect of NP tab, NPK tab, GCU and C were on par with that of NF treatment.

2.1.3 Dry matter production

Data on yield of dry matter at different growth stages viz. maximum tillering and panicle initiation are presented in Table 22. On perusal of the data, it was found that the dry matter yield varied from 2.4 to 4.0 g pot^{-1} at maximum tillering and 6.0 to 9.6 g pot^{-1} at panicle initiation stage. All the treatments except NP and NPK tab recorded comparatively higher dry matter yields than the NF treatment at maximum tillering. The low dry matter yield produced by the treatments NP tab, NPK tab and UF may be due to the poor vegetative growth of the crop under these treatments.

2.1.4 Grain yield

The yield of grain/pot is presented in the Table 23 and illustrated in

Table 23. Grain yield and straw yield (g pot^{-1}) as influenced by the treatments

Treatment	Grain yield	Straw yield
C	36.13	27.40
NF	26.50	18.70
UF	41.06	24.40
NP tab	29.30	19.70
NPK tab	30.80	23.80
GCU	39.90	26.06
UAS	49.60	26.00
MAP	56.50	25.80
SEm±	5.66	3.12
CD (0.05)	12.00	NS

Fig. 8. On perusal of the data, it was clear that the treatments exerted much influence on the yield of rice. The total grain yield was found to be the highest with MAP (56.5 g pot^{-1}) and the least with the NF treatment (26.5 g pot^{-1}). However the treatments are in the order MAP > UAS > UF > GCU > C > NPK > NP > NF, in registering the grain yield of rice. Though the vegetative growth was less for UF treatment, it recorded a grain yield of 41.06 g pot^{-1} which was on par with UAS and GCU. The NF treatment recorded the minimum which was on par with NP tab, NPK tab and the control. The treatments MAP, UAS and GCU were found to be better treatments with profusive vegetative growth and good dry matter production. Though the UF treatment was poor in vegetative growth, there was no much yield depression. The partitioning of dry matter into grain yield may be better for this treatment as there was slow release of 'N' throughout the crop growth. In the case of MAP and GCU, the additional presence of secondary elements such as magnesium and calcium might have influenced the grain yield favourably. The leaching loss of N, P and K which will be discussed in section 2.4.1 which was found to be less for both MAP and GCU. The treatments NP and NPK tab, were recorded as the poor yielders of rice due to their low recovery of N. Though the control treatment received urea at the critical growth stages of the crop, it was subjected to more leachate N loss so it registered comparatively less grain yield.

2.1.5 Straw yield

The straw yield of the crop (g pot^{-1}) as influenced by different treatments is presented in Table 23. The influence of treatments was found to be nonsignificant. However the control treatment recorded a maximum straw yield of 27.4 g pot^{-1} and the minimum by NF treatment, 18.7 g pot^{-1}.

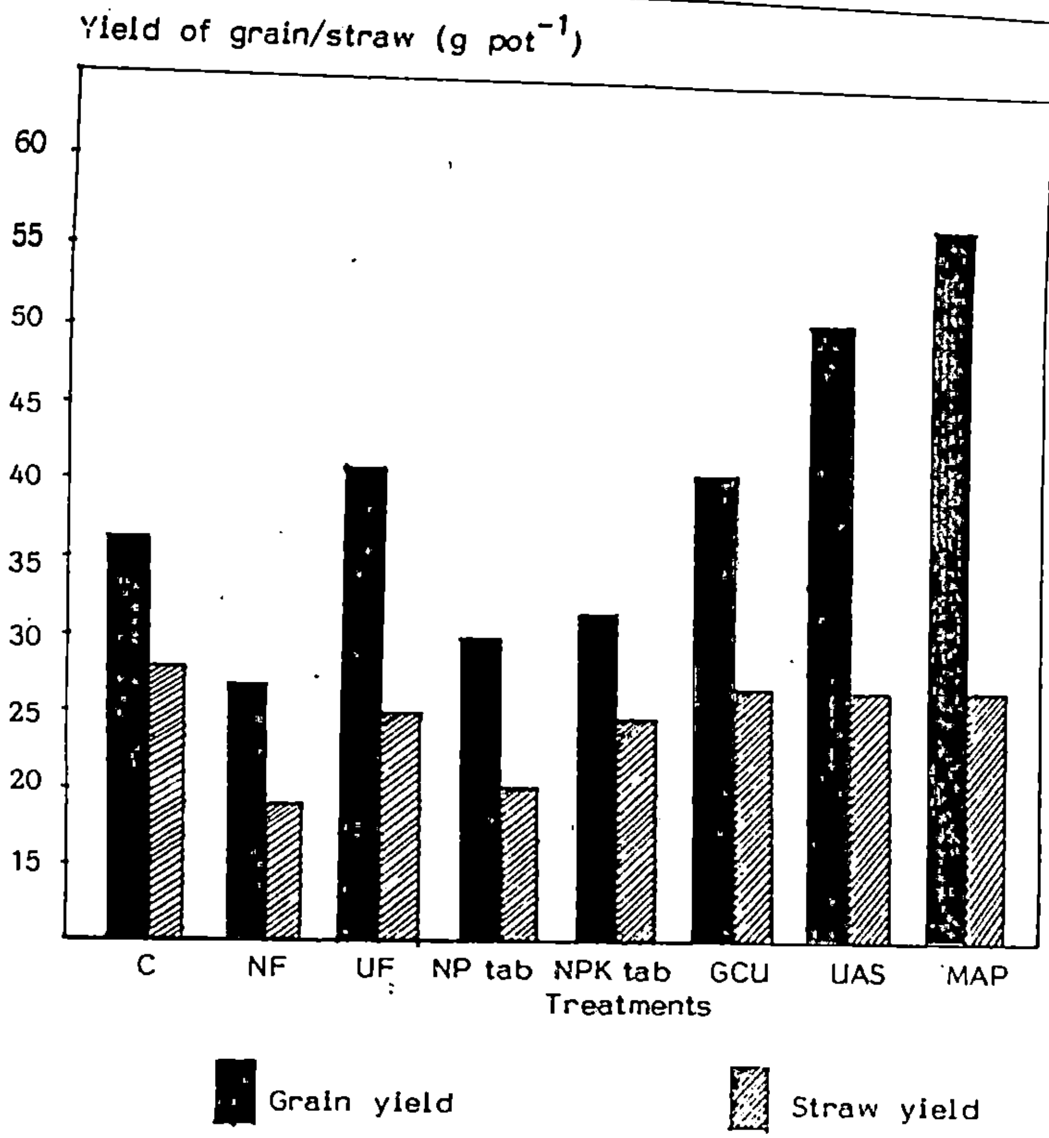

Fig.8. Yield of grain and straw as influenced by the treatments

C - Control
NF - No fertilizer
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum coated urea
UAS - Urea ammonium sulphate
MAP - Magnessium ammonium phosphate

2.2 Effect of different slow release N fertilisers on chemical characteristics of soil at different stages of crop growth

2.2.1 Soil reaction

Data on pH of the soil at different stages of crop growth viz. maximum tillering, panicle initiation and harvest as influenced by different slow release N fertilisers are presented in Table 24.

There was a sudden increase in pH at maximum tillering stage from original pH of soil (4.7) and then a slight increase in pH was noticed at the panicle initiation stage. At harvest stage, a reduction in pH was noticed due to the complete drainage of the crop before harvest. The effect of treatments was non significant at the first two stages.

2.2.2 NH_4-N content

Data pertaining to the NH_4-N content of the soil is presented in Table 25. As the stages of crop growth advanced, there was a decrease in the level of NH_4-N in soil due to crop uptake. The increase in NH_4-N content at harvest may be due to the low nitrification rate by the decrease in pH of the soil and the number of nitrifying bacteria. In laterite soils of Kerala a low nitrification rate was recorded by Anilakumar (1989).

The lowest value of NH_4-N was recorded by the NF treatment at all stages. The treatments NPK tab and MAP were on par with NF (24.5 ppm) at maximum tillering stage. At panicle initiation UF, C, NP tab and MAP were statistically at the same level of the NF treatment. There was no significant difference

Table 24. Soil reaction at various stages of crop growth

Treatment	Tillering	Panicle initiation	Harvest
C	4.80	5.10	5.00
NF	4.80	5.15	4.90
UF	4.90	5.15	5.00
NP tab	4.80	5.10	5.10
NPK tab	4.80	5.10	4.70
GCU	4.75	5.15	4.85
UAS	4.80	5.10	4.95
MAP	4.90	5.10	5.00
SEm±	0.07	0.05	0.06
CD (0.05)	NS	NS	0.13

Table 25. Ammoniacal nitrogen content (ppm) of soil at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest
C	37.80	18.13	26.60
NF	24.50	16.33	21.93
UF	34.53	18.20	35.93
NP tab	36.87	16.80	32.20
NPK tab	30.33	23.33	38.40
GCU	58.10	35.70	32.20
UAS	38.27	25.20	38.87
MAP	30.80	16.40	34.30
SEm±	3.25	1.57	3.31
CD (0.05)	6.89	3.33	7.02

between the treatments NF and C for the release of NH_4-N at the harvest stage. The highest value was recorded by GCU at maximum tillering and panicle initiation which was closely followed by UAS. But at harvest the latter treatment recorded the highest content of NH_4-N (38.87 ppm) which was on par with GCU. However, GCU with its higher concentration of N was found to be significantly superior to other treatments at the critical statges of maximum tillering and panicle initiation.

2.2.3 NO_3-N content

Table 26 represents the data on NO_3-N content in soil at different stages of crop growth.

The soil NO_3-N content decreased from maximum tillering to panicle initiation and then increased at harvest in the case of treatments C, GCU and MAP due to the complete removal of water prior to soil sampling. Comparatively lower values of NO_3-N may be due to low nitrification rate as well as loss of NO_3-N through leaching and denitrification.

Significant effect of treatments were also recorded at all stages of crop growth. The treatment GCU was found to be significantly superior (11.67 ppm) to other treatments in the release of NO_3-N in soil throughout the critical stages of crop growth. The NF treatment recorded the least value for NO_3-N (2.1 ppm) at all these stages. Among the other treatments GCU, UAS, MAP and UF registered higher values while control, NP tablet and NPK tablet registered lower values. This may be due to the high leaching loss from the control and lower nitrification rate of NP and NPK tablets as indicated by the incubation study detailed in 1.1.3. In the case of treatments such as GCU, UAS, MAP and UF lower leaching loss and higher

Table 26. Nitrate nitrogen content (ppm) of soil at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest
C	5.13	3.50	5.60
NF	2.10	2.33	1.87
UF	7.00	5.60	6.53
NP tab	7.00	5.60	2.80
NPK tab	5.60	3.73	2.80
GCU	11.60	7.70	14.70
UAS	8.40	4.90	4.20
MAP	8.40	5.60	6.30
SEm±	1.121	0.94	1.52
CD (0.05)	2.56	1.99	3.22

nitrification rate would have resulted in higher values of NO_3-N. Yadav and Srivasthava (1987) showed reduced rates of ammonification and nitrification of slow release N fertilisers as compared with urea. Though the control faired better at the first two stages of crop growth the release of NH_4-N was on par with the NF treatment at harvest.

2.2.4 Total release of NH_4-N and NO_3-N

The effect of different treatments on the total release of NH_4-N and NO_3-N from the soil under the pot study is depicited in Fig. 9 for the total NH_4-N release from the soil, the values varied from 62.76 to 126 ppm where as the values for total NO_3-N ranged from 6.3 to 31.97 ppm. The lowest valaues for both forms of nitrogen were registered by the NF treatment and the highest, by GCU (Fig. 9). The rate of nitrification was seemed to influence the total content of NO_3-N in the soil. Inherently, the nitrification process was at a slow pace as indicated by the NF treatment which was mainly due to the waterlogged situation. Regarding the treatments, the NH_4-N release was in the order NF < MAP < C < NP tab < UF < NPK tab < UAS < GCU and the NO_3-N was in the order NF < NPK tab < C < NP < UAS < MAP < UF < GCU. However the rate of nitrification was found to be very less for NP tab, C and NPK tab.

2.2.5 Available P

The variation on soil P as influenced by different treatments and stages of crop growth are presented in Table 27.

On perusal of the data it was revealed that there was a continuous decrease in the values of available P content of soil from maximum tillering to harvest.

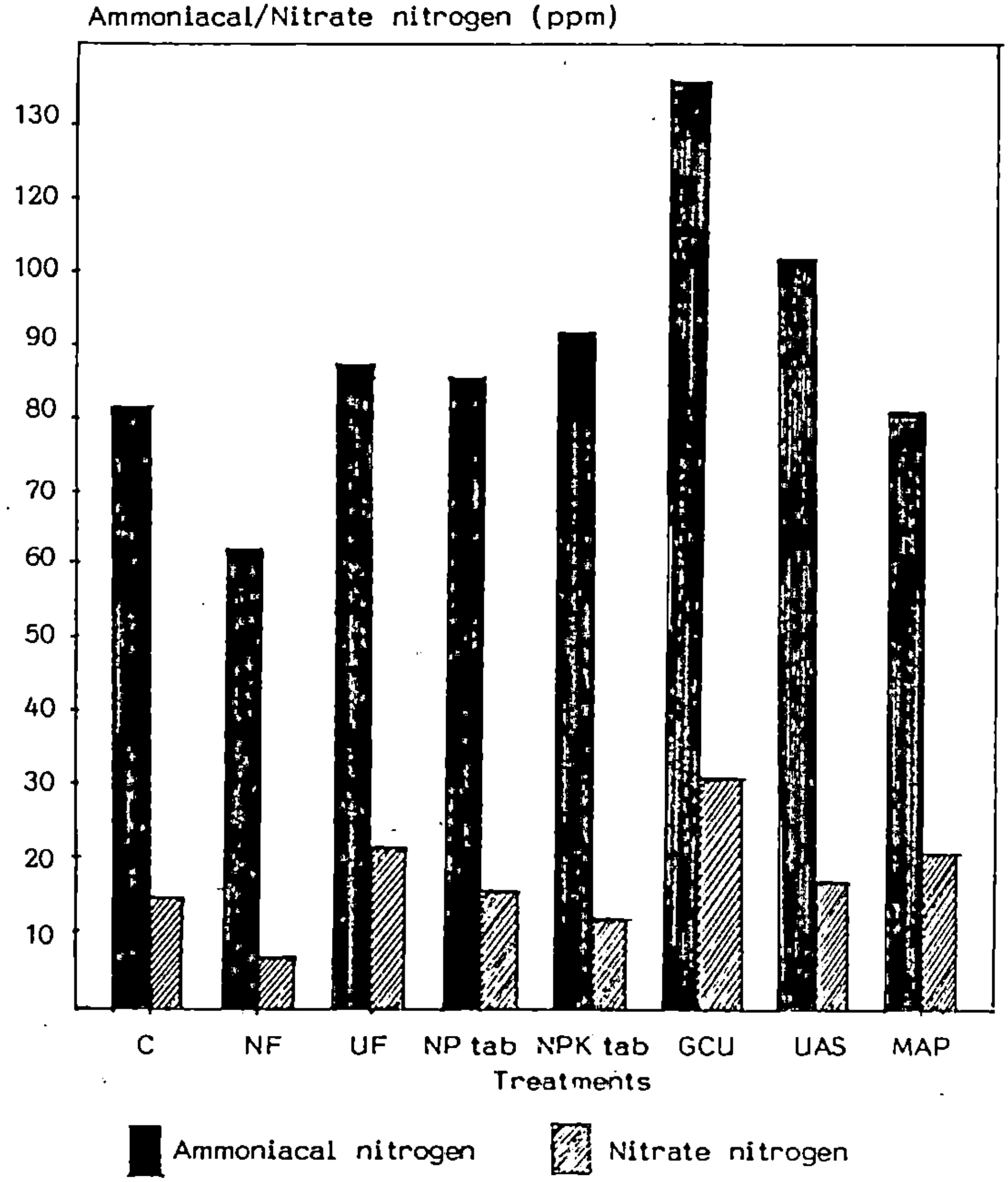

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Fig.9. Total release of Ammoniacal and Nitrate nitrogen in pot culture study as influenced by the treatments

C - Control
NF - No fertilizer
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum coated urea
UAS - Urea ammonium sulphate
MAP - Magnesium ammonium phosphate

Table 27. Available phosphorus content (kg ha^{-1}) of soil at various stages of crop growth

Treatment	Maximum Tillering	Panicle initiation	Harvest
C	63.94	60.81	47.51
NF	56.13	44.82	41.58
UF	58.69	57.37	42.66
NP tab	63.58	59.06	43.34
NPK tab	57.60	48.93	43.93
GCU	55.15	56.55	44.74
UAS	73.22	70.26	54.24
MAP	82.22	73.58	54.32
SEm±	1.91	4.72	1.60
CD (0.05)	4.06	10.00	3.40

At all the crop growth stages there was a significant difference for the different N-sources on available P release with MAP and UAS registering significantly superior value and NF the lowest value. However the release from NP and NPK tablets were found to be less. The treatments MAP, UAS and control recorded significant variation at all the intervals while others were on par with NF. The release of phosphate ions from MAP might have resulted for registering the high available P content in soil.

2.2.6 Available K

Data on K content of soil at different stages of crop growth are presented in Table 28.

In general the available K content of the soil continuously decreased from maximum tillering to panicle initiation and again slightly increased at harvest except for the NF treatment. This increase may be due to the second split dose of muriate of potash at panicle initiation. The available K content of the soil slightly dropped at maximum tillering. Further decrease in available K content of the soil at panicle initiation stage may be accounted to crop uptake of K and leaching loss.

The influence of the treatments on the available K content of the soil was found to be significant for all the three critical stages of crop growth. At maximum tillering, panicle initiation and at harvest the NF treatment recorded the lowest value. At maximum tillering, all the treatments were found to be superior to NF and at harvest NP tablet maintained superiority over all the other treatments.

Table 28. Available pottasium content (kg ha^{-1}) of soil at various stages of crop growth

Treatment	Maximum Tillering	Panicle initiation	Harvest
C	119.20	67.20	71.20
NF	76.00	50.40	48.00
UF	24.80	54.40	76.80
NP tab	138.40	90.40	127.20
NPK tab	94.40	54.40	77.60
GCU	113.60	73.60	55.20
UAS	124.00	60.80	71.20
MAP	94.40	62.40	68.80
SEm±	3.27	5.17	5.51
CD (0.05)	6.94	10.95	11.68

2.3 Nutrient uptake

2.3.1 Nitrogen uptake

The N uptake values at maximum tillering, panicle initiation and at harvest by grain and straw are presented in Table 29. The nitrogen uptake values by grain ranged from 556.5 to 1028.3 mg pot^{-1} recorded by NF and MAP respectively, the values by straw at harvest varied from 218.4 to 364.8 mg pot^{-1} that were registered by NF and GCU respectively. The treatment GCU recorded the highest N uptake both at maximum tillering and harvest by straw followed by UF. At panicle initiation UAS recorded the highest N uptake followed by NP tablet. The treatment NF always recorded the lowest values. The grain N uptake was maximum for MAP followed by the control treatment.

The higher straw yield and N content in the straw was reflected in the higher N uptake values of GCU and UF at maximum tillering and at harvest. At panicle initiation the highest straw yield of UAS was the reason for the higher N uptake at panicle initiation. The highest grain yield of treatment MAP caused for the highest grain N uptake and the highest N content in grain for treatment C was reason for the higher grain yield recorded by the treatment C. The total N uptake followed the decreasing order MAP > C > UF > UAS > GCU > NP tab > NPK tab > NF. The lower grain yield of NP and NPK tablet may be the reason for lower N uptake values.

2.3.2 Phosphorus uptake

The P uptake values increased as the growth stages advanced and maximum P uptake was recorded by grains. The P uptake by grains ranged from

55.7 to 152.0 mg pot^{-1} recorded by the treatments NF and MAP respectively (Table 30).

Treatment effects were also noticed. Maximum P uptake value was recorded by the treatment MAP in grains at harvest stage. But the P uptake by straw at harvest was maximum for the treatment C. However treatment NF recorded least values at all stages. The highest yield and P content were responsible for higher values of P uptake at all the stages of crop growth. The total P uptake values followed the decreasing order MAP > C > UF > GCU > UAS > NP > NPK > NF.

As in the case of total N uptake, P uptake also followed the same order with MAP registering the highest value and NF the lowest value. The lower P uptake of NP and NPK tablet may be due to the insoluble form of P in the tablet form. The treatment NP tablet recorded higher value than NPK because additional SSP was supplied for NP tablet and in the case of NPK tablet the whole P requirement was satisfied with the tablet form itself. The maximum value for MAP may be due to phosphate content in the MAP.

2.3.3 Potassium uptake

The K uptake values by grains ranged from 130.0 to 282.5 mg pot^{-1} recorded by the treatments NF and MAP respectively (Table 31).

At the maximum tillering stage the maximum value of 138.6 mg pot^{-1} was recorded by UF and the lowest value of 79.2 mg pot^{-1} by NF. The treatment NF recorded the lowest value at all the stages. At panicle initiation MAP registered the highest value and at harvest the maximum value was registered by UAS. The

Table 30. Uptake of phosphorus (mg pot^{-1}) by plant as influenced by the treatments at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest		
			Grain	Straw	Total
C	10.6	31.8	65.4	104.4	169.8
NF	10.7	25.9	55.7	53.0	108.7
UF	12.5	27.4	80.9	74.1	155.0
NP tab	08.7	35.0	65.9	58.3	124.2
NPK tab	10.7	28.2	56.2	61.0	117.2
GCU	13.9	26.5	84.2	62.3	146.5
UAS	13.2	36.6	63.3	65.1	128.4
MAP	13.9	41.2	152.0	54.4	206.4

Table 31. Uptake of potassium (mg pot^{-1}) by plant as influenced by the treatments at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest		
			Grain	Straw	Total
C	105.6	272.0	180.7	534.3	715.0
NF	79.2	216.0	130.0	467.5	597.5
UF	138.6	237.6	205.3	716.3	921.6
NP tab	86.8	316.8	146.5	551.6	698.1
NPK tab	95.2	234.6	107.8	523.6	631.4
GCU	136.0	250.8	199.5	703.6	903.1
UAS	128.0	307.2	138.6	754.0	892.6
MAP	108.8	317.4	282.5	657.9	940.4

higher K content in the straw attributed for respective increase in K uptake also. But in the case of grains MAP recorded high K uptake values due to the highest grain yield.

In general the total K uptake followed the decreasing order MAP > UF > GCU > UAS > C > NP tab > NPK tab > NF. From this it is clear that the release of K from NP and NPK tab forms is slow and so the total uptake was lowered for the same treatments as that of control.

2.4 Effect of slow release N fertilisers in reducing leaching losses of nutrients

2.4.1 N loss

Data on leaching loss of N during crop growth is represented in Table 32. Taking into consideration of total loss of N from the fertilisers maximum loss was occured from the treatment C (15.28 mg pot^{-1}) and the least (1.51 mg pot^{-1}) from NF. The efficiency in reducing the loss of N was in the decreasing order MAP > NPK tab > NP tab > GCU > UAS > UF > C (Fig. 10).

Significant leaching loss of N for treatments were observed up to 28 days and then the effect of the treatments was found to be non-sginifcant at the different intervals of crop growth (Table 32). Leaching loss of N upto 42 days after transplanting was reported by Sannigrahi and Mandal (1984). The leaching loss was found as the highest on 7th day and remained almost static upto 28th day.

Sannigrahi and Mandal (1991) reported leaching loss of N in the decreasing order UF > CDU > IBDU > urea > LCU in acidic alluvial soil.

Table 32. Nitrogen content (mg pot^{-1}) of leachate water at weekly intervals during crop growth

Treatment	Days after transplanting												
	7	14	21	28	35	42	49	56	63	70	77	84	Total loss
C	14.22	0.33	0.40	0.31	0.007	0.003	0.006	0.003	0.002	0.001	0.002	0.00	15.284
NF	1.31	0.83	0.07	0.04	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.00	1.511
UF	5.19	0.10	0.96	0.36	0.006	0.002	0.003	0.002	0.004	0.001	0.002	0.001	6.631
NP tab	2.70	0.28	0.58	0.16	0.002	0.003	0.003	0.001	0.002	0.003	0.002	0.00	3.736
NPK tab	2.91	0.20	0.36	0.14	0.004	0.001	0.002	0.003	0.002	0.003	0.001	0.00	3.626
GCU	3.83	0.20	0.11	0.13	0.006	0.002	0.003	0.002	0.004	0.001	0.001	0.00	4.289
UAS	4.11	0.22	0.16	0.26	0.004	0.004	0.004	0.002	0.003	0.001	0.001	0.00	4.768
MAP	1.53	0.18	0.29	0.13	0.001	0.002	0.002	0.006	0.001	0.002	0.001	0.00	2.145
SEm±	0.86	0.05	0.08	0.04	0	0	0	0	0	0	0	0	
CD(0.05)	1.83	0.11	0.16	0.08	NS	NS	NS	NS	NS	NS	NS	NS	

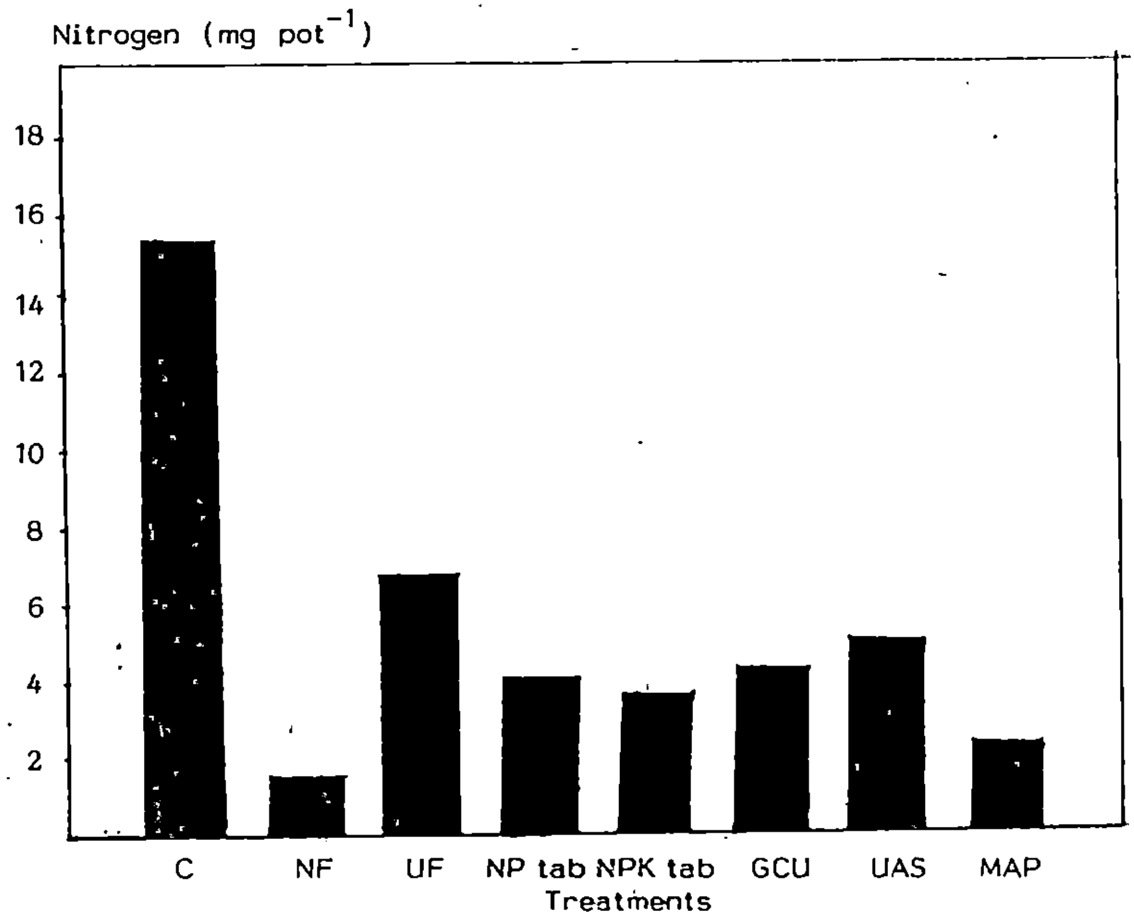


Fig.10. Total leaching loss of nitrogen as influenced by the treatments

C	- Control	NPK tab	- NPK tablet
NF	- No fertilizer	GCU	- Gypsum coated urea
UF	- Urea formaldehyde	UAS	- Urea ammonium sulphate
NP tab	- NP tablet	MAP	- Magnesium ammonium phosphate

Table 33. Phosphorus content (mg pot^{-1}) of leachate water at weekly intervals during crop growth

Treatment	Days after transplanting												
	7	14	21	28	35	42	49	56	63	70	77	84	Total loss
C	2.55	2.10	2.25	1.35	0.68	1.05	1.16	0.75	0.48	0.56	0.45	0.63	14.01
NF	1.95	0.30	0.30	0.60	0.20	0.56	0.41	0.27	0.30	0.11	0.17	0.12	5.29
UF	2.40	0.90	2.10	1.95	0.56	1.02	0.75	0.80	0.60	0.83	0.38	0.50	12.79
NP tab	2.55	2.10	1.05	1.35	0.78	1.10	0.57	0.41	0.57	0.95	0.41	0.60	12.45
NPK tab	2.40	2.10	0.90	1.50	0.38	1.01	1.35	0.60	0.45	0.80	0.63	0.41	12.52
GCU	2.40	1.50	3.00	1.05	0.45	1.17	1.02	0.60	0.75	0.50	0.56	0.80	13.80
UAS	2.40	0.90	0.90	1.65	1.05	0.65	0.75	0.38	0.83	0.78	0.78	0.48	12.60
MAP	2.25	1.95	0.90	1.05	0.75	1.31	0.78	0.68	0.65	0.38	0.63	0.72	12.00
SEm±	0.24	0.15	0.11	0.09	0.15	0.11	0.06	0.20	0.00	0.23	0.02	0.14	
CD(0.05)	0.52	0.31	0.24	0.20	0.31	0.23	0.13	0.42	NS	0.48	0.04	0.29	

The lowest leaching loss from MAP might have caused for the highest N recovery percentage and in the case of C both leaching loss and N recovery percentage was high. The treatments NP tab and NPK tab recorded lower leaching loss and lower N recovery percentage which indicated that the dissolution rate of the nutrients were low from the tablet form.

2.4.2 P loss

Data on cumulative leaching loss of P is represented in Table 33. The total loss values ranged from 5.25 to 14.01 mg pot^{-1}.

The loss of P in leachate water was observed at weekly intervals and it was noted that only up to 21st day, significant loss of P were recorded and after that there was no significant difference in the P loss. The highest loss was recorded on 7th day after transplanting and on 14th and 21st day the losses were found to be comparatively less.

The total loss was in the increasing order NF < MAP < NP tab < NPK tab < UAS < UF < GCU < C.

The phosphate ion associated with MAP recorded slow release so that leaching loss was less and the P uptake was found to be the maximum as discussed in 2.3.2. The treatments NP tab and NPK tab recorded higher loss and the P uptake was also less.

2.4.3 K loss

Data on K loss are presented in Table 34. The total loss values varied from 107.31 to 268.9 mg pot^{-1}.

There was leachate loss for K throughout crop growth. The losses were maximum on 7th day of sampling. Afterwards a slight decline in value was noticed and recorded gradual and slow decrease up to 35th day and on 42nd day a slight increase was noticed which again decreased up to 84th day. The increase in K loss on 42nd day may be due to the application of second split of MOP before panicle initiation. The leaching loss of K may be attributed to the availability of K ions in soil because all the treatments except NPK tab were supplied with MOP.

Significant effect of treatments were also noticed and the total loss was in the increasing order NF < NPK < GCU < MAP < UAS < NP < C < UF. The lowest uptake and leaching loss from NPK indicate less release of K from this tablet form.

2.5 N response

The data on N response are presented in Appendix V. The ranking of fertilisers on the basis of N response was MAP > UAS > UF >GCU > C > NPK tab > NP tab (Fig. 11). The values of grain yield recorded by the treatments were reflected in the N response values.

2.6 Nitrogen recovery percentage

Data on N recovery per cent is presented in Appendix V. The total N

Table 34. Potassium content (mg pot^{-1}) of leachate water at weekly intervals during crop growth

Treat-ment	Days after transplanting												
	7	14	21	28	35	42	49	56	63	70	77	84	Total loss
C	33.30	31.50	33.50	24.50	21.75	37.50	17.42	15.67	15.00	14.17	12.83	9.50	266.64
NF	27.50	26.50	13.50	7.00	4.50	19.50	2.08	2.25	1.23	1.25	1.35	0.65	107.31
UF	32.00	36.00	31.75	25.00	24.00	36.31	18.33	16.00	14.17	14.00	11.67	9.67	268.90
NP tab	41.50	33.85	36.75	21.25	19.50	33.15	14.50	12.50	14.18	10.50	9.08	6.83	253.59
NPK tab	33.00	34.75	15.50	10.00	10.50	27.15	7.33	7.08	6.00	6.33	5.58	4.25	167.47
GCU	34.15	34.15	24.00	16.50	11.50	36.00	9.50	8.83	8.97	8.00	7.92	6.83	206.35
UAS	36.00	39.65	32.35	21.50	18.00	26.70	14.17	11.50	14.18	10.33	9.50	8.17	242.05
MAP	35.75	42.50	26.15	21.50	17.00	30.75	12.67	14.18	10.67	10.17	8.67	6.83	236.84
SEm±	1.73	1.63	2.14	1.64	1.16	1.35	0.35	0.44	0.89	0.74	0.67	0.60	
CD(0.05)	3.71	3.45	2.98	3.47	2.46	2.85	0.74	0.93	1.88	1.58	1.43	1.26	

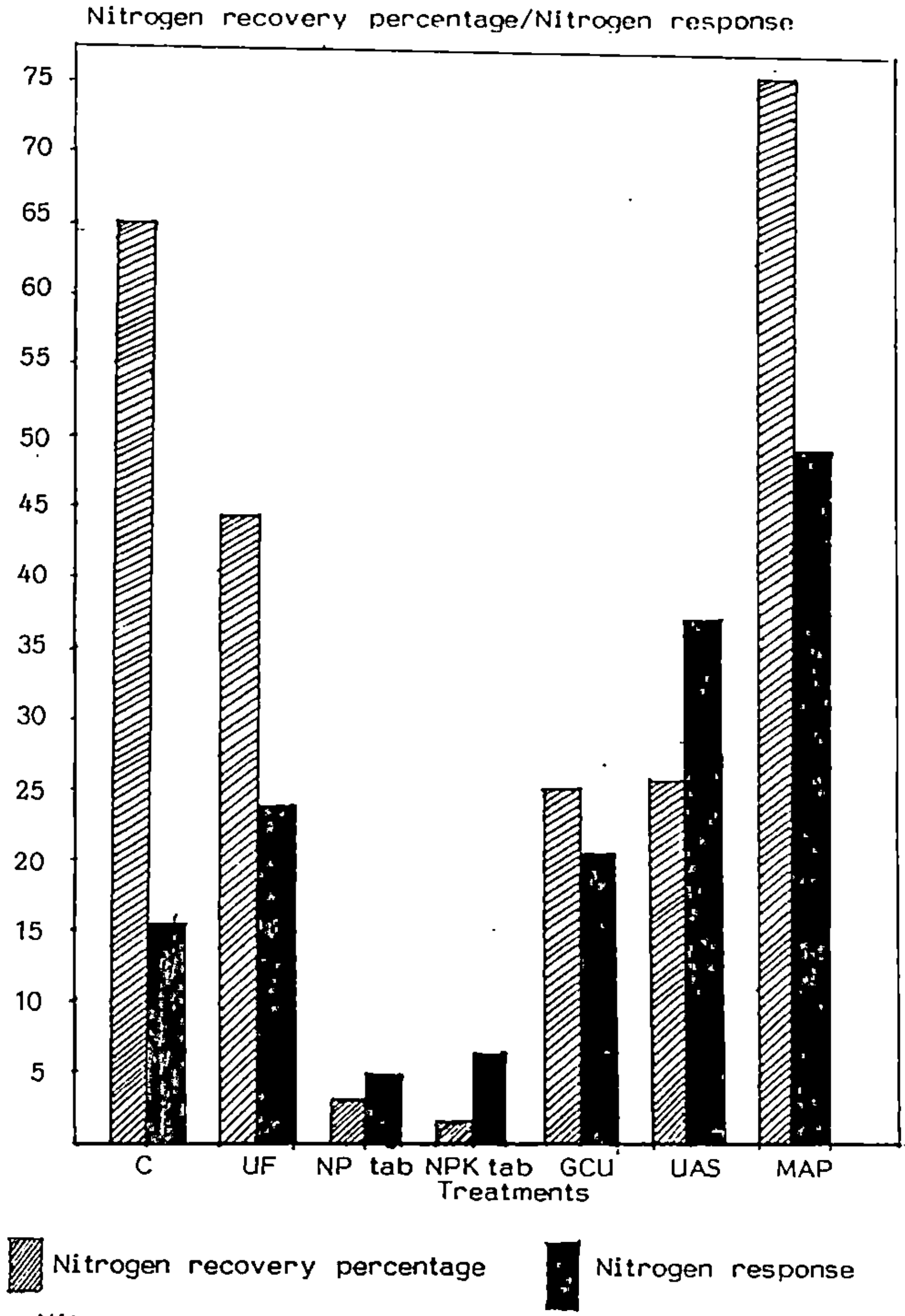


Fig.11. Nitrogen recovery percentage and Nitrogen response as influenced by the treatments

C - Control
UF - Urea formaldehyde
NP tab - NP tablet
NPK tab - NPK tablet
GCU - Gypsum coated urea
UAS - Urea ammonium sulphate
MAP - Magnesium ammonium phosphate

recovery values ranged from 1.45 to 75.37 per cent recorded by the treatments NPK tab and MAP respectively. The ranking of fertiliser on account of N recovery percentage was MAP > C > UF > GCU > UAS > NP tab > NPK tab (Fig. 11).

As revealed from the incubation study and pot culture study, due to more release of major nutrients from MAP the crop registered good N recovery percentage with MAP. It may be due to the slow releasing effect of N from MAP coupled with the split application of urea along with MAP to satisfy the nitrogen recommendation for rice. Moreover the P release from MAP were also found better and the highest grain yield was obtained. So, these might have caused for the highest N recovery. The lowest leaching loss from MAP also made the treatment superior among other treatments.

The treatment C was ranked as the second one in high N recovery percentage. In the case of N, P and K uptake MAP was closely followed by the treatments C. The highest dry matter yield, straw yield and N content in the grain might have attributed for the high recovery percentage. Due to split application of urea, the nutrient requirement of the crop at critical stages might have caused for higher N uptake as well as crop growth. Grain yield was comparatively less due to the highest leaching loss of N from the fertiliser. The fast nitrification of urea may be the reason for high leaching loss of N from the same treatment.

Split application of urea gave maximum grain yield compared to full basal application in rice (Datta *et al.*, 1990 and Moletti *et al.*, 1990). The rock phosphate coated urea and urea gypsum did not perform better than devided urea split application as revealed in a study with wet land rice (Singh and Katyal, 1987).

Kumar and Singh (1983) reported that split application of urea was superior to sulphur coated urea and lac coated urea for flooded rice.

The slow nitrification of UF due to its resistance to microbial decomposition and less solubility might have caused for higher grain yield and nutrient uptake by rice. Hence more N recovery percentage was obtained for UF. Slow hydrolysis of urea to ammonia in the UF because of very low activity of urease enzyme was reported by Bopaiah and Biddappa (1987). In the laterite soils single dose of UF was found to be effective as a sustained N release fertiliser up to 4 years after application (Vijayachandran and Devi, 1982).

The treatment GCU and UAS recorded comparatively high N recovery per cent, grain yield, straw yield and nutrient uptake values since the NH_4-N and NO_3-N release were maximum. In the case of GCU the coating with gypsum provided slow releasing effect and secondary nutrient calcium, might have attributed for the higher release of nutrients by liming effect. Singh and Yadav (1985) while recommending ways of increasing N use efficiency in low land rice, highlighted the use of rock phosphate and gypsum coated urea. The observations done by Moorthy (1982) were also corroborative to these findings.

The treatments NP and NPK tablets gave low values in the case of N recovery percentage, major nutrient uptake, grain yield, straw yield and leaching loss. The dissolution rate of these treatments is found to be slow and not sufficient for the requirement of crop at critical growth stages. The treatment NPK tab recorded higher NH_4-N release than NP tab but low NO_3-N release than NP tab. On account of the yield obtained NPK tab was better than NP tab may be due to the higher dissolution rate of 3 mg N day^{-1} where as for NP tab it was 2 mg N day^{-1}.

Out of 2.36 g of NP tab applied, 1.8 g was remaining in the soil after the experiment and 2.0 g of the NPK tab was remaining out of 3.83 g of applied tablet. The tablet form remained in the soil after the pot experiment was found to be containing 70 per cent of N and 80 per cent P for NP tab, while NPK tab contained 52 per cent N, 75 per cent P and 60 per cent K. Thus it is clear that only 30 per cent N of the NP tab was released during crop growth while NPK tab released 48 per cent N. But NP tab gave higher uptake values and N recovery percentage than NPK tab and the reason for this may be due to the more N per cent in the NP tab than NPK tab. On average these two treatments were almost similar in all aspects and were inferior to other treatments. The results also tend to suggest that for short duration crops these treatments were not suitable.

Thus it can be concluded that the superiority of the treatments MAP, UAS, GCU and UF over NP and NPK tab could be attributed to slow release of N, maintenance of higher concentration of ammonia in the rhizosphere, nitrification inhibition and subsequent less loss of nitrate through leaching.

Summary

SUMMARY

A laboratory incubation study was undertaken, with four different acid rice soils of Kerala namely laterite, kari, kuttanad alluvium and coastal sandy to assess the transformation of applied nitrogen. The efficiency of slow release fertilisers in relation to yield and plant uptake of nutrients was also evaluated by a pot culture experiment with the rice test variety, Jyothi. The results obtained and salient conclusions drawn are summarised below.

1. Significant reduction in pH was recorded at 60th, 90th and 150th days after incubation for the sandy soil while there was a slight decrease in pH for the laterite soil up to 90th day and then remained static up to 180th day. The effect of treatments were not significant throughout the period of incubation in the case of kari soil. For kuttanad alluvium a significant decrease in pH was noticed at 90th and 150th day of incubation.

2. The effect of treatments on NH_4-N content of soil was significant for all the soil types under study. Maximum release of NH_4-N was on 90th day, in the case of sandy, laterite and kuttanad alluvium, while it was on 150th day for the kari soil. The treatment MAP and NPK tablet recorded the highest release and UF and NP tablet the lowest.

3. Nitrate-N content of the soil also recorded significant variation due to the effect of treatments. An increased nitrification rate was recorded during early periods of incubation for the laterite and sandy soil while in kuttanad alluvium and

kari, the later periods of study recorded maximum nitrification. The treatment MAP and UAS registered the maximum NO_3-N content and UF and NPK tablet the minimum.

4. There was significant influence on available P content of soil due to the application of slow release fertilisers. In the case of sandy soil the available P status was static throughout the incubation period and in laterite maximum available P was recorded on 90th day. Both for kari and kuttanad alluvium soils, maximum available P release was recorded on 60th day. The treatments registered homogenous trend in Kari soil and in other soil types with UAS and MAP recording the maximum available P and NPK tablet recording the minimum.

5. Regarding the available K content of soil significant influence was noticed at all intervals. An increasing trend in the release of the same was noticed up to 120th day in Kari soil while in sandy and laterite soils, there were almost the same rate of release. But for kuttanad alluvium, the maximum release of available K was observed on 60th day of incubation. The treatment NF always registered the lowest values irrespective of the soil types.

6. Regarding the pH of the soil in pot culture study, the treatment effects were significant only at the harvest stage.

7. The NH_4-N content decreased with advanced stages of crop growth. The NF treatment recorded the lowest values whereas the highest values were recorded by GCU followed by UAS

8. With respect to the contents NO_3-N a decrease was noticed on 40th day which again increased at 90th day. Significant effects were noticed, with GCU registering the maximum and NF, the minimum.

9. Available P content of soil decreased as stages advanced, with MAP and UAS registering the highest values and the NF, the lowest.

10. Significant influence on available K content of soil was noticed with a continuous decrease from 25th to 90th day.

11. There was effect for the slow release fertilisers on plant height and tiller count. The treatment MAP recorded maximum values for these biometric observations on all the days of sampling.

12. With regard to the grain yield, the trend was in the order MAP > UAS > UF > GCU > C > NPK tablet > NP tablet > NF and for the straw yield the order was C > GCU > UAS > MAP > UF > NPK tablet > NP tablet > NF.

13. The uptake of major nutrients were also significantly influenced by the treatments. Uptake of N, P and K were recorded as the maximum with MAP, and the minimum with NF.

14. Leaching losses of N, P and K were significant for different N sources. Loss of N was more up to 28 days and there after, it decreased to insignificant levels. The control treatment recorded the maximum loss of N and MAP the minimum. The P loss was detectable only upto 21 days while the loss of K was

significant throughout the crop period in all the treatments. However, the cumulative K loss was the highest with UF and the lowest with NPK tablets.

15. Maximum N recovery percentage and N response was recorded by MAP.

Plate 1 Crop stand in UF as compared to C and NF

Plate 2 Crop stand in NP tablet as compared to C and NF

Plate 3 Crop stand in NPK tablet as compared to C and NF


ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
UREA FORMALDEHYDE


ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
NP TABLETS


ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
NPK TABLETS

Plate 4 Crop stand in GCU as compared to C and NF

Plate 5 Crop stand in UAS as compared to C and NF

Plate 6 Crop stand in MAP as compared to C and NF


ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
GYPSUM COATED UREA


ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
BLENDED UREA AMMONIUM SULPHATE

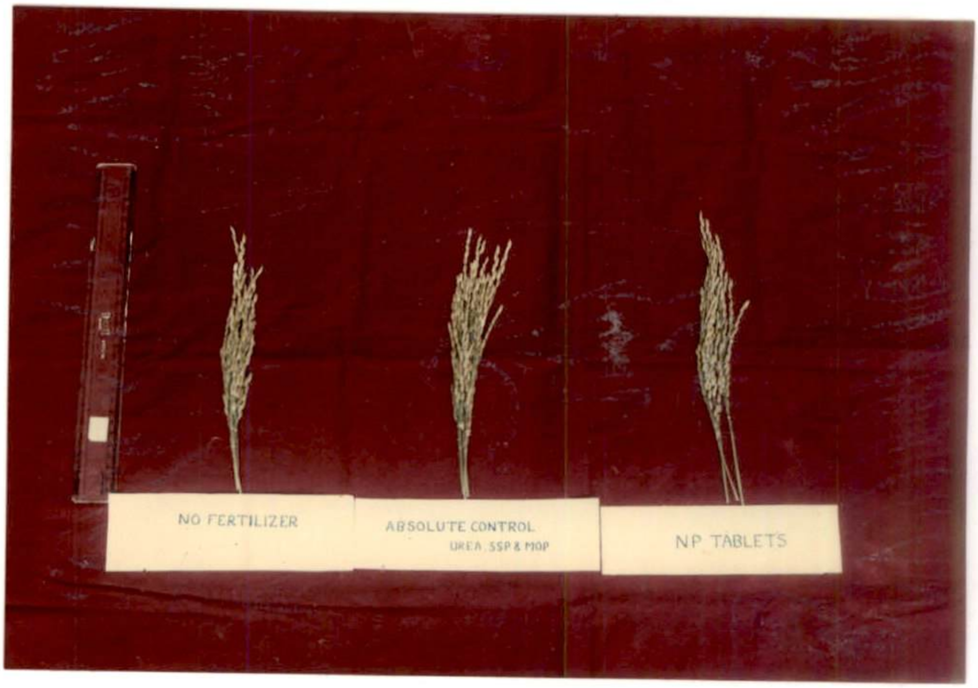

ABSOLUTE CONTROL (UREA, SSP & MOP)
NO FERTILIZER
MAGNESIUM AMMONIUM PHOSPHATE

Plate 7 Influence of UF over C and NF on panicle characteristics

Plate 8 Influence of NP tablet over C and NF on panicle characteristics

Plate 9 Influence of NPK tablet over C and NF on panicle characteristics


NO FERTILIZER
ABSOLUTE CONTROL
UREA, SSP & MOP
UREA FORMALDEHYDE


NO FERTILIZER
ABSOLUTE CONTROL
UREA, SSP & MOP
NP TABLETS


NO FERTILIZER
ABSOLUTE CONTROL
UREA, SSP & MOP
NPK TABLETS

Plate 10 Influence of GCU over C and NF on panicle characteristics

Plate 11 Influence of UAS over C and NF on panicle characteristics

Plate 12 Influence of MAP over C and NF on panicle characteristics


NO FERTILIZER
ABSOLUTE CONTROL
COATED UREA


NO FERTILIZER
ABSOLUTE CONTROL
UREA SSP & MOP
BLENDED UREA AMMONIUM
PHOSPHATE


NO FERTILIZER
ABSOLUTE CONTROL
UREA, SSP & MOP
MAGNESIUM AMMONIUM
PHOSPHATE

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Appendices

APPENDIX-I

Quantity of application of different fertilizers

Treatment	Quantity of fertilizer applied (g)							
	Incubation - 1 kg soil				Pot culture - 15 kg soil			
	Urea	SSP	MOP	SLNF	Urea	SSP	MOP	SLNF
C	0.089	0.114	0.034	-	1.335	1.710	0.51	-
NF	-	-	-	-	-	-	-	-
UF	-	0.114	0.034	0.108	-	1.710	0.51	1.62
NP tab	-	0.079	0.034	0.157	-	1.185	0.51	2.36
NPK tab	-	-	-	0.260	-	-	-	3.83
GCU	-	0.114	0.034	0.108	-	1.710	0.51	1.62
UAS	-	0.114	0.034	0.128	-	1.710	0.51	1.92
MAP	0.079	-	0.034	0.064	1.185	-	0.51	0.96

APPENDIX-II

Nitrogen per cent in plant as influenced by the treatment at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest		Total
			Grain	Straw	
C	3.50	4.48	2.52	1.12	3.64
NF	3.22	3.50	2.10	1.40	3.50
UF	5.04	3.64	1.82	1.40	3.22
NP tab	4.76	4.60	2.10	1.12	3.22
NPK tab	4.34	4.76	1.82	1.12	2.94
GCU	5.04	4.48	1.54	1.40	2.94
UAS	3.64	4.48	1.54	0.84	2.38
MAP	3.64	3.92	1.54	0.98	2.52

APPENDIX-III

Phosphorus per cent in plant as influenced by the treatments at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest		Total
			Grain	Straw	
C	0.331	0.398	0.181	0.381	0.562
NF	0.381	0.431	0.239	0.348	0.587
UF	0.348	0.381	0.197	0.300	0.497
NP tab	0.364	0.398	0.225	0.269	0.494
NPK tab	0.381	0.414	0.181	0.256	0.437
GCU	0.348	0.348	0.211	0.239	0.450
UAS	0.331	0.381	0.142	0.225	0.367
MAP	0.431	0.448	0.269	0.211	0.480

APPENDIX-IV

Potassium per cent in plant as influenced by the treatments at various stages of crop growth

Treatment	Maximum tillering	Panicle initiation	Harvest		Total
			Grain	Straw	
C	3.30	3.40	0.50	1.95	2.45
NF	3.10	3.60	0.50	2.50	3.00
UF	3.85	3.30	0.50	2.90	3.40
NP tab	3.30	3.60	0.50	2.80	3.30
NPK tab	3.40	3.45	0.35	2.20	2.55
GCU	3.40	3.30	0.50	2.70	3.20
UAS	3.20	3.20	0.35	2.90	3.25
MAP	3.40	3.45	0.50	2.55	3.05

APPENDIX-V

Nitrogen recovery percentage and N response as influenced by the treatments

Treatment	N response	N recovery percentage
C	15.68	64.99
NF	-	-
UF	23.71	44.76
NP tab	4.56	2.87
NPK tab	7.0	1.45
GCU	21.82	26.22
UAS	37.62	26.74
MAP	48.86	75.37

DYNAMICS OF NUTRIENT RELEASE AND TRANSFORMATIONS FROM SLOW RELEASE FERTILISERS IN ACID RICE SOILS

By

P.T. NISHA

ABSTRACT OF A THESIS

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ABSTRACT

A study was conducted to assess the pattern of release and transformation of major plant nutrients from slow release nitrogen fertilisers (SLNF) and to evaluate the efficiency of SLNF at the College of Horticulture, Vellanikkara, during 1992-94. Urea formaldehyde (UF), NP tablet (NP tab), NPK tablet (NPK tab), gypsum coated urea (GCU), blended urea ammonium sulphate (UAS) and magnesium ammonium phosphate (MAP) were compared with no (NF) and recommended dose of fertilisers (C). Evaluations were conducted with four acid soils viz., laterite, kari, kuttanad alluvium and coastal sandy kept under incubation for six months and a pot culture study using laterite soil and rice variety Jyothi during puncha season.

The release of ammoniacal nitrogen (NH_4-N) was found maximum in kari soil, followed by kuttanad alluvium and laterite and the lowest in sandy soil. Release of nitrate nitrogen (NO_3-N) was maximum in the earlier periods in the case of sandy and laterite soils with lower release at later stages. In the case of kari and kuttanad alluvium the trend was opposite with higher release at later intervals and lower release at early periods. In general nitrification was found to be low in all the soils. Irrespective of the soil types, the maximum content of NH_4-N was recorded by the NPK tab which was closely followed by MAP, whereas the maximum NO_3-N was registered by MAP. For these two different forms of nitrogen, the minimum valaues were always found in the NF treatment.

The available P content of the soil recorded significant variation throughout the period of incubation. Among the treatments MAP and UAS recorded

the maximum values and NPK tab the minimum P content. Irrespective of the soil types, there was uniformity in the release of available K throughout the incubation period. In pot culture trial NH_4-N decreased as crop stages advanced. With NO_3-N, an initial decrease followed by an increase at harvest stage was noticed. The treatment GCU recorded maximum NH_4-N and NO_3-N content, while NF the minimum. There was decrease in available P and K contents of the soil as the crop growth proceecded.

Significant influence on morphological observations were also recorded with MAP maintaining superiority over other treatments. Maximum dry matter, straw and grain yield were recorded respectively by the treatments UAS, C and MAP. Uptake of N, P and K were also influenced significantly with MAP registering the highest and NF the lowest values. Both NP and NPK tab recorded lower values.

Maximum leaching loss of N and P were seen with the control and the minimum with MAP whereas it was respectively with UF and NPK tab for K. The total N recovery percentage, was recorded in the decreasing order: MAP > C > UF > GCU > UAS > NP tab > NPK tab. There was a decreasing order of MAP > UAS > UF > GCU > C > NPK tab > NP tab for N response of different treatments under study.