

FIXATION OF NH_4^+ IN SOILS AND ITS AVAILABILITY TO CROPS

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by
Dipankar Saha

Department of Agricultural Chemistry and Soil Science
Faculty of Agriculture
Bidhan Chandra Krishi Viswa Vidyalaya
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BIDHAN CHANDRA KRISHI VISWA VIDYALAYA
FACULTY OF AGRICULTURE
DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
KALYANI, NADIA, WEST BENGAL.

Dr. Asit Kumar Mukhopadhyay,
Reader in Soil Science.



No

Date July 24th, 1981....

This is to certify that the work recorded in the thesis entitled "FIXATION OF NH_4^+ IN SOILS AND ITS AVAILABILITY TO CROPS" submitted by Sri Dipankar Saha for the award of the degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science of the Bidhan Chandra Krishi Viswa Vidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

(Asit Kumar Mukhopadhyay)

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Dipankar Saha
(Dipankar Saha)

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INTRODUCTION

Relatively large quantities of nitrogenous fertilizers are usually required for obtaining high crop yields, particularly in the fields where high yielding varieties are grown. But the cost of nitrogen fertilization assumes a considerable proportion of the total cost of production. Therefore, efficient utilization of the added nitrogenous fertilizer is considered inevitable to decrease the cost of crop production. Most widely used nitrogenous fertilizers are either ammoniacal or ammonium yielding. In view of the rapid increase in the use of such nitrogenous fertilizers to meet the requirements of crops, clay fixation of applied NH_4^+ assumes importance of practical significance in high NH_4^+ fixing soils. It is, therefore imperative to understand the dynamics of fixed NH_4^+ along with soluble and exchangeable NH_4^+ in soils where fixed NH_4^+ -N fraction is quantitatively important. Results of few laboratory and field studies have indicated that the fixation of applied ammonium in soils is quite rapid but its release or conversion to available forms is rather slow. These studies have pointed out that although the process of ammonium fixation prevents its leaching loss to deeper soil layers, being converted to unavailable form, it reduces the recovery percentages of the applied nitrogen by the crop plants. From the practical point of view, therefore, it is necessary to study the dynamics of clay fixed NH_4^+ under different

situations both in laboratory and in field with growing plants. Such studies shall not only throw light on the quantitative significance of native and recently fixed NH_4^+ in the perspective of nitrogen transformation in soil under different management practices but also will increase our understanding as to whether efficiency of added ammonium fertilizers can be increased by preventing fixation of ammonium ions or increasing the availability of fixed NH_4^+ ions.

Although, it is now a well known fact that many soils are capable to fix considerable amount of ammonium, it has not yet received much attention like potassium and phosphorus fixation. McBeth (1917) was probably the first scientist who recognized that under moist condition, soils fix a considerable amount of applied ammonium which could not be extracted by alkaline distillation or 10 per cent hydrochloric acid. Since the discovery of NH_4^+ fixation in soils, considerable work has been done on various aspects of this phenomenon, like, distribution of native fixed NH_4^+ in surface soils in different parts of the world and many factors affecting NH_4^+ fixation in soil. But most of the studies on factors affecting fixation of added NH_4^+ were done in one or two soils and after a fixed time period. The changes with time have rarely been monitored. Moreover, studies were not usually accompanied with simultaneous changes in other inorganic forms of nitrogen present in the soil like exchangeable NH_4^+ and soluble NO_3^- .

Besides, considerable inconsistencies exist in most of the

previous studies regarding the methods employed for the preparation of the soil and methods used for the determination of fixed NH_4^+ . As for example, some workers have subtracted the amount of available N (exchangeable and soluble) from that of added NH_4^+ -N and termed as fixed, while others have used Silva and Bremner's (1966) method, again some others have used other extraction methods for estimation of fixed NH_4^+ -N in soil. Naturally, the knowledge that have accumulated with respect to this phenomenon were not uniformly obtained. Hence, the present investigation was conducted to study the effect of some of the important but less studied factors on fixation of ammonium in few soils of West Bengal. In order to study the fate of applied ammonium-N and the possible transformation of fixed ammonium to exchangeable form, periodic changes were simultaneously monitored for fixed ammonium, exchangeable ammonium and soluble nitrate forms of nitrogen in the soil and the results have been incorporated under the section entitled 'FIXATION OF NH_4^+ AND ITS TRANSFORMATIONS TO OTHER MINERAL FORMS IN SOILS'.

Regarding the availability of clay fixed ammonium to crops, we know that generally native fixed ammonium nitrogen is of very low availability and controversy exists as to the availability of recently fixed ammonium nitrogen. The increased use of ammonium or ammonium producing forms of fertilizers create an increasing need for more accurate determination of ammonium fixation and release phenomenon under different climatic regions and management practices, particularly in soils where

this fraction is quantitatively and dynamically important. Since most of our knowledge on the availability of fixed ammonium to crops was largely due to laboratory and green house oriented studies, the relevance of field situation was difficult to extrapolate. As adequate information through field experimentation is not available on the effect of cropping on the release of native fixed ammonium nitrogen and availability of recently fixed ammonium in soils of West Bengal, three successive field experiments were conducted and the results have been incorporated under the section entitled 'AVAILABILITY OF FIXED NH_4^+ TO CROPS'.

FIXATION OF NH_4^+ AND ITS TRANSFORMATION TO OTHER MINERAL FORMS IN SOILS

Process of fixation

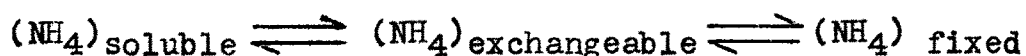
Hendricks and Fry (1930) were among the pioneer research workers to demonstrate with the help of X-ray diffraction analyses that soil materials, even in their finest size fractions, are crystalline in nature. Some years later, Volk (1933) found that the clay fraction (0.3 to 2 μ) in soil samples taken from a plot of a long term field experiment, fertilized with K for nearly 50 years gave stronger second order diffraction lines of muscovite on X-ray analysis than did the soil from a corresponding untreated plot. He concluded that a portion of the added K had reacted with silica and alumina gel to form muscovite. Gorbunov (1936) pointed out that drying of clay minerals following treatment with a K^+ - containing solution resulted in occlusion of K^+ ions into Helmholtz-Stern double layer. Chaminade and Drouineau (1936) however, were of the opinion that fixation, was the result of migration of cations in the crystal nuclei of the colloids.

The reaction mechanism of cation fixation was further clarified when it was proved that the fixation of K was accompanied by a corresponding decrease in the C.E.C. of the soil (Hoagland and Martin, 1933; Joffe and Levine, 1939; Karlsson, 1952; Troug and Jones, 1938). This gave a strong indication that the exchange sites were involved in the fixation reaction. Further

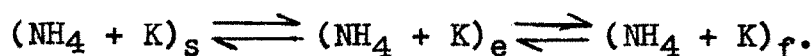
progress in the field of cation fixation was made possible mainly by successful X-ray diffraction studies on the structure of the clay minerals as this information is of great importance for a correct understanding of the cation fixation and release reactions (Grim, 1953; Mackenzie, 1955; Marshall, 1949; Rich and Thomas, 1960; Schuffelen and Marel, 1955).

Page and Baver (1940), considered that cation fixation is related to the size of the cation and kind of fixing materials. The generally accepted idea is that the fixation of ions of certain critical dimension (diameter $2.8\overset{\circ}{\text{\AA}}$) by layer silicate minerals of 2:1 lattice type be ascribed to their accommodation in sites similar to those occupied by potassium in muscovite. They assumed that on drying, the K^+ ions lose their hulls of oriented water molecules and are forced into free hexagonal spaces between the Si_2O_5 layers, where they fit most tightly. Similarly, ions of about the same dehydrated diameter are also likely to become fixed. Wiklander (1950), however, demonstrated that Ba^{++} ions whose ionic diameter is almost equal to that of K^+ and NH_4^+ does not get fixed by the clay minerals.

To explain the phenomenon of fixation and release of K^+ in clay minerals, it has been suggested that there exists a kind of dynamic equilibrium between the ions in the soil solution, K_s ; the exchangeable K, K_e ; and the fixed K, K_f (Bartholomew and Janssen, 1931; Chaminade, 1934; Schachtschabel, 1937). A similar equilibrium may occur between the different forms of ammonium in the soil.



According to this equation, a change in any of the above forms of NH_4 will affect other forms involved in the equilibrium reaction. When the concentration of $(\text{NH}_4)_s$ exceeds the equilibrium value (e.g., after addition of NH_4^+ containing fertilizers), the reaction proceeds to the right, leading ultimately to fixation of some of the added NH_4^+ . On the other hand, the fixed NH_4 $(\text{NH}_4)_f$, will be released when $(\text{NH}_4)_e$ falls below the actual equilibrium value. In view of the generally overwhelming predominance of K^+ Vs. NH_4^+ in soil systems and the similarity of these ions with respect to fixation reaction, it is often more realistic to introduce into the equilibrium equation the sum of NH_4^+ and K^+ ions rather than NH_4^+ alone (Nommik, 1957).



With the aid of tracer techniques, Wiklander (1950) and Nommik (1957) showed that only a part of the K or fixed NH_4 participates in a real equilibrium with the exchangeable ions, indicating that the last stage of the equilibrium reaction is strongly hysteretic.

Wear and White (1951) pointed out that when montmorillonite is saturated with K^+ and dried, its layers contract and the interlayer K^+ ions are pressed into the spaces formed by the superimposition of two voids with hexagonal nets of O ions from each silica layer. In this position, cations possess fourteen fold co-ordination and not twelve fold, as the OH^- ions are in

proximity to the spaces. In such a situation, the radius of the O ions in the fourteen-fold co-ordination with K^+ ions becomes equal to the radius of these ions as was calculated by Pauling (1940) empirically from wave mechanics ($O = 1.23\overset{\circ}{\text{\AA}}$) and K^+ ion forms the most stable co-ordination. Rb ions form moderately stable ($O = 1.46\overset{\circ}{\text{\AA}}$), Na^+ ions less stable ($O = 1.23\overset{\circ}{\text{\AA}}$) and Cs ($O = 1.55\overset{\circ}{\text{\AA}}$) and Li ions ($O = 1.07\overset{\circ}{\text{\AA}}$) unstable configurations.

Some of the relevant factors affecting NH_4 fixation

Nature and amount of clay, silt, sand and oxides of iron and aluminium

The layer lattice silicate minerals which are responsible for NH_4^+ fixation are vermiculite, hydrobiotite, illite and montmorillonite (Page and Baver, 1940; Stanford and Pierre, 1947; Allison, Doetsch and Roller, 1951, 1953a; Barshad, 1951, 1954b; Allison, Roller and Doetsch, 1953c; Allison, Kefauver and Roller, 1953b; Vander Marel, 1954; and Allison and Roller, 1955b).

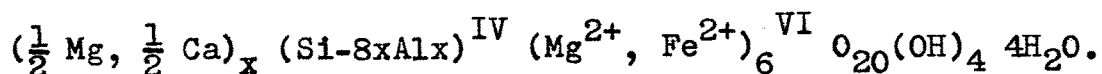
Montmorillonite minerals have the capacity to swell in water. The extent of this swelling depends on the exchangeable ion and the electrolyte concentration. Montmorillonite also forms inter-layer complexes with double sheets of glycerol molecules and yields a basal spacing of $18\overset{\circ}{\text{\AA}}$ (MacEwan, 1944 and Bradley, 1945). According to Barshad (1950), when montmorillonite is saturated with K^+ or NH_4^+ or Cs^+ or Rb^+ , it will have an expanded lattice containing mono-molecular layer of water. Hence as cation fixation requires lattice

collapse and close approach of adjacent clay plates, no fixation of either K^+ or NH_4^+ takes place as long as the mineral remains hydrated. So under wet conditions, fixation by montmorillonite is very small. On the other hand, when K-treated montmorillonite is heated to $30^\circ C$, the lattice collapses and K^+ ions are fixed (Stanford, 1948; Caillere et al., 1948; and Caillere and Henin, 1949). Dowdy and Hutchenson (1963b) also reported that air-drying ($<4\%$ moisture) of potassium saturated montmorillonite results in fixation of K^+ ions. Surface charge density to a large extent determines the expansion of the lattices and hence K^+ and NH_4^+ fixation (Marshall, 1964). The negative charge per unit cell is 2 equivalents for micas, around 1.3 for vermiculite and approximately 0.66 for montmorillonite. Presumably, the smaller lattice charge of montmorillonite (as compared with vermiculite and mica) is responsible for the thick layers of interlayer water on montmorillonite at high vapour pressure and the small "wet" fixation observed for that mineral.

Vermiculite is defined as consisting of trioctahedral mica or talc-like sheets separated by layers of water molecules occupying a definite interlayer space of $4.98\text{\AA}$. The thickness of the water layer depends on the nature of the interlayer cation (Barshad, 1950). Ca^{++} and Mg^{++} are the exchange cations in natural vermiculite and are associated with double layers of water molecules. According to Gruner (1939), Walker (1949, 1950), Walker and Milne (1950) and Barshad (1948, 1950, 1951), vermiculite has a 14.1 to $14.3\text{\AA}$ reflection. When the mineral is treated with K^+ or NH_4^+ , due to entrapment of these ions, layers contract and the basal spacing

shifts to $10.9\text{\AA}$. Heating causes further shrinkage to $10.1\text{\AA}$, and hence the mineral can fix large amounts of NH_4^+ or K^+ ions. As a result cation exchange capacity decreases from 140 to 50 m.e/100 g.

Grim (1953) has suggested the following mineral formula for vermiculite.



As a result of isomorphous substitution of Al^{3+} for Si^{4+} , vermiculite has a net negative charge, mainly in the tetrahedral layer. When K^+ or NH_4^+ saturated vermiculite is air dried, the lattice collapses and traps these ions regardless of the presence of water (Barshad, 1948; Wear and White, 1951). Even under moist conditions, K^+ or NH_4^+ will be fixed by vermiculite (Dowdy and Hutchensen, 1963a). Solvation of vermiculite with glycerol does not materially change its interlayer expansion (Walker, 1950 and Barshad, 1950).

Dyal and Hendricks (1952) and Van der Marel (1954) indicated that the saturation of vermiculite and degraded illite with NH_4 and K may lead to a contraction of the crystal lattice. Barshad (1954a) offered the theory that fixation of NH_4 by vermiculite and montmorillonite is depended on the magnitude of the interlayer charge of the mineral. He stated that if all of the cavities in the interlayer oxygen sheets of the mica minerals were to be occupied by a monovalent cation, the interlayer charge of the mineral would range from 240 to 260 me/100g. Hence, a mineral with a lesser charge than this would have empty cavities. According

to Barshad, they act as ports of entry and departure from the interior of the particle. He showed evidence that when interlayer charge is greater than 200 m.e./100g; NH_4 fixation would be high; whereas a mineral with an interlayer charge of less than 110 m.e./100g would not fix NH_4 . It should be mentioned that Barshad used minerals which were vermiculite interleaved with chlorite to obtain various interlayer charges.

According to Grim (1953) chlorite is similar to vermiculite except that it has a layer of brucite, which is not readily replaceable in the interlayer space instead of K as in biotite. The brucite has a positive charge to balance the negative charge of the mineral. Since Barshad used the total exchangeable interlayer cations to measure the interlayer charge, the chlorite in the presence of vermiculite would have a diluting effect in so far as the measurable interlayer charge is concerned. The interlayer charge of the vermiculite present would not be changed by diluting it with chlorite.

Gruner (1934) first applied the name "hydrobiotite" to mineral with characteristics similar to biotite, yet containing substantial amounts of water. Subsequently hydrobiotite has been identified as a more or less regularly interstratified biotite - vermiculite minerals (Brindley, 1951 and Bassett, 1959). Bassett(1959) reported that it will have a potassium content approximately one-half that of biotite. Generally, hydrobiotite gives a poorly defined first order peak at around 24 to $25\text{\AA}$, strong basal reflections at $11.4\text{\AA}$ and weak third order peak at

8.1Å . The exact position varies according to the proportion of biotite and vermiculite. K^+ and NH_4^+ saturation gives a 10.5Å spacing (Brindley, 1951). The main difference between hydrobiotite and vermiculite is the presence of K^+ in alternate layers of hydrobiotite. Layers not occupied by K^+ may have Mg^{++} or Ca^{++} on the exchange sites. From the literature it is evident that hydrobiotite fixes K^+ and NH_4^+ as was indicated for vermiculite. Thus, hydrobiotites are also capable of fixing K^+ and NH_4^+ under wet conditions and of yielding a 10Å mineral upon K^+ or NH_4^+ saturation and drying. Illite or hydrous mica is a 2:1 lattice having characteristics of muscovite and is also recognised as a clay mineral capable of fixing large amounts of K^+ as well as NH_4^+ .

Harada and Kutsuna (1954) were of opinion that ammonium fixation by residual soils from crystalline schist's at Yahatahama was due to degraded vermiculite apparently developed from chlorite during weathering of schist. Stevenson and Dhariwal (1959) reported that naturally fixed NH_4^+ in great soil groups was related to the amount and kind of clay minerals present and the order of ammonium fixation was illite > montmorillonite > kaolinite. Grewal and Kanwar (1967a, b and c) attributed the ammonium fixation in Punjab soils to the presence of illite clay minerals. Prasad et al. (1970) considered that montmorillonite along with illite clay minerals were responsible for ammonium fixation in black soils of Putida (Bihar).

Pathak and Srivastava (1963) reported that clay fraction of

the soils fixed highest amount of NH_4^+ and contributed nearly 68.2 per cent of the ammonium fixation capacity. The contribution of silt was 10 per cent and that of sand 18.3 per cent. The ammonium fixation by sand fraction was attributed to the association of some clay minerals with the sand particles. Kowalenko and Ross (1980) demonstrated with N^{15} that the relative quantitative importance of recently fixed NH_4^+ in various particle size fractions was not in the same order as that of the native fixed NH_4^+ . The fine silt fraction (2-5 μm) fixed a larger amount (whole soil basis) than the fine clay fraction (0.2 μm). The coarse clay fraction (0.2 to 2 μm) fixed the most NH_4^+ added. Sand size fractions were shown to contain native fixed NH_4^+ and were capable of fixing small amount of added NH_4^+ .

The fixation of added NH_4^+ has also been demonstrated in some Hawaiian amorphous soils free of layer lattice silicates (Tamini, 1963). These soils contain large amounts of colloidal hydrated oxides of Fe and Al, and they show high capacity to fix phosphate. Sahrawat (1979) studied by treating 10 g soil samples with 50 mg NH_4^+ as $(\text{NH}_4)_2\text{SO}_4$ dissolved in 20 ml of water and equilibrating for 2 hrs by continuous shaking and then extracting NH_4^+ with 2M KCl. The portion of NH_4^+ added which was not extracted by KCl was termed as fixed. This fixed NH_4^+ in soils was not related to pH, organic matter or clay content but correlated with the amount of active iron in the soils. The results of the study suggest that because of the reversible oxidation and reduction of iron oxides in rice soils, this mechanism of NH_4^+ fixation may be of special importance in sorption and desorption of NH_4^+ - N and needs a thorough

investigation. In a recent study Saha and Mukhopadhyay (1981) reported that NH_4^+ fixing capacity of the soils are well correlated with the amount of free iron oxide and clay content of the soils. Fixation of added NH_4^+ increased with the increasing amount of hydrous oxides of iron added to the soil.

Organic matter content of the soil

Sohn and Peech (1958) reported that some of the ammonium fixing capacities of the representative New York soils can be attributed to organic matter. The destruction of soil organic matter by oxidation with H_2O_2 markedly decreased the capacity of most soils to fix ammonia into non-exchangeable form. It was concluded that at least 50 per cent of the amount of ammonium fixed by surface soils was due to some reaction of ammonia with the soil organic matter. Schachtschabel (1960) observed that the ammonium liberated from the undecomposed organic matter averaged 3.2 mg nitrogen in marsh soil and 4.4 mg nitrogen in loess soil per 100 mg carbon. He determined native fixed ammonium following treatment with H_2O_2 by extraction with HF and H_2SO_4 on a sand bath.

Broadbent, Burge and Nakashima (1960) observed that the process of ammonium fixation by organic matter was more rapid in alkaline than in acid soils and pure polyphenolic compounds fix ammonium only in the presence of oxygen. Burge and Broadbent (1961) reported that in presence of oxygen 1 mole of ammonia was fixed per 29 atoms of carbon and 1 for every 45 atoms of carbon in the absence of oxygen. They also reported that the hydroxyl groups in soil organic matter are involved in the fixation reaction. Nommik and Nilsson

(1963) observed that ammonium fixing capacity of the soils was closely correlated with their organic carbon content; organic soils fixing substantially more than mineral soils.

Prasad and Sinha (1969) reported that the destruction of organic matter of soils by H_2O_2 caused considerable increase in soluble and exchangeable but decrease in fixed ammonium. In alluvial soils about 50 per cent and in sedentary soils about 33 per cent of the ammonium fixation was due to organic matter of soils. It was assumed that the fixation is greater in alluvial soils due to richer in lignin content than that in sedentary soil. Niederbudde and Fischer (1974) reported that the H_2O_2 oxidation under acidic conditions of soils rich in organic matter produces NH_4^+ , which is then fixed by clay minerals. Whereas, Griffith and Schnitzer (1977) when analysed air dried soil sample, for fixed NH_4^+ by the KBr - HF method of Silva and Bremner (1966) before and after H_2O_2 oxidation, found no differences between the fixed NH_4^+ content of untreated and oxidised soils. Mukhopadhyay and Das (1973) reported that the H_2O_2 oxidizable organic matter was capable of rendering added fertilizer ammonium into non-exchangeable form. Ammonium fixation by 100 g of organic matter ranged from 22 to 79 times that by 100 g of clay present in the soil. Mandal (1979) pointed out that the nature of organic matter present in the soil rather than its amount is responsible for fixation of ammonium. It has also been emphasized that the applied ammonium nitrogen reacted with the soil organic matter to form a chemically stable complex in which nitrogen is not susceptible to removal by 2M KCl extraction.

pH - Base saturation - Liming

The significance of the degree of hydrogen saturation of soils and clay minerals on their capacity to fix NH_4^+ and K^+ has been the subject of several investigations. Many research workers (Hauser, 1941; Martin *et al.*, 1946; Attoe, 1947; Wiklander, 1950; Harada and Kutsuna, 1954; Nommik 1957; Ghildyal and Singh, 1961; Raju and Mukhopadhyay, 1976), have pointed out that in H-saturated soil the fixation of NH_4^+ and K^+ is extremely low. A significant tendency for increase of NH_4^+ to fix with an increase in pH of the soils was observed by Nommik (1957) and Raju and Mukhopadhyay (1976). Kaila (1962) also observed positive correlation between soil pH and ammonium fixing capacity. Wiklander and Andersson (1959) analysed soil from a liming experiment 22 years after the application of lime and observed that NH_4^+ and K^+ fixation subsequently increased by liming. This is in accordance with the observations that in the H-saturated soils the fixation capacity is as a rule insignificant (Barshad, 1954b; Ghildyal and Singh, 1961; Harada and Kutsuna, 1954; Hauser, 1941; Karlsson, 1952; Nommik, 1957; Wiklander, 1950).

The extraordinarily marked effect of low pH on the feasibility of NH_4 and K is not fully understood. The high replacing power of H ions is presumably one of the factors of importance influencing the state of equilibrium between exchangeable NH_4^+ and fixed NH_4^+ . Barshad (1954b) considered that the decrease in NH_4^+ fixation in the presence of exchangeable H^+ may be due to the somewhat expanded state in which the adsorbed H^+ leaves the crystal lattice, which

therefore renders the interlattice NH_4^+ more accessible to a replacing cation. According to Rich (1964), H^+ ions when in concentration as low as 1×10^{-5} moles/litre, actively participate in K^+ exchange (in wedge shaped regions around edges) and the exchange of K^+ is enhanced by a high H^+ concentration (low pH) and this takes place very rapidly. This occupation of interlattice positions by H^+ ions will leave the crystal in a somewhat expanded state (Barshad, 1954b), so that subsequently added NH_4^+ could neither effectively replace the strongly bound H^+ ions in the crystal lattice or contract the crystal lattice. Moreover, in such an expanded state, the adsorbed NH_4^+ is more accessible at least in the vicinity of the adsorbed H^+ , to a replacing cation (Barshad, 1954b). The other factor is that the highly acidic environment in H-saturated condition may lead to partial filling up of interlayer space of 2:1 clay minerals by $\text{Fe}(\text{OH})_3$, $\text{Al}(\text{OH})_3$ or difficulty exchangeable iron and aluminium. This may result in the reduction of the collapsibility of the lattice. As a result of these blocks, reduction in the fixation of NH_4 occurs (Joffe and Levine, 1947; Stanford, 1948; Van der Marel, 1954; Rich and Obenshain, 1955; Rich, 1960; Rich and Thomas, 1960; Sawhney, 1960; Scheffer *et al.*, 1961). Carter, Harward and Young (1963) are of opinion that Al^{3+} is capable of replacing K^+ in mica and Mg^{++} in vermiculite interlayers and the Al^{3+} probably forms a six-fold coordination with water or hydroxyl ions blocking lattice collapses upon subsequent K^+ treatment. This Al^{3+} when produced experimentally, results in a stable $14\text{\AA}$ spacing and reduces the cation exchange capacity of the original minerals

(Rich, 1960). The low NH_4^+ fixing capacity of H^+ -treated soils was attributed by Scheffer et al. (1961) to this propping action of hydroxyl aluminium groups.

Removal of H^+ , Al^{3+} and Fe^{3+} from interlattice positions would naturally result in increase of fixing ability of soils. Karlsson (1952) and Nommik (1957) demonstrated that H-saturated soil regained their partial fixing capacity when they are leached with calcium acetate solution. According to Stanford (1948), addition of $\text{Ca}(\text{OH})_2$, NaOH and even of phosphates and fluorides will remove H^+ , Fe^{3+} and Al^{3+} from interlattice positions and will increase the fixation of K^+ .

Magnesium and Lithium ions may "pry open" the lattice and thus assist the entry of protons. The principal exchange by magnesium chloride was ascribed by Rich (1964) to the hydrogen ions released by hydrolysis of exchangeable aluminium or non-exchangeable hydroxy-aluminium, rather than to direct exchange of potassium by magnesium. Potassium or ammonium ion fixation (especially at edges) would, therefore, be favoured at a high pH and they would be released at a low pH because of proton exchange (Rich, 1964).

pH has no distinct effect on fixation but the exchange sites associated with interlayer spaces of soil clays are due primarily to lattice composition was reported by Page and Ganje (1964). Mukhopadhyay and Das (1973) observed that liming of acid soils caused a decrease in ammonium fixation. Raju and Mukhopadhyay (1976) also observed that the fixation of applied NH_4^+ increased with the increase in Ca^{++} saturation upto 30 to 40 per cent,

which they attributed to the ability of the base to remove H^+ (H_3O^+), Al^{+++} from interlayers positions. Moreover, the neutralisation of H^+ ions with increasing base saturation, reduced the competition of H^+ ions for exchange sites. Since, the exchange reaction followed by neutralisation results in reduction of competition for exchange sites by H^+ ions, increased NH_4^+ fixation was possible. The decreasing trend in the fixation of applied NH_4^+ following Ca^{++} saturation beyond 30 to 40 per cent was likely the result of competition between Ca^{++} and NH_4^+ for the exchange sites. At higher Ca^{++} saturation, Ca^{++} ions by virtue of higher valency and concentration, occupied more exchange sites than the subsequently added NH_4^+ .

Presence of potassium and other cations

Many workers (McBeth, 1917; Stanford and Pierre, 1947; Bower, 1950) have shown that K and NH_4 are fixed by the same mechanism. The depressive effect of K on the fixation of NH_4 , and vice-versa, is well known and has been demonstrated by several workers. Nommik (1957), Jansson (1958) and Wiklander and Anderson (1959) showed that there was a highly significant correlation between the ability of soils to fix NH_4^+ and K^+ when added in equivalent amount. It was established that the fixation of NH_4^+ was reduced by K^+ added prior to addition of NH_4^+ , and that this reduction was proportional to the amount of K^+ previously fixed. A similar relationship has also been found for bentonite (Joffe and Levine, 1947) and vermiculite (Barshad, 1951).

Although in any soil, the capacity to fix NH_4 and K is nearly

the same, in some cases different results have been reported. Nommik (1957) observed that in vermiculite containing clay soil, 10 to 15 per cent more NH_4^+ than K^+ was fixed over a wide concentration. He also observed that when NH_4^+ and K^+ were added simultaneously in equal amounts (1 m.e per 100 g soil), 3.4 times more NH_4^+ than K^+ was fixed. Bower (1950) observed more fixation of NH_4^+ than K^+ in one soil when both were applied in equal amounts, but he did not observe any such preference in other soils. Wiklander and Andersson (1959) likewise observed preferential fixation of NH_4^+ over K^+ from the same amount of simultaneously added cations in subsoil but not in surface soil. The interlayer space of the contracted NH_4^+ saturated vermiculite mineral was about $0.8\text{\AA}$ greater than the corresponding K-saturated mineral (Barshad, 1954b). Barshad is of opinion that because of the difference in interlayer space, fixed K^+ became more accessible to replacement by NH_4^+ .

The magnitude of the depressive effect of K on the fixation of NH_4 has been shown to be different, depending on whether K is added simultaneously, prior to or after the addition of NH_4^+ . The addition of K^+ prior to the addition of NH_4^+ will depress the fixation of the NH_4^+ . An addition of K^+ after the addition of NH_4^+ will, on the other hand, not appreciably influence the amount of NH_4^+ fixed. Results obtained by Jansson (1958) may illustrate this. Raju and Mukhopadhyay (1973) observed that addition of potassium caused higher fixation of added nitrogen in Purulia soil but not in Canning soil whereas, in both the

soils fixation of added ammonium nitrogen increased with increasing period of incubation. In both the soils, higher amount of added ammonium nitrogen was fixed when nitrogen and potassium were added simultaneously and lowest fixation was recorded when potassium was applied three days before the application of nitrogen.

It is evident that not only NH_4^+ but also K, Rb, Cs may be subject to fixation in 2:1 layer clay minerals. It is, therefore, likely that the last mentioned cations, if present, will compete with NH_4 for fixing sites in the minerals. From numerous investigations, it is clear that not only Rb, K and Cs but also other cations which do not contract the crystal lattice may influence the capacity of clay minerals to fix NH_4 . This ~~may~~ very likely be explained by competition between NH_4 and other cations for the exchange positions, influencing thereby the equilibrium between the exchangeable and fixed NH_4^+ . The addition of a cation of high replacing power will, according to this, lead to a decrease of the exchangeable NH_4^+ in soil and consequently to a lower fixation of the added NH_4 , or alternatively, to a release of some of the already fixed NH_4^+ . From this, it is apparent that the greatest depressive effect on NH_4 fixation may be exerted by the Di- and tri- valent cations and by the hydrogen ions. According to Nommik (1957), the depressive effect of different cations increased in the following order : $\text{Na} > \text{Mg} > \text{Ca} > \text{Ba} > \text{La} > \text{H}$. Approximately, the same trend was reported by Aomine and Wada (1953), Harada and Kutsuna (1954) and by Wiklander (1950) for fixation of K.

The studies of Bolt et al. (1963), Coleman et al. (1963) and Rich (1964) revealed that two situations must be recognised in the displacement of fixed NH_4^+ by other cations. Bolt et al. (1963) concluded that the surface exchange sites are not very specific for K^+ ions and therefore can be rapidly replaced by cations. Whereas, the interlattice sites near the edge of clay particles are very specific for K^+ and NH_4^+ ions (possibly certain other cations) and hence very difficult to replace from such positions by cations other than K^+ or NH_4^+ . Exchange with K^+ or NH_4^+ is however, rapid. On the other hand, interlattice positions away from the edge of the particles are also very specific for both NH_4^+ and K^+ ions but the exchange rate is higher for NH_4^+ than for K^+ . Similar type of results were also obtained by Coleman et al. (1963) and Rich (1964). Jackson (1964) suggested that NH_4^+ and K^+ are more effective mutual replacing cations than are Ca^{++} and the large hydrated ions. Raju and Mukhopadhyay (1976) in a laboratory experiment showed the influence of saturation of specific cations (Ca^{++} , Na^+ , Ba^{++} and K^+) on NH_4^+ fixation in six soil samples with different physicochemical and mineralogical characteristics. The results revealed that their effects were in the following order : $\text{Ba}^{2+} > \text{Na}^+ > \text{Ca}^{2+} > \text{Control} > \text{K}^+$.

Rate of fixation

Fixation is relatively a rapid process, the rate of which is mainly determined by ion diffusion. The fixation rate is highest in the period immediately after the ammonium addition and becomes slower as the equilibrium point is approached (Harada and Kutsuna, 1954; Van den Hendi, 1962; Nommik, 1957; Stanford and Pierre, 1947;

Legget and Moodie, 1962; Legget, 1958; Jansson, 1958). Under certain conditions, about 60 to 90% of the total fixation can occur within a few hours. Raju and Mukhopadhyay (1975) reported that maximum fixation of applied ammonium following its application was attained within 3 to 12 days depending upon the nature of the soil. Opuwaribo and Odu (1978) reported that during an eight day period of moist incubation with ammonium chloride and air drying, ammonium fixation was found to take place within minutes of equilibration, 96 to 100 per cent ammonium fixation took place within 48 hrs. incubation, increased from 14 to 914 ppm with increasing concentration of the equilibrating ammonium solution, but ammonium fixed expressed as a percentage of added ammonium decreased from 70 to 0.5 per cent.

Temperature

Very little informations are available on the effect of temperature on NH_4^+ fixation. In short term fixation tests, Harada and Kutsuna (1954) and Nommik (1957) demonstrated that within the temperature interval of 0 to 60°C, fixation increased with increasing temperature (Aomine and Wada, 1952a). Distinctly higher amount of fixation occurred at 35°C than at 10°C in all the soils (Mukhopadhyay and Das, 1975). Temperature affects not only the ion diffusion phenomenon but also the mineralisation rate of organic forms of nitrogen. At optimum temperature, the mineralisation rate is enhanced with the release of increased amount of NH_4 ions which take part in fixation mechanism. Investigation in this aspect is, however, very limited to support the hypothesis.

Chemical nature of added inorganic ammonium salts

The nature of the anion associated with NH_4 has been found to influence the NH_4^+ fixation by soils. This may be ascribed, inter alia, to the effect of anion on pH of the soil. The effect of anion on the adsorption capacity of the associated cation needs also to be considered. Joffe and Kolodney (1937) reported that a soil which had been treated for 20 years, with phosphatic fertilizers, fixed more K than the corresponding untreated soil. McBeth (1917) in his earlier work on ammonium fixation, concluded among other things, that various anions associated with NH_4^+ do not affect fixation. Harada and Kutsuna (1954) also noted that NH_4^+ fixation by the soil was same and independent of whether NH_4^+ was added as sulfate or chloride. However, a somewhat lower fixation was recorded when ammonium was added as dihydrogen ammonium phosphate. Legget (1958) reported that NH_4^+ fixation is affected due to associated anions with NH_4^+ . He observed highest NH_4 -fixation in diammonium hydrogen phosphate treated soil. The order of fixation due to different added NH_4 -salts was, diammonium hydrogen phosphate > ammonium acetate > ammonium chloride > ammonium tartrate > ammonium sulphate > ammonium chloride. Using isotopically labelled ammonium nitrogen, Stojanovic and Broadbent (1960) have noted that recovery of ammonium from added ammonium chloride and added ammonium hydroxide was consistently lower than from diammonium phosphate and ammonium nitrate. Although they have restricted their studies with the recovery of added ammonium nitrogen by two extraction procedures and have not actually determined the clay fixed ammonium, result of their investigation indicated a measurable effect of anion associated with ammonium in

the fixation process. In explaining their results for low recovery of tracer nitrogen from added chloride and hydroxide associated ammonium, Stojanovic and Broadbent (1960) have suggested the possibility of exchange between fixed and non-fixed ammonium.

Tamini et al. (1963) observed that amorphous silty loam soil of Hawaii fixed 1.33 m.e. ammonium/100 g soil when ammonium chloride was used, while it fixed 2.61 m.e. ammonium/100 g soil when $(\text{NH}_4)_2\text{HPO}_4$ was supplied. The soils which contained large amount of colloidal hydrated oxides of Fe and Al show a high capacity to fix phosphate. In a leaching study with this types of soils Kanehiro et al. (1960) found that sorption of NH_4^+ ion was higher when applied as $\text{NH}_4\text{H}_2\text{PO}_4$ or $(\text{NH}_4)_2\text{HPO}_4$ than when applied as $(\text{NH}_4)_2\text{SO}_4$ or NH_4Cl .

In treating soils with acidic phosphate solutions containing NH_4 or K, formation of slightly soluble crystalline products, inter alia, ammonium tarnakite, $\text{H}_6(\text{NH}_4)_3\text{Al}_5(\text{PO}_4)_8 \cdot 18\text{H}_2\text{O}$ and its potassium analogue, $\text{H}_6\text{K}_3\text{Al}_5(\text{PO}_4)_8 \cdot 18\text{H}_2\text{O}$ has been reported by number of workers (Birrell, 1961; Lindsay et al. 1962; Lindsay and Taylor, 1960; Tamini et al. 1963; Wada, 1969). Malquori and Radaelli (1960) suggested on the other hand, that fixed NH_4^+ in soil may be released in the zone of high concentration of phosphate occurring in the immediate surroundings of the granules of soluble phosphate fertilizers. In a recent study Mukhopadhyay and Das (1976) pointed out that the relative order of ammonium fixation from different ammonium salts was, calcium ammonium nitrate > ammonium hydroxide > ammonium nitrate > ammonium

dihydrogen phosphate > ammonium chloride > urea > ammonium sulphate.

Effect of moisture including a drying phase between different but uniformly maintained moisture conditions : Alternate wetting and drying and freezing and thawing

Moisture is an important factor for the growth of micro-organisms and in controlling the rate of organic matter decomposition. Although presence of moisture above a certain level is not critical for the microbial activity (Miller and Johnson, 1964), indirectly it is important, because higher the moisture present in the soil lesser the oxygen available for microbial growth. Stanford and Epstein (1974) studied the relationships between nitrogen mineralisation in soils with moisture suction in rice soils of widely different chemical and physical properties. They observed highest rates of mineralisation between 1/3rd to 0.1 bar i.e., under the situation of 80 to 90 per cent of the total pore space being filled with water. A near linear relationship between nitrogen mineralisation and soil water content was reported in the range 1/3rd to 15 bar. With increasing dryness, N-mineralisation tended to decline.

It has been shown by number of studies (Patrick and Wyatt, 1964; Borthakur and Mazumdar, 1968) that mineralisation of organic nitrogen in waterlogged soil is probably due in part to the lower nitrogen requirement of an anaerobic population of microorganisms and to their lower synthetic efficiency. Conventional measurements

of N-loss are subject to considerable error unless nitrogen fixed as NH_4^+ within the crystal lattice of certain clay minerals is accounted for (Broadbent and Tusneem, 1971).

The information about the effect of soil moisture level on the transformation of fixed ammonium of both fertilizer and native origins and exchangeable ammonium and soluble nitrate in soils, are sparse. In fact, determination of ammonium fixation in waterlogged soil is extremely rare (Kai and Wada, 1979). After addition of ^{15}N -tagged ammonium sulphate to waterlogged Sacramento soil, Broadbent and Tusneem (1971) measured N-transformation at various incubation periods. The results of their study indicated that the amount of clay fixed ammonium is comparable with and in many situations exceeds the amount of ammonium incorporated into the soil organic matter. They have further suggested that clay fixed ammonium is stable against attack of heterotrophic soil microflora. Besides, while tracing the changes in N^{15} tagged exchangeable ammonium following the addition of 100 ppm of N^{15} tagged $(\text{NH}_4)\text{SO}_4$ to Sacramento soil, they observed a progressive decrease in the amount over 30 days incubation period. Thus their result indicated that the rate of mineralisation was sufficiently rapid to overshadow the effect of other processes including clay fixation of ammonium which were withdrawing ammonium from the soil solution. Bhattacharyya (1971) reported that 10 day waterlogging for paddy soils in West Bengal caused an increase in exchangeable NH_4^+-N , from 6.0 - 9.2 to 13.7 - 28.0 ppm; accompanied by a simultaneous decrease of native fixed ammonium nitrogen.

Drying soil at mid season in continuously flooded situation caused an increase in the yield of rice (IRRI, 1974). This was explained as the nitrogen effect. Drying the soil at mid season was found to be beneficial because it caused extra nitrogen to be released. Since the rice plant needs the released nitrogen at the early stages of growth, in order to confirm their finding that a short period of drying causes increased release of nitrogen, they repeated their experiment in the next year when they subjected the soil to drying soon after transplanting instead of mid season. The results of their experiments confirmed that soil drying after transplanting was beneficial as evidenced by the fact that plants became more green on resubmergence and gave higher yields (IRRI, 1975). In an earlier report Matsushima (1962) also regarded the soil drying procedure under waterlogged soil as indispensable for producing a drastic increase in the amount of nitrogen soluble in water. The results of the investigations thus clearly indicate that a short period of drying under waterlogged condition, influence the transformation of nitrogen in soil which results in increased release of nitrogen in available form. But so far there does not exist any report on whether the said effect is the result of microbiological process or their transformation. Information is also inadequate as to whether such effect of drying also exist in soil maintained at lower moisture levels.

Enhanced mineralisation of sulphur due to drying of the moist soils and rewetting after some period was reported by Williams (1967) in some but not all soils. Besides, drying results in release of sulphate from soil has also been reported by number

of workers (Freney, 1958; Barrow, 1961; Williams and Steinbergs, 1964 and Williams, 1967). Very little is known about the process involved in the release of either nitrogen or sulphate sulphur due to drying. However, there are some reports to show that the solubility of soil organic matter increases as a result of drying (Donald and Williams, 1954; Stevenson, 1956 and Birch, 1959). There may exist an association between the above two processes.

It has been established that soil drying increases the amount of extractable K by ammonium acetate in many soils (Hanway *et al.*, 1960 and Reitermeier, 1951). But the release of K on drying is difficult to explain. Scott and Hanway (1960) however related this phenomenon to the clay fraction. Bates and Scott (1964) showed that a soil, which released large amounts of K during drying was inhibited from doing so by alcohols having high boiling temperature and by sucrose. They have further showed that the release mechanism was partly reversible. Rich (1972), however, failed to observe any release of K on drying in Virginia soils, which contain appreciable K in the mica vermiculites and hydroxy-Al groups in interlayer positions. These facts do suggest that K release due to drying is related to the collapse of the expansible layer silicates. Besides, drying may change the rotation of the tetrahedral layer - causing a change in K-O bond. Rich (1972) further suggested that dehydration of cations may permit a redistribution of inter layer cations allowing Ca to compete with K for wedge sites. On rehydration there may be a partial return of the original distribution of interlayer ions. Although so much information has been reported on the release of fixed K, virtually no information is available on

the effect of short duration drying on the amount of similarly fixable NH_4^+ .

In soils containing montmorillonite type of clay minerals NH_4^+ fixation generally increases due to drying because drying causes dehydration of the mineral resulting in partial contraction of the lattice, thus favouring the fixation reaction. On the otherhand, since vermiculite and illite type minerals are capable of fixing NH_4^+ even under moist conditions, the effect of drying is not important. Dehydration increases the concentration of NH_4^+ in soil solution which may cause an increase in fixation. This is especially true when a dilute solution of NH_4^+ is added to soils containing vermiculite and illite type of minerals but when concentrated solution of NH_4^+ is added, this effect is of limited value.

The studies carried out by Allison et al. (1951) indicated that the ammonium fixation capacity of Harpster clay loam soils increased when the soils were air dried after the addition of 1, 5 and 25 m.e. NH_4 per 100 g soil. Under moist conditions the amount fixed was 37, 10 and 4 per cent respectively of the added ammonium, while on air-drying, the fixation rose to 56, 26 and 10 per cent respectively. Repeated wetting and drying did not further increase the fixation. It was further reported by Allison et al. (1953 a,b) that five subsoils fixed 1.6 to 4.0 m.e. ammonium per 100 g on air drying and 3.1 to 6.3 m.e. ammonium per 100 g on heating at 100°C . The soils containing high amounts of vermiculite gave the highest value under moist conditions but when heated, the illite soils

absorbed the most ammonium. Allison et al. (1953 a, b) observed that ammonium fixation capacity of vermiculite was not markedly affected by air-drying or by heating at 100°C.

Jansson (1958) reported that in a Swedish soil, one single drying (30°C) caused 63 per cent and three wetting and drying cycles caused 77 per cent fixation of added NH_4^+ . Thus alternate wetting and drying cycles are more effective than a single drying so far the fixation of ammonium is concerned. Similar results were also reported by Bower (1950); Aomine (1951); Harada and Kutsuna (1954); Legg and Allison (1959); Stojanovic and Broadbent (1960); Ivanov (1962) and Tewari, Datta and Deka (1969). In a recent investigation, Mukhopadhyay and Das (1975) pointed out that generally the soils which are kept under waterlogged condition fixed higher amount of ammonium than the corresponding soils maintained at 50 per cent of the water-holding capacity. Opuwaribo and Odu (1978) reported that five alternate wet and dry cycles after ammoniation brought about increases in the amounts of ammonium fixed. At higher concentration of ammonium, 9 to 29 per cent increase in ammonium fixation were noted mostly in soils containing 2:1 type of clay minerals.

Most of the studies on the effect of levels of soil moisture on N-mineralisation and nitrification in soils have been done with soils of the temperate region (Parker and Larson, 1962; Miller and Jhonson, 1964; Ekpete and Cornfield, 1966). Generally, N-mineralisation and nitrification increased with moisture content to about 50 per cent saturation but decreases with further increase in the

level of moisture saturation. Nitrification stopped at about 75 per cent saturation but at higher moisture saturation ammonification continued. Under waterlogging, initial nitrate usually disappeared, presumably by denitrification. In a recent study, Choudhury and Cornfield (1978) showed the effect of soil moisture content on mineral nitrogen changes during incubation. In red soil, N-accumulation increased with moisture content upto 75 per cent saturation, decreased slightly at 100 per cent saturation and was maximum at 133 per cent saturation; mineral-N-accumulated entirely as nitrate at 25 and entirely as ammonium at 133 per cent saturation.

Like drying, freezing also removes water from the system, it may very likely influence the amount of NH_4 fixed. Information in this aspect is meagre. Walsh and Murdock (1960) demonstrated that soils kept at -15°C for 5 days caused an increase of 0.08 to 0.14 m.e./100 g of fixation of NH_4^+ . Similar results were also observed by Ivanov (1962) and Walsh and Murdock (1963). Hence, the available information indicates that freezing influences fixation of NH_4^+ .

Microbial activity

The activity of microbes and higher plants which involve consumption of exchangeable and soluble NH_4^+ in soil, may play a critical role in the fixation of NH_4^+ . The activity of microbes in soil not only influence the rate and extent of release of fixed ammonium (Bower, 1951; Allison *et al.*, 1951; 1953a, b, c; Allison and Roller, 1955b; Nommik 1957; Jansson, 1958; Axley and Legg,

1960; Aomine and Higachi, 1953b) but also the rate of fixation of NH_4^+ produced by the mineralisation of organic nitrogen. In rhizosphere soil, the microbial population is much higher than the corresponding non-rhizosphere soil. As a result the fixed ammonium content is likely to be higher in rhizosphere soil, than in soils in absence of growing plants.

Presence of plants

The presence of plants has tremendous impact so far the mechanism of fixation of NH_4^+ is concerned. It has been postulated by many research workers (Bower, 1951, Allison *et al.*, 1953a; Aomine and Higachi, 1953b; Nommik 1957; Jansson, 1961; Welch and Scott, 1961; Walsh and Murdock, 1963; Nommik, 1965; Black and Waring, 1972; Raju and Mukhopadhyay, 1974; Osborne, 1976; Kowalenko and Cameron, 1978; Mohammed, 1979) that as the soluble and exchangeable NH_4^+ are taken up by the growing plants, the fixed NH_4^+ is released to maintain the equilibrium of NH_4^+ ion in the soil system.

In a recent study Osborne (1976) pointed out that the level of intercalary NH_4^+ can be increased upon addition of an ammonium source of fertilizer. The growth of plants reduced the level of native intercalary NH_4^+ by an average 8 and 15 per cent in the red brown earth and grey soils of heavy texture respectively. Again, it is to be noted here that the rhizosphere and remote soils do not bear same soil characteristics. With time, the roots of the plants proliferates and the microbes of that very region become very active both in number and in their behaviour. Those microbes not

only utilize part of the fixed ammonium but also help to mineralise the organic form of nitrogen, part of which may ultimately be converted to fixed NH_4^+ form.

AVAILABILITY OF FIXED NH_4^+ TO CROPS

Previous reports in general indicated that a very small portion of the clay fixed ammonium in the soil become available to crops and microorganisms.

Literature on the practical significance of NH_4^+ fixation is rather sparse. Notwithstanding the fact that NH_4^+ fixation is relatively widespread and a common reaction in many arable soils, its significance so far as its availability to field crops is concerned, is extremely deficient. Mostly the available informations are based upon results obtained in pot experiments, and is not, therefore, directly applicable to field conditions.

Availability of fixed NH_4^+ to Microorganisms

Many research reports (Allison et al., 1951; 1953a,b; Bower, 1950 and Nommik, 1957) revealed that a very small portion of the fixed NH_4^+ is nitrified by nitrifying organisms. One of the first thorough studies on the subject was made by Bower (1951). With two soils he observed that only 13 to 28 per cent of the fixed NH_4^+ was nitrified during the 14 day incubation. Extending the period of incubation did not yield any further release of fixed NH_4^+ . Allison et al. (1951, 1953a,b,c) reported that the availability

of fixed NH_4^+ to nitrifiers did not exceed 10 per cent. In another study Allison et al. (1953a), however, reported that among other factors, availability of fixed NH_4^+ to nitrifiers depends on the mineralogical composition of the soil. They observed lowest availability in vermiculite containing soil and the highest in soil containing montmorillonite. Allison et al. (1953c) further observed that the availability of fixed NH_4^+ to nitrifiers varied in different types of vermiculites. In one geological specimen of vermiculite, almost all of the fixed NH_4^+ was nitrified, whereas in another specimen (a South African sample) only 11 to 16 per cent was available. Nommik (1957) and Jansson (1958) also reported low availability of fixed NH_4^+ to nitrifying organisms in Swedish soils. Furthermore, Nommik (1957) indicated that the degree of saturation of fixing sites by NH_4^+ does play a significant role in determining the percentage availability of fixed NH_4^+ , the availability increasing with NH_4^+ saturation. In an incubation study, Axley and Legg (1960) noted an inverse relationship between the percentage availability of fixed NH_4^+ to nitrifiers and NH_4^+ fixing capacity of the soil. Their result is in good agreement with that of Aomine and Higachi (1953b).

Some workers (Welch and Scott, 1960; Allison et al., 1953c) have demonstrated that K^+ significantly interferes with nitrification of fixed NH_4^+ . Marked decrease in the amount of fixed NH_4^+ nitrified was observed with the increase in the amount of exchangeable K^+ (Welch and Scott, 1960). Allison et al. (1953a) pointed out that leaching of soil with KCl to remove the exchangeable NH_4^+ exerted a blocking effect on the availability

of fixed NH_4^+ to nitrifiers, whereas leaching with CaCl_2 caused fixed NH_4^+ to be more available. Smirnov and Fruktova (1963) also leached the soil with KCl to remove exchangeable NH_4^+ in which K^+ exerted a blocking effect on the availability of the fixed NH_4^+ to nitrifying organisms.

To measure the amount of fixed NH_4^+ available to the heterotrophic microorganisms, many investigators (Nommik, 1957; Jansson, 1958) estimated the CO_2 production rate as well as remineralisation of the organically bound nitrogen during the decomposition of nitrogen-poor-organic material in soil. Nommik (1957) tried to demonstrate the availability of fixed NH_4^+ to heterotrophic microorganisms by using wheat straw which is a slowly decomposable organic matter. Nommik (1957) further set up an experiment with glucose for a ready-made source of energy for the microorganism and observed that the heterotrophic organisms are able to utilize most of the fixed NH_4^+ . Nommik (1957) also reported that simultaneous addition of K^+ along with glucose caused a considerable decrease in the availability of fixed NH_4^+ . In a recent study Raju and Mukhopadhyay (1974) pointed out that 5.5 to 47.9 per cent of the fixed NH_4^+ is nitrified over a 45 day incubation period and most of the fixed NH_4^+ is nitrified between 15th and 30th day. They also reported that when NH_4^+ fixing power of the soil increases the availability of fixed NH_4^+ to nitrifying bacteria decreases.

Availability to plants

Native fixed ammonium (i.e. fixed ammonium nitrogen which occurs in unfertilized soils) is generally considered of very low solubility and biologically only slowly available (Walsh and Murdock,

1963; Martin et al., 1970; Black and Waring, 1972; Osborne, 1976; Kowalenko and Cameron, 1976; Mohammed, 1979). Aomine and Higachi (1953b) reported that plants are capable of utilizing fixed NH_4^+ from a low NH_4^+ fixing soils in higher amount than from a soil of high NH_4^+ fixing power.

Black and Waring (1972) observed that due to intensive cropping small but non-significant amount of native fixed ammonium was released. Conflicting reports however persist on the availability of recently fixed ammonium nitrogen (Bower, 1951; Allison et al., 1953; Black and Waring, 1972; Osborne, 1976; Kowalenko and Cameron, 1976; Mohammed, 1979). These reports indicate that recoveries by plants vary from less than 10 to about 100% of the recently fixed ammonium in soils. Allison et al. (1953a) found that 7 per cent of the applied ammonium fixed by the soil was available to millet when fixation had been brought about by air drying and 12 per cent when fixation was brought about by oven drying (100°C). The availability of applied ammonium fixed by semiarid soils was determined by Bower (1950) using modified Neubauer technique. When cultures were not inoculated with nitrifying bacteria, he found only 10 per cent recovery with a crop of barley as compared to a recovery of 13 to 28 per cent with inoculated cultures. This findings led Bower to conclude that bacteria could more effectively remove recently fixed ammonium than could higher plants. Most of the early workers reported that less than 30 per cent of the recently fixed ammonium was taken up by plants, whereas, Jansson (1958) and Nommik (1957) suggested much higher availability. Black and Waring (1972) reported that 15 per cent of the added ammonium nitrogen which

was fixed, only 50 per cent was released by a single low density cropping by wheat tops from ammonium compared with nitrate nitrogen sources. Intensive or successive cropping released almost all the recently fixed ammonium nitrogen.

Results of green house and laboratory studies on the availability of applied ammonium (NH_4) fixed by the soils or clay minerals were found to vary considerably. Most of the differences in the availability of applied NH_4^+ fixed by soils or clay minerals can probably be attributed to differences in the experimental procedure adopted for estimating the availability of fixed ammonium to crops. Besides, this can also be partially attributed to varying levels of exchangeable potassium present in the soils used for their investigations. Welch and Scott (1960) found that almost all the ammonium fixed by three different vermiculities was nitrified in the absence of added K, but at moderate to high levels of K, practically none of the applied NH_4 fixed by the minerals was nitrified. Nommik (1957) also suggested that the levels of exchangeable K in the soil controls the release of applied NH_4 fixed. Using oats as test crop in green house, he found that $(\text{NH}_4)_2\text{SO}_4$ compared favourably with $\text{Ca}(\text{NO}_3)_2$ when applied to a high fixing soil if K was not applied simultaneously, but when simultaneous applications of 300 pounds per acre of nitrogen and 175 or 700 pounds of K per acre were made, recoveries of ammonium nitrogen ($\text{NH}_4\text{-N}$) as compared to $\text{NO}_3\text{-N}$ at two rates of K application were 86 and 32 per cent respectively. Nommik (1957) reported that plants can more effectively utilize applied NH_4 fixed in the soil

because they are able to lower the level of exchangeable K^+ in the soil much more than microorganisms. Whereas Osborne (1976) reported that the addition of small amounts of K^+ prior to NH_4^+ did not affect fixation; however, addition of 500 ppm of K reduced ^{of} the fixation/ammonium by 80 per cent.

Legg and Allison (1959) reported that in absence of added K, banded $(NH_4)_2SO_4$ applied to soils with high ammonium fixing capacities was as available to Sudan grass as similar application to non-fixing soils. When the $(NH_4)_2SO_4$ was mixed throughout the soil as compared to surface applied $NaNO_3$, these workers found a small but significant increase in recovery from the nitrate nitrogen treatment. However, they concluded that these differences cannot entirely be attributed to ammonium fixation because microbial utilization may have been enhanced by mixing $(NH_4)_2SO_4$ throughout the soil.

Walsh and Murdock (1963) investigated the availability of native fixed NH_4 and applied NH_4 fixed in the Ap and B₁ horizons of a Dodge silt loam soil. By applying potassium and nitrogen to either the same or separate layers of soils in green house pots, it was possible for them to evaluate the effect of K on the release of fixed NH_4^+ . Highly significant correlation between the exchangeable K in the moist soil after cropping and the amount of applied NH_4 fixed as measured by differential nitrogen uptake showed that the levels of exchangeable K in the soil influenced the release of fixed NH_4^+ to crops. Their studies further indicated that even under most advantageous conditions very little of the native fixed

NH_4^+ was available to crops.

Black and Waring (1972) studied the availability of fixed NH_4^+ nitrogen in a fixing montmorillonitic soil of Queensland by directly following fixation and release of fertilizer ammonium-nitrogen during the growth of wheat plants as well as by relating the differential uptake from NH_4 and NO_3 sources to changes in fixed NH_4^+ nitrogen in the soil. Their study of fixation and release under pot culture conditions provided strong circumstantial evidence that in the montmorillonitic soil, lower uptake of nitrogen by plant from ammonium and nitrate sources was due mainly to the ammonium fixation reaction. The availability of recently fixed NH_4^+ nitrogen was shown to depend on the intensity and duration of cropping. Only moderate availability was indicated at normal cropping intensities during a single cropping season. They finally concluded that less than half of the fixed NH_4^+ nitrogen would be available to the first crop. Much of the remaining fixed ammonium nitrogen may well be released during next one or two croppings. In this respect the result of Black and Waring (1972) are in agreement with that of Nommik (1957), who suggested that there is a slow equilibrium between fixed and exchangeable ammonium nitrogen. Based on their results Black and Waring (1972) concluded that fixation of NH_4^+ is generally of little significance in field fertilizer practice in most of the soils of Queensland. Conducting experiments on six major farming soils of the slopes and plains of Southern New South Wales, Osborne (1976) also arrived at a similar conclusion. He did not consider that clay fixed NH_4^+ is of any importance in the nitrogen economy of the soils. In a recent study however, Mohammed

(1979) reported the availability of fixed NH_4^+ to barley seedlings in a Libyan soil. He pointed out that 38 per cent of the total fixed NH_4^+ - nitrogen and 70 per cent of the KBr extractable nitrogen in the soil were available to barley seedlings. This was estimated by the difference method of before and after cropping.

The results of the studies so far reported was largely laboratory oriented and the relevance to the field situation was difficult to extrapolate. Hence Kowalenko and Ross (1980) studied the dynamics of fixation and release of ammonium in soils using tracer-N under field conditions. Field data showed that the release of fixed NH_4^+ was relatively slow after an initial moderately fast release. Earlier studies of Kowalenko and Cameron (1976) demonstrated that clay fixed NH_4^+ was in equilibrium with soluble and exchangeable NH_4^+ . This suggests that release of clay fixed NH_4^+ occurs when soluble and exchangeable NH_4^+ are depleted by the nitrification process or by plant uptake. This implies that biological processes only indirectly have an effect on release of fixed NH_4^+ . Kowalenko and Cameron (1978) showed that 71 to 96 per cent of the recently fixed NH_4^+ being released or made available to barley over the complete growth period. The presence of N-serve (a nitrification inhibitor) resulted in lesser amount of fixed fertilizer NH_4^+ being released during crop growth. This suggests that nitrifying organisms were intermediaries in making this fraction of inorganic nitrogen (fixed NH_4^+) available for crop uptake.

From the review of literature on the availability of fixed

NH_4^+ to crops presented above, it is quite evident that the changes of clay fixed NH_4^+ must be included in any study of nitrogen processes in soil, particularly where this fraction is quantitatively and dynamically important. The increased use of ammonium or ammonium producing forms of fertilizers creates an increasing need for more accurate quantification of ammonium fixation and release under different climatic regions and management practices.

FIXATION OF NH_4^+ AND ITS TRANSFORMATION
TO OTHER MINERAL FORMS IN SOILS

In the present investigation, a series of laboratory incubation experiments were conducted to study the effect of some of the important but less studied factors on changes in the amount of native fixed ammonium and fixation of applied ammonium in some soils of West Bengal. Besides, periodic changes in the amount of 2M KCl extractable (exchangeable) ammonium and nitrate were determined in these experiments with an aim to partially integrate some of the individual processes involved in the complex system of nitrogen transformation in soils maintained under different environmental conditions. All the experiments are divided into three main sections.

Section A : Effect of moisture levels in soils.

Section B : Effect of addition of different ammonium producing fertilizers to soils.

Section C : Effect of liming soils of acidic reaction.

The effect of moisture levels in soils on fixation of native and applied NH_4 during incubation has been attempted through 4 separate experiments. The quantitative changes in the amount of exchangeable NH_4 , soluble NO_3 and fixed NH_4 form of nitrogen due to maintenance of soils under different but uniform moisture

levels, a short period of drying phase between them and number of wetting and drying cycles after ammoniation has been determined.

EXPERIMENT 1 : Effect of three uniformly maintained soil moisture levels during incubation on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium in five soils.

Materials used — The soil samples (0-15 cm depth) used in the present investigation were composite samples of cultivated field and were collected from Kalyani, Haringhata, Bankura, Bagdubi and Canning. The relevant physical and chemical characteristics of the soils are presented in Table 1. Before use, the soils were air dried and crushed to pass through 0.5 mm sieve.

Methods — Duplicate samples of 10 g each of the five air dried soils were taken in 100 ml beakers for each of the three incubating moisture levels. Respective soil samples were then moistened separately to either 50% of their moisture holding capacity (MHC) or saturated or waterlogged state by addition of distilled water. After moistening to the appropriate levels, the soil samples were allowed to incubate at room temperature (30 ± 2)°C. There were four sampling stages corresponding to 2, 5, 10 and 20 day after the soils were moistened. Separate sets were maintained for each of the above four sampling stages. Loss of moisture due to evaporation was replenished by the addition of distilled water on every 2nd day by difference in weight.

TABLE - 1

General characteristics of the soils used for investigation

Soil collected from :	pH (Soil:water) 1:2:5	Organic carbon (%)	Total nitrogen (%)	Moisture holding capacity (%)	2M KCl extractable NH_4^+ -N (ppm)	2M KCl extractable NO_3^- -N (ppm)	Native fixed NH_4^+ -N (ppm)	NH_4^+ - fixing capacity (ppm)	Conductivity (mmhos/cm)	Cation exchange capacity (me/100g)	Clay (%)	Silt (%)	Sand (%)	Textural Class
Haringhata	6.75	0.653	0.072	48	56	21	312	572	0.236	17.19	57	18	22	Clay
Kalyani	7.05	0.554	0.052	47	35	7	586	1027	0.241	12.79	21	27	48	Loam
Bankura	5.50	0.934	0.094	54	28	7	518	892	0.064	6.28	41	25	30	Clay loam
Bagdubi	5.40	0.551	0.071	51	35	14	514	1079	0.088	7.84	39	38	22	-do-
Arabari	5.30	0.905	0.099	45	28	14	684	870	0.088	4.25	45	9	41	Sandy clay
Canning	6.80	0.627	0.083	55	28	14	615	1114	2.092	10.52	46	46	5	Silty clay

Soil samples corresponding to each of the 4 sampling stages were identically collected and analysed for exchangeable ammonium, soluble nitrate and fixed ammonium. 2M KCl solution was employed for extraction of exchangeable ammonium nitrogen and soluble nitrate nitrogen and estimated according to the method of Bremner and Keeney (1966). Fixed ammonium nitrogen was determined on the air-dried and ground NH_4 -free soil residue from exchangeable NH_4 determinations by the method of Silva and Bremner (1966). This procedure was considered essential for fixed NH_4 -N analysis in the laboratory incubation experiments, since air drying in presence of NH_4 -N greatly increases fixation in these soils.

In the reports of soil analysis, presented in Table 1, pH was determined with glass electrode (soil : water ratio, 1:2.5), organic carbon by the wet digestion method of Walkley and Black (Jackson, 1968), total nitrogen by a semimicro-Kjeldahl method (Bremner, 1965) and mechanical analysis by the International Pipette Method (Piper, 1942).

Ammonium fixing capacity was determined by treating the soil sample with saturated solution of ammonium sulphate followed by drying. This process of ammoniation following drying was repeated thrice. The excess salt from the soil solution was removed by leaching with distilled water. Then the leached soil was dried and finally the fixed ammonium was determined by the method of Silva and Bremner (1966).

EXPERIMENT 2 : Effect of a short period of drying between different but uniformly maintained moisture levels on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium in five soils.

Materials used — Same as in Experiment 1.

Methods — Duplicate samples of 10g each of the five air dried soils were taken in 100 ml beakers for each of the three incubating moisture levels. Respective soil samples were then moistened to either 50 per cent of their MHC or saturated or waterlogged state by the addition of distilled water. After moistening to the appropriate levels, the soil samples were allowed to incubate at room temperature (30 ± 2)°C for 20 days. After 20 days of incubation under moist state, the soil samples were allowed to dry. Immediately after drying the soil samples were remoistened to their respective predrying moisture levels and allowed to incubate for 5 days. Soil samples were analysed at three different stages corresponding to 20 day period of incubation under three different moisture levels prior to drying, upon air drying and after 5 days of incubation in the post drying moist state. Separate sets were maintained for each of the three sampling stages. Loss of moisture due to evaporation during both the predrying and post drying moist incubation was replenished by the addition of distilled water on every 2nd day by difference in weight.

Soil samples were analysed for exchangeable ammonium nitrogen, soluble nitrate nitrogen and fixed ammonium nitrogen, following the same methods as were employed in Experiment 1 of this section.

EXPERIMENT 3 : Effect of added $(\text{NH}_4)_2\text{SO}_4$ on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil incubated under three different but uniformly maintained moisture levels.

Materials used — Same as in Experiment 1 except that the present investigation was restricted to the soil collected from Kalyani.

Methods — The incubation procedure used, sampling stages for analysis during incubation, items of analysis and methods of determinations were exactly the same as in Experiment 1. The only difference was in the treatment material added. Each of the 10 g soil sample in 100 ml beakers were separately treated with ammonium sulphate solution equivalent to 200 ppm prior to incubation.

EXPERIMENT 4 : Effect of numbers of wetting and drying cycles after ammonium fertilizer addition on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil incubated under three different moisture levels.

Materials used — Same as in Experiment 1 except that the present investigation was restricted to the soil collected from Haringhata.

Methods — 500 g of air dried and sieved soil sample was treated with $(\text{NH}_4)_2\text{SO}_4$, equivalent to 400 ppm of nitrogen and mixed thoroughly. After the addition of ammonium fertilizer, the soil was divided into two equal lots of 250 g each. One lot of 250 g of the treated soil was subjected to one cycle of wetting to

saturation level by addition of distilled water followed by air drying. The other lot of 250 g of the treated soil was similarly subjected to two such alternate wetting and drying cycles. After the respective number of cycles of wetting and drying, both the soil samples were separately leached with distilled water to wash the soil free from excess ammonium salt in soil solution. The washed soils were then air dried and ground to pass through 0.5 mm sieve.

The two soil samples so prepared were then separately incubated under three different moisture levels. The incubation procedure used, the three different moisture levels maintained, sampling stages for analyses during incubation, items of analysis and methods of determinations were exactly the same as in Experiment 1 of this section.

SECTION B : This section comprises of 2 experiments. Although fixation of added ammonium due to addition of different ammonium producing fertilizers to soil is the primary aim of these experiments, they were conducted not only under different but uniformly maintained moisture levels but also in the situation where a short period of drying occurred during incubation of soil under different moisture levels.

EXPERIMENT 5 : Effect of different ammonium producing fertilizers on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in four soils incubated under different moisture levels.

Materials used — The soil samples used in the present investigations were collected from 0-15 cm layers of cultivated fields from Kalyani, Bankura, Bagdubi and Canning. The method of collection, sampling procedure and physical and chemical characteristics of the soils used were the same as in Experiment 1. Four ammonium producing fertilizers were used in this experiment, namely, ammonium sulphate, urea, calcium ammonium nitrate and ammonium dihydrogen phosphate.

Methods — The incubation procedure used, the three different moisture levels maintained, sampling stages for analyses during incubation, items of analyses and methods of determinations were exactly the same as in Experiment 1.

EXPERIMENT 6 : Effect of a short period of drying during incubation under different moisture levels on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil treated with four different forms of ammonium producing fertilizers.

Materials used — Same as in Experiment 5 except that the present investigation was restricted to the soil collected from Bankura.

Methods — Duplicate samples of 10 g of the air-dried soil were taken in 100 ml beakers for each of the four forms of added

ammonium producing fertilizers. Each of the four such sets of duplicate beakers containing treated soil was taken separately for the three moisture levels under which the incubation experiment was conducted. Except for the above mentioned variation in the treatments, the incubation procedure followed during predrying, upon drying and post drying period as well as the soil moisture levels maintained, sampling stages, items of analyses and methods of determinations adopted were exactly the same as in Experiment 2.

SECTION C : This section also comprises of 2 experiments.

Effect of liming soils of acidic reaction on clay fixation of ammonium has been done by number of workers. The methodology applied by those workers were not uniform. Moreover, considerable discrepancies exist among them with respect to the term, "limed soil" or the term, "effect of liming". In the present set of experiments, liming operation has been done in the following manner. The liming material, equivalent to lime requirement was added to the soil uniformly and allowed to react with the soil mass for 3 month period with repeated wetting followed by air-drying. The soil so prepared has been termed as limed soil. The effects of treatment materials on limed soils were studied by addition of such materials to soils so prepared. Besides, increase in soil pH, many other associated changes occur in the soils during the 3 month reaction period of liming material with the soils. Due consideration to some of the related changes has been given in the present investigation.

One such less studied area is the changes that occur in the forms of organic nitrogen present in the soil. Besides, an attempt has also been made to assess the extent of relevance these changes have on the reaction processes involved in the fixation of ammonium by soils.

EXPERIMENT 7 : Effect of liming soil of acidic reaction on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen under independent and simultaneous presence of added $\text{NH}_4\text{-N}$, K and organic matters of varying nitrogen content.

Materials used — Soil selected for the present investigation was collected from the surface (0-15 cm) layer of Bagdubi village of Midnapore district. The relevant physical and chemical characteristics of the soil are presented in Table 1. After collection, the soil was air dried and crushed to pass through 0.5 mm sieve.

Methods — Liming soil of acidic reaction preceded the actual incubation experiment. The following procedure was adopted for liming operation. The amount of lime equivalent to lime requirement was added to the soil. The lime was allowed to react for 3 months with repeated cycles of alternate wetting followed by air-drying. The corresponding unlimed soils was also subjected to the same processes of alternate wetting and drying cycles.

So prepared unlimed and limed soils were incubated with the following treatments.

1. Control, where no source of nitrogen, potassium or organic matter was added.

2. Starch was added @ 0.5% of the soil (W/W)
3. Rice straw (1.20% N) was added @ 1% of the soil (W/W)
4. Treatment 1 + 400 ppm N added through $(\text{NH}_4)_2\text{SO}_4$
5. Treatment 2 + 400 ppm N added through $(\text{NH}_4)_2\text{SO}_4$
6. Treatment 3 + 400 ppm N added through $(\text{NH}_4)_2\text{SO}_4$
7. Treatment 1 + 200 ppm K added through KCl.
8. Treatment 2 + 200 ppm K added KCl.
9. Treatment 3 + 200 ppm K added through KCl.
10. Treatment 4 + 200 ppm K added through KCl.
11. Treatment 5 + 200 ppm K added through KCl.
12. Treatment 6 + 200 ppm K added through KCl.

Duplicate samples of each of the treated soil was taken in 100 ml beakers. The soil was moistened to 50% of its MHC by the addition of calculated amount of distilled water. Then the soils were allowed to incubate at laboratory temperature $(30 \pm 2)^\circ\text{C}$. Any loss in soil moisture due to evaporation was replenished on every alternate day by the addition of distilled water by difference in weight.

The soil samples were identically collected at two stages corresponding to 5th and 15th day of incubation. At each stage, the treated soil samples were analysed for exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen. The extraction and analytical methods adopted were the same as in Experiment 1 of Section A.

EXPERIMENT 8 : Effect of liming soils of acidic reaction on changes in the amount of different forms of organic nitrogen and exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in soils.

Materials used — The three soil samples (0-15 cm depth) of acidic reaction used in the present investigation were composite samples of cultivated field and were collected from Bankura in the district of Bankura, Bagdubi and Arabari in the district of Midnapore. The relevant physical and chemical characteristics of the soils used are presented in Table 1. Before use, the soils were air dried and crushed to pass through 0.5 mm sieve.

Methods — Both the limed and unlimed soils were prepared following the same method as was adopted in previous experiment (Experiment 7). Analyses of duplicate samples for different items were conducted in each of the so prepared limed and unlimed soils.

pH was determined by glass electrode pH meter (soil : water 1:2.5), 2M KCl extractable (Exchangeable) ammonium and nitrate by the method of Bremner and Keeney (1966), fixed ammonium by Silva and Bremner's method (1966), exchange acidity by the method of Peech et al. (1962), and different fractions of organic nitrogen was determined by the method of Bremner (1965).

AVAILABILITY OF FIXED NH_4^+ TO CROPS

In order to study the availability of fixed ammonium nitrogen to crops, three field experiments in succession were conducted during the period 1978 to 1980 in a field of the University Experimental Farm at Kalyani. Fixation of ammonium from the native and fertilizer ammonium sources as well as release of both native and recently fixed ammonium to crops were investigated by growing maize crop. Besides, attempts have been made to relate the differences in nitrogen uptake by the crop from ammonium and nitrate sources with changes in the amount of fixed ammonium nitrogen in the soil. This study was conducted under two planting densities of maize crop.

General characteristics of the soil

Some of the important chemical and physical characteristics of the soil collected from the field of the experimental farm are presented in Table 13.

Relevant meteorological data collected in the experimental field during the period the experiments were conducted are presented in Table 14.

Experiments in the field

No crop was raised in the experimental plot for at least 10 years before laying out this experiment. The field was thoroughly ploughed to 25 cm depth followed by harrowing, discing and levelling at a suitable moisture condition before sowing. Three experiments were conducted in the field in succession.

TABLE 13

Relevant physical and chemical character of the soil

Serial No.	Analysis done	Data of analysis	Methods adopted
1.	Mechanical Analysis	-	International Pipette Method, Piper (1942)
	a) Percentage of sand.	48	
	b) Percentage of silt	27	
	c) Percentage of clay	21	
	d) Textural classes	Loam	
2.	pH (Soil : water, 1:2.5)	7.05	Glass Electrode pH meter
3.	Percentage of organic carbon	0.554	Walkley and Black (1934)
4.	Percentage of total nitrogen	0.052	Bremner (1965)
5.	Cation Exchange Capacity (me/100 g)	12.79	Schollenberger and Simon (1945)
6.	Percentage of moisture holding capacity	47	Keen-Raczkowski method (Piper, 1942)
7.	Exchangeable NH_4^+ (ppm)	35	Bremner and Keeney (1966)
8.	Soluble nitrate (ppm)	7	Bremner and Keeney (1966)
9.	Native fixed NH_4^+ (ppm)	450	Silva and Bremner (1966)
10.	NH_4^+ fixing capacity (ppm)	1027	Silva and Bremner (1966)

TABLE 14

Relevant Meteorological data. University Experimental
Farm, Kalyani

Month	Average Maximum temp.°C	Average Minimum temp.°C	Total Rainfall (cm)	Average maximum relative humidity (%)	Average minimum relative humidity (%)	Sunshine hours
Nov.1978	31.70	20.05	0.00	90.02	45.60	9.88
Dec.1978	26.24	13.08	0.00	91.46	45.52	10.31
Jan.1979	27.27	14.11	0.00	92.19	44.66	9.09
Feb.1979	28.50	13.87	2.11	90.66	43.55	10.45
Mar.1979	34.73	20.32	0.00	85.83	35.54	10.45
April,1979	38.75	24.02	0.76	89.85	46.96	10.38
May,1979	39.64	25.21	1.40	86.88	44.91	10.37
June,1979	37.36	26.63	30.61	86.73	51.04	5.67
July,1979	34.33	26.63	29.37	86.80	65.59	3.82
Aug.1979	33.45	25.56	22.23	88.03	69.13	4.90
Sept.1979	33.24	25.75	6.76	88.74	64.11	5.86
Oct.1979	32.72	23.26	0.43	84.25	56.05	8.58
Nov.1979	33.76	19.76	1.73	88.23	57.00	9.26
Dec.1979	26.68	13.02	0.46	86.13	50.56	8.36
Jan.1980	26.76	11.76	0.68	82.99	43.00	6.15

All the three experiments were conducted with maize as test crop and Diara being the variety.

EXPERIMENT 9 : Availability of native fixed NH_4^+ to crops.

This experiment was conducted to study the changes in the amount of exchangeable ammonium, soluble nitrate and native fixed ammonium forms of nitrogen in the soil and nitrogen uptake at various stages of plant growth. Maize was raised in 20 plots (2.5 m X 2 m) sown at two densities. The two density sowings were randomly distributed in ten replications in the field. The seeds of the Diara variety of maize were sown in 4 lines per plot with row to row distance of 60 cm. For low (D_1) and high (D_2) density cropping 7 and 17 plants per line were maintained respectively. The crops were raised with best possible management practices and uniform cultural operations. Irrigation was provided from farm water source (shallow tube well). The crops were allowed to grow upto 95th day after sowing. Due to attack by monkeys and parrots as well as theft of some cobs by some offenders, yield of maize grain could not be accurately recorded.

Before sowing, initial composite soil samples were drawn for laboratory analysis. During crop growth, soil and above ground plant samples were collected correspondings to 30th, 70th and 95th day stages after sowing.

EXPERIMENT 10 : Availability of recently fixed NH_4^+ to crops.

This experiment was conducted to study the changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium forms of nitrogen in soil and nitrogen uptake by maize crop following the application of ammonium and nitrate forms of nitrogenous fertilizers.

The area under this experiment was divided into three blocks to receive 10 treatments in each block (total 30 plots). Each block was separated by about 2m wide bunds. Each plot was separated from adjacent plot by about 0.5 m. wide bund. The following 10 treatments were adopted for this experiment.

<u>Treatment No.</u>	<u>Treatment</u>
T ₀	Control D ₁
T ₁	Control D ₂
T ₂	D ₁ Ca(NO ₃) ₂ @ 60 kg N/ha
T ₃	D ₂ Ca (NO ₃) ₂ @ 60 kg N/ha
T ₄	D ₁ Ca (NO ₃) ₂ @ 300 kg N/ha
T ₅	D ₂ Ca (NO ₃) ₂ @ 300 kg N/ha
T ₆	D ₁ (NH ₄) ₂ SO ₄ @ 60 kg N/ha
T ₇	D ₂ (NH ₄) ₂ SO ₄ @ 300 kg N/ha
T ₈	D ₁ (NH ₄) ₂ SO ₄ @ 300 kg N/ha
T ₉	D ₂ (NH ₄) ₂ SO ₄ @ 300 kg N/ha

Replications — Three.

Lay out — Completely randomised block design in field trial.

Basal applications

In this field experiment phosphate @ 60 kg P_2O_5 /ha and potassium @ 60 kg K_2O /ha in the form of single super phosphate and muriate of potash were applied to each treatment.

The test crop, variety, densities of sowing and cropping operations were maintained as in Experiment 9. The crops were allowed to grow upto 85th day stage after sowing.

During crop growth, soil samples were collected for laboratory analysis on 0, 7, 30, 60 and 85th day after the application of nitrogenous fertilizers. Above ground plant samples were collected for chemical analysis on 30th and 60th day after sowing of seeds.

EXPERIMENT 11 : Availability of residual fixed NH_4^+ to crops.

This field experiment was conducted to study the residual effect of each of the same 10 treatments adopted in Experiment 10. As in previous experiments, changes in the amount of exchangeable NH_4^+ , soluble NO_3 and fixed NH_4^+ form of nitrogen in the soil as well as nitrogen uptake by plants were studied in each of those plots by growing maize crop (variety : Diara) at two densities. Experimental site, lay out, design, total area, number and size of blocks and plots were the same as in Experiment 10.

The crops were allowed to grow for 50 day period after sowing. During crop growth, soil samples were collected for laboratory analyses on 0, 20, 35 and 50th day of crop growth. Above ground

plant samples were collected for chemical analysis on 20, 35 and 50th day after sowing of seeds.

The growing period of the crops were as follows :

	<u>Date of sowing</u>	<u>Date of final harvest</u>
Experiment 9	28th Nov.1978	2nd March,1979
Experiment 10	10th April,1979	4th July, 1979
Experiment 11	14th Nov.,1979	3rd January,1980

After harvest of each crop in the sequence, the field was ploughed by spading to maintain the plot as such; stubbles were removed and the next crop was grown.

Processing of plant and soil samples for analysis

Preparation of plant samples for analysis

The plant samples from field experiments were dried in air followed by oven drying at about 50°C for 6 to 8 hrs and finally at 70°C for complete removal of moisture as tested by constant weights after which the dry matter yields were recorded. The entire quantity of dried plant samples was ground plotwise and passed through a 20 mesh sieve in a Wiley Mill.

Preparation of soil samples for analysis

The soil samples collected from the experimental field at various stages were ground in a wooden pestle and mortar and passed through 0.5 mm sieve for the use of the analytical determinations.

Soil Analysis

Exchangeable ammonium and nitrate nitrogen were analysed by the method of Bremner and Keeney (1966). Fixed NH_4^+ nitrogen was determined on the air-dried and ground NH_4 -free soil residue from exchangeable ammonium nitrogen determinations following the method of Silva and Bremner (1966). This modification was considered necessary for fixed NH_4^+ nitrogen analysis since air drying in the presence of ammonium nitrogen in exchangeable form greatly increases the amount of fixed NH_4^+ in these soils.

Plant Analysis

Total nitrogen in the oven dried and ground plant samples were determined by the method of micro Kjeldahl digestion (Jackson, 1973).

Statistical Analysis

The data on yield, uptake of nitrogen at each stages as well as the soil analysis for exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen were statistically analysed for analysis of variance. Standard error of mean as well as critical difference were calculated at 5% level of probability to test the significance of means for the treatment differences.

FIXATION OF NH_4^+ AND ITS TRANSFORMATION TO OTHER MINERAL FORMS IN SOILS

EXPERIMENT 1 : Effect of three uniformly maintained soil moisture levels during incubation on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium in five soils.

Mineralisation of nitrogen present in the soil organic matter results an increase in the concentration of NH_4^+ and NO_3^- ions in the soil solution. It is likely that in absence of growing plants, part of it may be immobilised by the clay colloids (chemically fixed) and part by the microbes present in the soil (biologically fixed). Very few studies have so far been made on this aspect of NH_4^+ fixation in soils. In order to have a better understanding of the above subject a laboratory incubation study for a short period (upto 20 days) was conducted at 3 increasing moisture levels in five soils varying in pH and native organic matter content.

Results on changes in the amount of 2M KCl extractable ammonium and nitrate nitrogen (termed respectively, as exchangeable NH_4^+ and soluble NO_3^- in the subsequent text) and clay fixed ammonium nitrogen in five soils during moist incubation for 2, 5, 10 and 20 day periods maintained separately at 3 different moisture levels are presented in Tables 2A, 2B and 2C.

TABLE - 2A

Effect of different moisture levels during incubation on periodic changes in the amount (ppm) of exchangeable ammonium in soils

Soils	Moisture levels during incubation	Incubation period in days			
		2	5	10	20
Haringhata	M ₁	56	25	24	24
	M ₂	59	28	24	24
	M ₃	99	92	92	61
Kalyani	M ₁	42	31	21	21
	M ₂	42	35	27	24
	M ₃	56	42	21	21
Bankura	M ₁	49	49	42	35
	M ₂	49	49	42	42
	M ₃	63	46	53	42
Bagdubi	M ₁	49	42	42	35
	M ₂	49	49	42	42
	M ₃	49	49	42	42
Canning	M ₁	42	42	35	24
	M ₂	49	35	35	24
	M ₃	56	42	35	24

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

The amount of exchangeable NH_4^+ increased with increase in the moisture levels of the soil (Table 2A). This was observed generally in all the five soils under incubation. Thus irrespective of soils under investigation and periods of sampling, highest amount of exchangeable NH_4^+ was found in the waterlogged soils and least in the soils maintained at 50 per cent of the moisture holding capacity. It was further observed that the amount of exchangeable NH_4^+ tended to decrease with increase in the period of incubation upto 20 days. The increase in the amount of exchangeable ammonium with increase in the level of incubating soil moisture, from 50 per cent of MHC to waterlogged stage, may be the combined result of more rapid mineralisation of organic nitrogen in waterlogged soil over nonflooded condition, less scope for nitrification under the increasingly reduced condition with increase in the soil moisture level and lower nitrogen requirement of an anaerobic microbial population. Patrick and Wyatt (1964) as well as Borthakur and Mazumdar (1968) have also observed faster mineralisation of soil organic nitrogen in flooded than unflooded soil, which they have attributed partly to the lower N requirement of microbial population under anaerobic environment and to their lower synthetic efficiency.

However, changes in the amount of nitrate nitrogen with increase in the soil moisture level was not so marked (Table 2B). Although least amount of NO_3^- - N was, in general, noted in most of the waterlogged soils under investigation, no definite trend with the level of soil moisture could be detected. With increase in the period of incubation, however, the amount of NO_3^- - N tended to increase in most of the soils.

TABLE 2B

Effect of different moisture levels during incubation
on periodic changes in the amount (ppm) of soluble
nitrate in soils

Soils	Moisture levels during incubation	Incubation period in days			
		2	5	10	20
Haringhata	M ₁	21	28	35	49
	M ₂	21	21	35	35
	M ₃	21	21	21	28
Kalyani	M ₁	14	21	21	28
	M ₂	14	21	21	28
	M ₃	14	14	14	17
Bankura	M ₁	17	17	17	35
	M ₂	21	21	35	56
	M ₃	7	7	14	14
Bagdubi	M ₁	14	17	21	42
	M ₂	14	17	17	42
	M ₃	7	7	14	21
Canning	M ₁	7	14	17	21
	M ₂	17	21	21	35
	M ₃	7	21	21	21

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

A decrease in the amount of fixed NH_4^+ in the soil was observed immediately after moistening (2 day period) them to 50 per cent of moisture holding capacity over the premoist air dried state. The said decrease amounted to 21, 22, 12, 12 and 59 ppm in the soils collected from Haringhata, Kalyani, Bankura, Bagdubi and Canning respectively (Table 2c). Whereas, during the same period, an increase in the amount of fixed NH_4^+ (8 to 78 ppm) over the premoist state was noted in the same soils maintained at higher levels of moisture, i.e. under saturated and waterlogged condition. A decrease in the amount of fixed ammonium during the early period of incubation in soils at 50 per cent of MHC over the pre-moist state may possibly be attributed to biological immobilisation. Activity of soil microbes would be expected to increase considerably on moistening an air dried soil. The burst of biochemical activity associated in the process would demand for increasing amount of nitrogen in available form. Since, the rate of mineralisation of soil nitrogen was slower under 50 per cent of MHC than under waterlogged condition, microbes had possibly utilized part of the fixed NH_4^+ present in the relatively accessible sites. Following the same logic, lower demand for nitrogen by the microbial population under waterlogged condition coupled with faster rate of mineralisation of native soil organic nitrogen under those environment (Patrick and Wyatt, 1964) would have possibly resulted an increase in the amount of available ammonium in the soil. Naturally, demand for utilization of the native fixed ammonium in the soil would be remote under waterlogged and saturated condition. However,

TABLE 2C

Effect of different moisture levels during incubation
on periodic changes in the amount (ppm) of fixed
ammonium in soils

Soils	Moisture levels during incubation	Incubation period in days			
		2	5	10	20
Haringhata	M ₁	291	320	373	348
	M ₂	320	338	373	356
	M ₃	356	373	373	356
Kalyani	M ₁	590	610	664	592
	M ₂	610	610	664	664
	M ₃	646	664	682	682
Bankura	M ₁	467	502	502	485
	M ₂	556	556	592	502
	M ₃	574	610	648	610
Bagdubi	M ₁	502	520	538	467
	M ₂	538	538	538	502
	M ₃	592	610	646	556
Canning	M ₁	556	574	664	664
	M ₂	610	610	754	682
	M ₃	664	668	772	700

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

conclusive evidence in support of the above explanation could only be obtained by tracing changes in the forms of N^{15} tagged soil organic nitrogen under similar moisture level. Due to non-availability of the facility for N^{15} analysis in the laboratory, the explanation could not be conclusively verified.

Like exchangeable NH_4^+ (Table 2A), the amount of fixed ammonium (Table 2C and Fig. 1, 2, 3 and 4) was also found to increase in all the soils with increase in the incubating soil moisture level. In general, highest amount of fixed NH_4^+ was observed in waterlogged soil and least in the soils maintained at 50 per cent of the moisture holding capacity. Similarity in the trend of results of exchangeable and fixed NH_4^+ confirms the observations of Wiklander (1950) that NH_4^+ ions in exchangeable form is a necessary prerequisite for its fixation in the soil. The result further indicates that a considerable amount of the recently mineralised NH_4^+ was fixed in the soil. The amount of fixed NH_4^+ tended to increase with increase in the period (upto 10th day) of incubation. Thereafter the amount tended to decrease.

When the difference between the fixed ammonium nitrogen content under waterlogged and 50 per cent of the moisture holding capacity was computed separately for each of the four sampling stages of incubation, the trend of results observed in Haringhata and Kalyani soils were found to be different from the other three soils, namely that of Bankura, Bagdubi and Canning. In the first two soils, the values, tended to decrease (from 65 ppm to 0 ppm) with increase in the period of incubation

FIG. 1 EFFECT OF DIFFERENT MOISTURE LEVELS DURING INCUBATION ON PERIODIC CHANGES IN THE AMOUNT (ppm) OF FIXED AMMONIUM IN SOILS

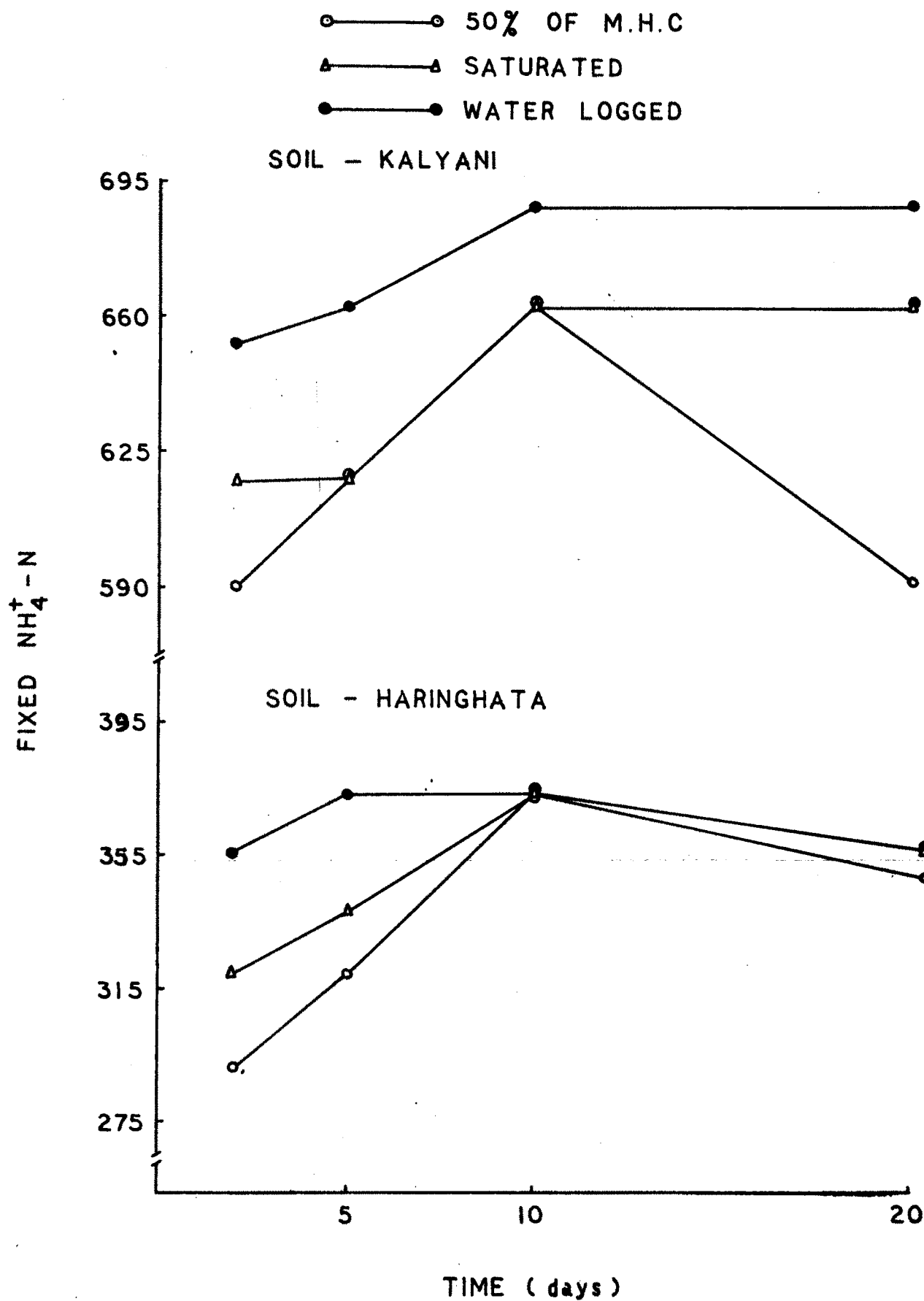


FIG. 2 EFFECT OF DIFFERENT MOISTURE LEVELS DURING INCUBATION ON PERIODIC CHANGES IN THE AMOUNT (ppm) OF FIXED AMMONIUM IN SOILS

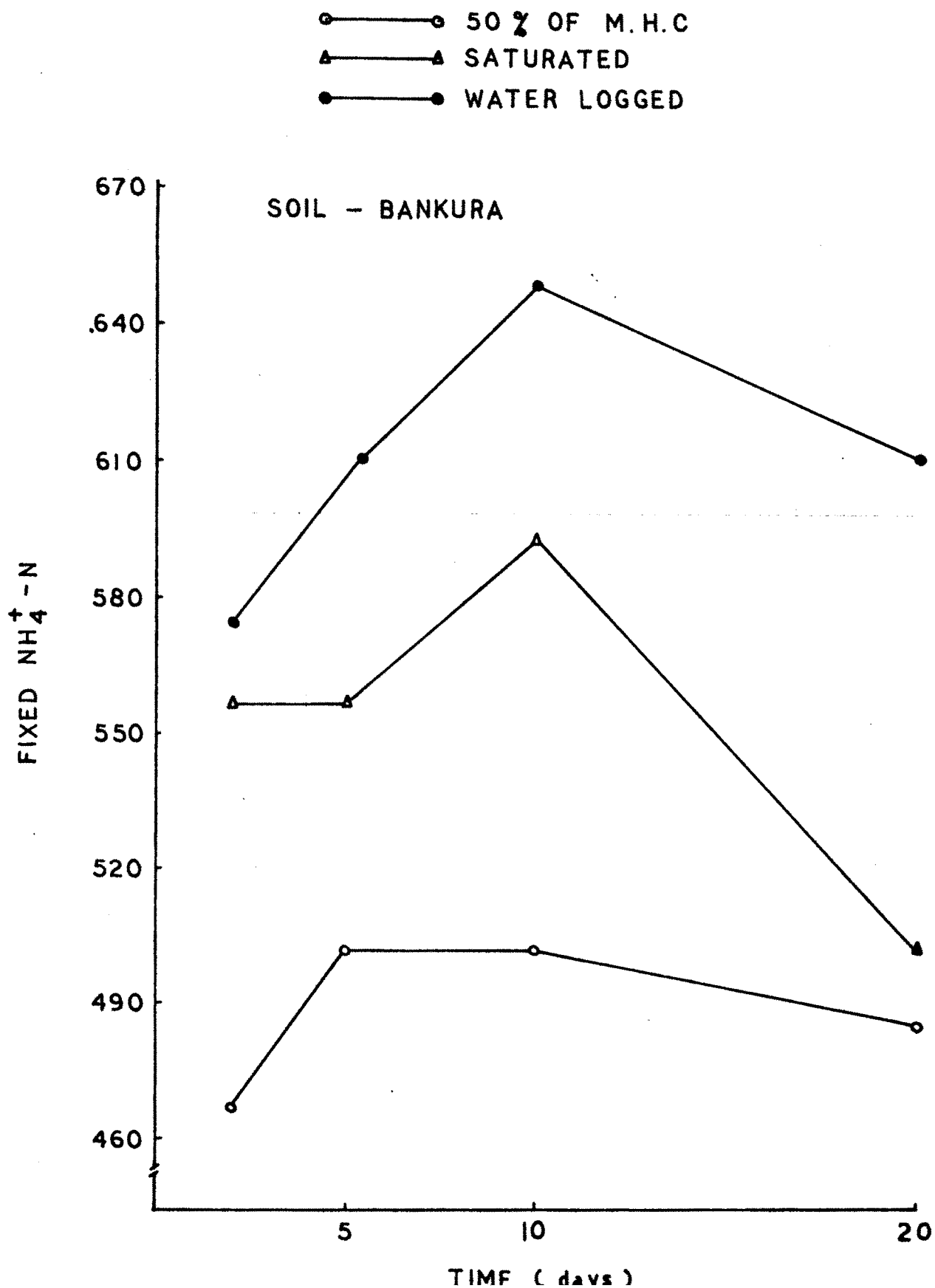


FIG. 3 EFFECT OF DIFFERENT MOISTURE LEVELS DURING INCUBATION ON PERIODIC CHANGES IN THE AMOUNT (ppm) OF FIXED AMMONIUM IN SOILS

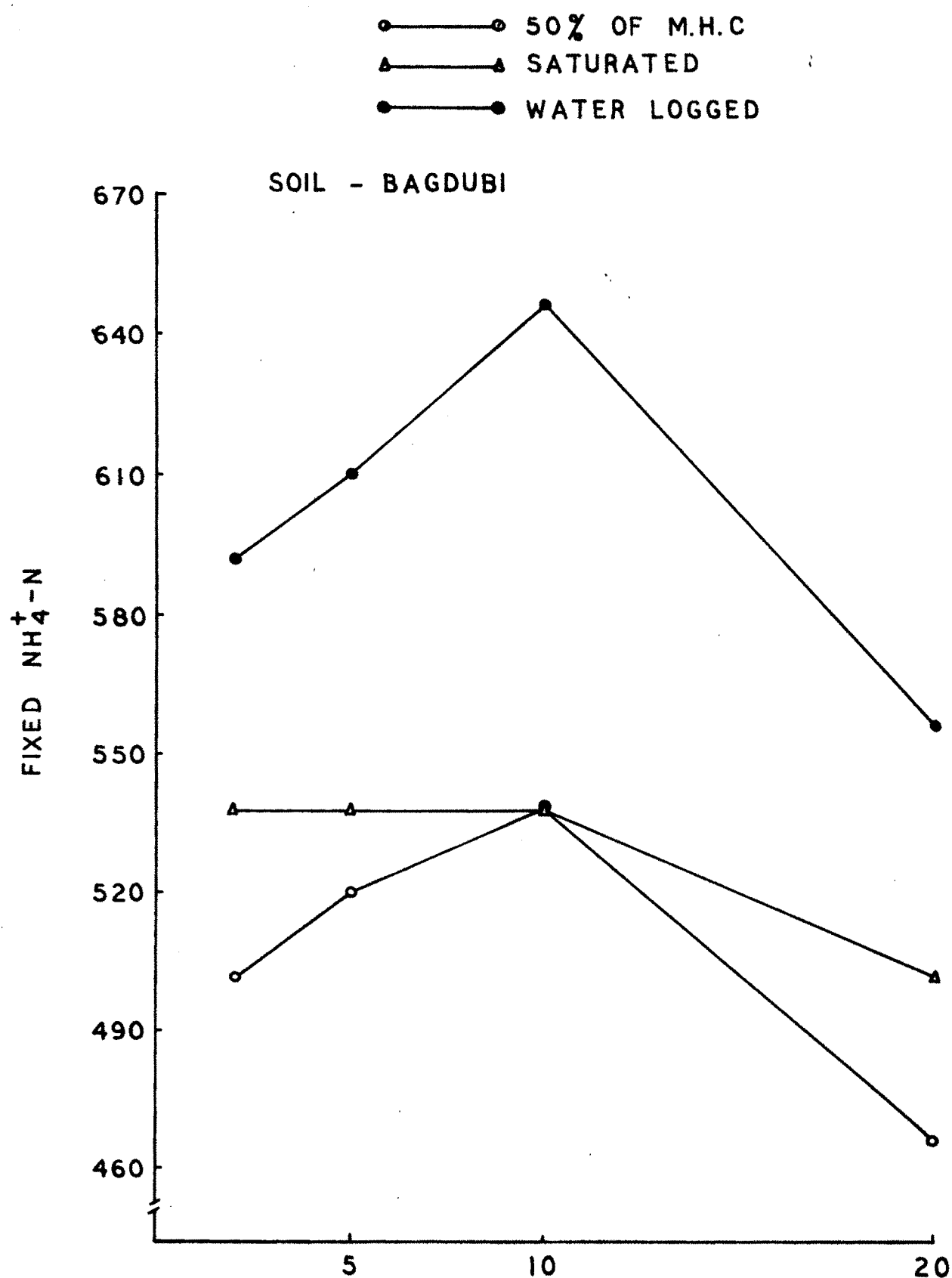
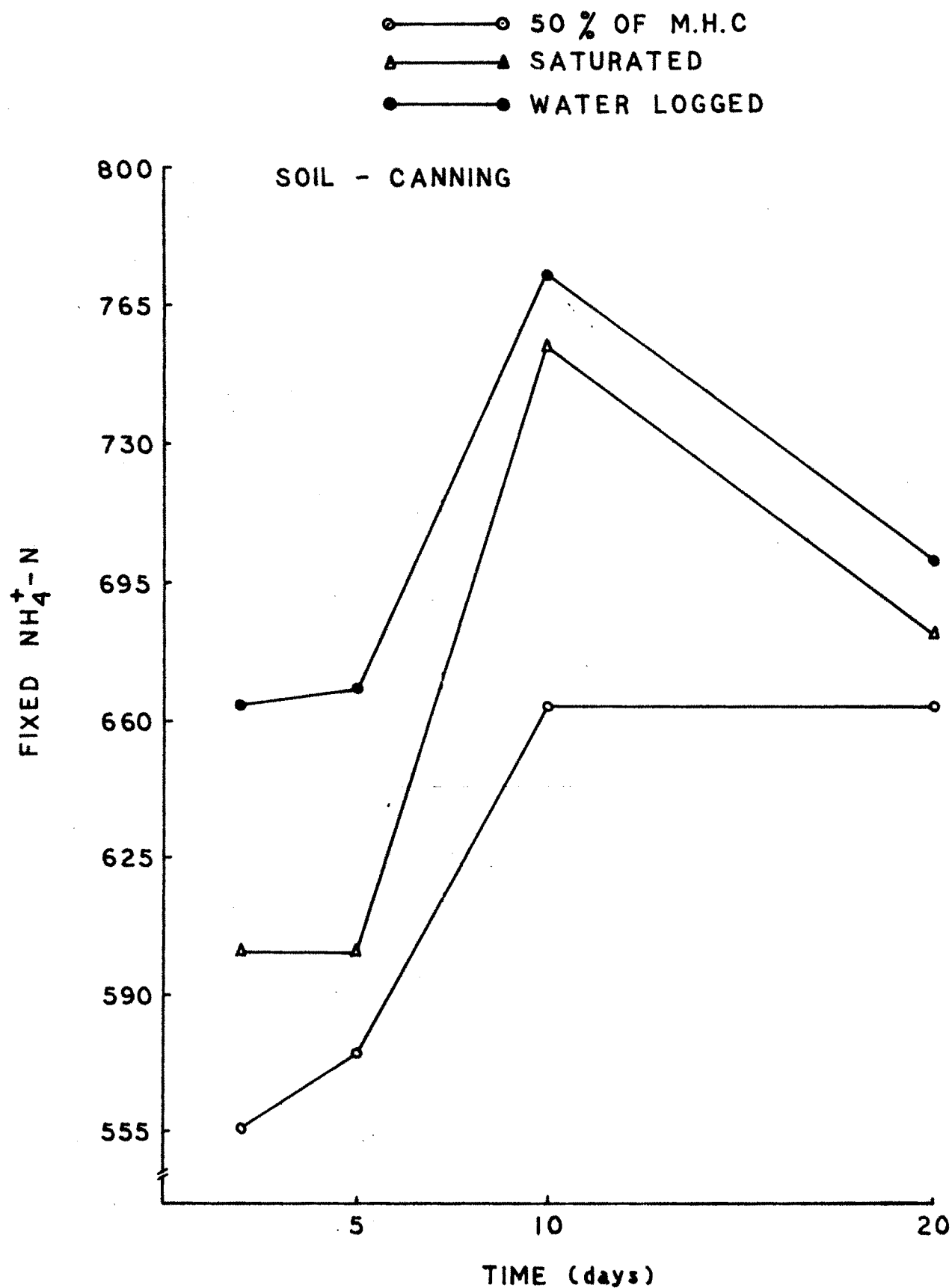


FIG. 4 EFFECT OF DIFFERENT MOISTURE LEVELS DURING INCUBATION ON PERIODIC CHANGES IN THE AMOUNT (ppm) OF FIXED AMMONIUM IN SOILS



(upto 10th day) , suggesting that the relative increase of the amount of fixed NH_4^+ in the soils at lower moisture levels (50 per cent of MHC) was higher (82 ppm in Haringhata and 90 ppm in Kalyani) than that in the soils under waterlogged state (17 ppm in Haringhata and 46 ppm in Kalyani). Whereas, during the same period, the amount of exchangeable NH_4^+ at all the moisture levels tended to decrease (Table 2A).

EXPERIMENT 2 : Effect of a short period of drying between different but uniformly maintained moisture levels on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium in five soils.

A short period of drying between different but uniformly maintained moisture conditions in soils may cause changes in the physico-chemical and microbiological environment and thus influence the transformations and availability of many nutrient ions in the soil system. It has been demonstrated by many workers that a short drying phase between uniformly maintained moisture regime in soil caused release of plant available nitrogen (IRRI, 1974, 1975, Matsushima, 1962). In view of this, it was considered necessary to obtain more informations about the effect of drying soils maintained at 3 different moisture regimes on the transformation of inorganic forms of nitrogen in the soils with particular emphasis on fixed NH_4^+ .

Changes in the amount of exchangeable NH_4^+ , soluble NO_3^- and fixed NH_4^+ due to a short period of drying between the

three different but uniformly maintained moisture levels (viz., 50 per cent of MHC, saturated and waterlogged) in the five soils are separately presented in Tables 3A, 3B, 3C, 3D and 3E. Analyses were done at three stages corresponding to 20th day of incubation at each of the respective moisture levels, immediately upon drying and 5th day after remoistening to the same moisture levels maintained prior to drying.

Results (Tables 3A, 3B, 3C, 3D and 3E) indicate that a short period of drying caused an increase in the amount of exchangeable NH_4 in the remoistened soil. This trend of result was in general observed in almost all the five soils under investigation and at all the three increasing levels of soil moisture in which incubations were carried out. The release of nitrogen was found to be least in the moisture saturated soils (4 to 21 ppm) and highest in the soils maintained at 50 per cent of MHC (7 to 35 ppm). The order of increase in the amount of exchangeable NH_4^+ due to incubating moisture levels was, however, not consistent among the 5 soils under investigation. Least amount of nitrogen release due to air drying was recorded in three out of 5 saturated soils (vide Tables 3A, 3B and 3C) whereas, in the other two soils, the least amount of increase in the amount of exchangeable NH_4^+ due to drying was observed under waterlogged condition (vide Tables 3D and 3E).

The result thus confirms the previous findings of Matsushima, 1962 and IRRI, 1974, 1975; that a short period of

TABLE 3A

Effect of a short period of drying during incubation under different moisture levels on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Haringhata soil

Moisture levels during incubation	Amount of forms of nitrogen during incubation on									
	20th day					15th day after remoistening				
	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	
M ₁	24	49	348	35	56	327	31	65	327	
				(+11)	(+7)	(-21)	(-4)	(+9)	(0)	
M ₂	24	35	356	32	42	338	28	51	327	
				(+8)	(+7)	(-18)	(-4)	(+9)	(0)	
M ₃	61	28	356	42	29	356	45	28	338	
				(-19)	(+1)	(0)	(+3)	(-1)	(-18)	

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sample just prior to the stage under consideration.

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE 3B

Effect of a short period of drying during incubation under different moisture levels on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Kalyani soil

Moisture levels during incubation	Amount of forms of nitrogen during incubation on							
	20th day				5th day after remoistening			
	Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Upon drying Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3 Fixed NH_4
M_1	21	49	592	49	(+28)	(0)	(-36)	(+7) (56) 70 538 (-18)
M_2	24	28	664	31	(+7)	(+14)	(-54)	(+11) (42) 70 592 (-18)
M_3	21	17	682	35	(+14)	(+4)	(-72)	(+14) (49) 21 592 (-18)

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled just prior to the stage under consideration.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE 3C

Effect of a short period of drying during incubation under different moisture levels on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Bankura soil

Moisture levels during incubation	Amount of forms of nitrogen during incubation on									
	20th day			Upon drying			5th day after remoistening			
	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Fixed NH ₄
M ₁	35	35	485	56	42	485	70	56	485	
				(+21)	(+7)	(0)	(+14)	(+14)	(0)	
M ₂	42	56	502	63	56	502	63	63	502	
				(+21)	(0)	(0)	(0)	(+7)	(0)	
M ₃	42	14	610	35	24	610	49	24	520	
				(-7)	(+10)	(0)	(+14)	(0)	(-90)	

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled just prior to the stage under consideration

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE - 3D

Effect of a short period of drying during incubation under different moisture levels on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Bagdubi soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		15th day after remoistening	
	Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Fixed NH_4	Soluble NO_3
M_1	35	42	467	49	467	49
				(+14)	(0)	(0)
						(+14)
						(-18)
M_2	42	42	502	56	484	56
				(+14)	(-18)	(0)
						(+7)
						(-17)
M_3	42	21	556	35	538	42
				(-7)	(-18)	(+7)
						(-14)
						(-72)

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled just prior to the stage under consideration.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 3E

Effect of a short period of drying during incubation under different moisture levels on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Canning soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on							
	2th day				5th day after remoistening			
	Exch. NH ₄	Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Upon drying Soluble NO ₃	Fixed NH ₄	Exch. NH ₄	Fixed NH ₄
M ₁	24	14	664	49	31	610	56	610
				(+25)	(+17)	(-54)	(+7)	(0)
M ₂	24	35	682	45	63	610	45	610
				(+21)	(+28)	(-72)	(0)	(0)
M ₃	24	21	700	49	24	664	56	610
				(+25)	(+3)	(-26)	(+7)	(-54)

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled just prior to the stage under consideration.

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

drying does cause an increase in the amount of exchangeable NH_4^+ in the remoistened soils. The result of the present investigation provide an additional information that such release occurs not only under waterlogged condition as reported by the previous workers but also in soils maintained at lower moisture levels. However, the order of increase varied considerably in different soils.

In order to further elucidate the effect of a short period of drying, soils maintained at different moisture levels on mineral nitrogen accumulation, the result of exchangeable NH_4 and soluble NO_3 nitrogen were added together at all the stages of incubation and are presented in the corresponding Tables 3A', 3B', 3C', 3D' and 3E' and graphically presented in Figs. 5, 6, 7, 8 and 9. The increase in the amount due to drying are presented in parenthesis under the values obtained on 5th day after remoistening the soils. Perusal of the data in the Tables clearly reveal that the net increase of mineral nitrogen in the soils were least under waterlogged condition. No definite trend between 50 per cent of MHC and saturated soil could be detected. The results thus support the findings of previous workers (IRRI 1974, 1975, Matsushim 1962). But this is probably the first report to indicate that the net increase in mineral nitrogen due to drying is more in soils incubated at 50 per cent of MHC and saturated condition than under waterlogged state. It is also evident from the data that the magnitude of increase in the dried soil was invariably less than that after remoistening. The result thus suggest that due either to

TABLE - 3A'

Effect of a short period of drying during incubation under different moisture levels on the amount (ppm) of mineral nitrogen accumulation (exchangeable NH_4^+ + soluble NO_3^-) in Haringhata soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		5th day after remoistening	
	Amount of mineral N accumulated	Fixed NH_4^+	Amount of mineral N accumulated	Fixed NH_4^+	Amount of mineral N accumulated	Fixed NH_4^+
M_1	73	348	91 (+18)	327	96 (+23)	327
M_2	59	356	74 (+15)	338	79 (+20)	327
M_3	89	356	71 (-18)	356	73 (-16)	338

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled at 20th day of incubation.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 3B'

Effect of a short period of drying during incubation under different moisture levels on the amount (ppm) of mineral nitrogen accumulation (exchangeable NH_4^+ + soluble NO_3^-) in Kalyani soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		5th day after remoistening	
	Amount of mineral N accumulated	Fixed NH_4^+	Amount of mineral N accumulated	Fixed NH_4^+	Amount of mineral N accumulated	Fixed NH_4^+
M_1	70	592	98 (+28)	556	126 (+56)	538
M_2	52	664	73 (+21)	610	112 (+60)	592
M_3	38	682	56 (+18)	610	70 (+32)	592

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled at 20th day of incubation.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 3C'

Effect of a short period of drying during incubation under different moisture levels on the amount (ppm) of mineral nitrogen accumulation (exchangeable NH_4^+ + soluble NO_3^-) in Bankura soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		5th day after remoistening	
	Amount of	Fixed	Amount of	Fixed,	Amount of	Fixed
	mineral N	NH_4^+	mineral N	NH_4^+	mineral N	NH_4^+
	accumulated		accumulated		accumulated	
M_1	70	485	98	485	126	485
			(+28)		(+56)	
M_2	98	502	119	502	126	502
			(+21)		(+28)	
M_3	56	610	59	610	73	520
			(+3)		(+17)	

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled at 20th day of incubation.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 3D'

Effect of a short period of drying during incubation under different moisture levels on the amount (ppm) of mineral nitrogen accumulation (exchangeable NH_4^+ + soluble NO_3^-) in Bagdubi soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		5th day after remoistening	
	Amount of	Fixed	Amount of	Fixed	Amount of	Fixed
	mineral N	NH_4^+	mineral N	NH_4^+	mineral N	NH_4^+
	accumulated		accumulated		accumulated	
M_1	77	467	91	467	105	449
			(+41)		(+28)	
M_2	84	502	105	484	112	467
			(+21)		(+28)	
M_3	63	556	70	538	63	484
			(+7)		(0)	

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil sampled at 20th day of incubation.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 3E'

Effect of a short period of drying during incubation under different moisture levels on the amount (ppm) of mineral nitrogen accumulation (exchangeable NH_4^+ + soluble NO_3^-) in Canning soil.

Moisture levels during incubation	Amount of forms of nitrogen during incubation on					
	20th day		Upon drying		5th day after remoistening	
	Amount of	Fixed	Amount of	Fixed	Amount of	Fixed
	mineral N accumulated	NH_4^+	mineral N accumulated	NH_4^+	mineral N accumulated	NH_4^+
M_1	38	664	80	610	84	610
			(+42)		(+46)	
M_2	59	682	108	610	115	610
			(+49)		(+56)	
M_3	45	700	73	664	73	610
			(+28)		(+28)	

Values in the parenthesis represent the amount of increase/decrease in the corresponding soil samples at 20th day of incubation.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged.

change in the distribution of other forms of inorganic nitrogen or biological transformation or through chemical changes upon drying, mineral nitrogen is released in the soil. The increased release of mineral nitrogen on remoistening the dried soil could possibly be an effect of accelerated rate of mineralisation due to spurt in microbial activity (Shioiri et al., 1941; Birch, 1958; Souliides and Allison, 1961).

Changes in the amount of fixed ammonium upon drying soils maintained for 20 days at three different moisture levels and on remoistening to the corresponding predried moisture levels show a general decrease in amount in all the soils and at all the moisture levels. But the amount of decrease did not show any relationship either with the predried or the post dried moisture levels. Critical analysis of the results on the net increase in the amount of mineral nitrogen and the net decrease in the amount of fixed ammonium upon drying possibly suggest that a part of the fixed NH_4^+ was released during the process and contributed to the increase in the amount of mineral nitrogen in dried soil.

The over all analysis of changes in the amount of three forms of nitrogen in five soils due to drying and upon remoistening to three levels of moisture thus suggest that the net increase in the amount of mineral nitrogen does occur on drying as well as upon remoistening after drying. The said increase in the amount of mineral nitrogen is the result of simultaneous processes occurring in the soils. Part of the increase in mineral nitrogen may possibly be due to the release of fixed NH_4^+ . The mineralisation

FIG. 5 EFFECT OF A SHORT PERIOD OF DRYING DURING INCUBATION ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED $\text{NH}_4^+ - \text{N}$ IN HARINGHATA SO

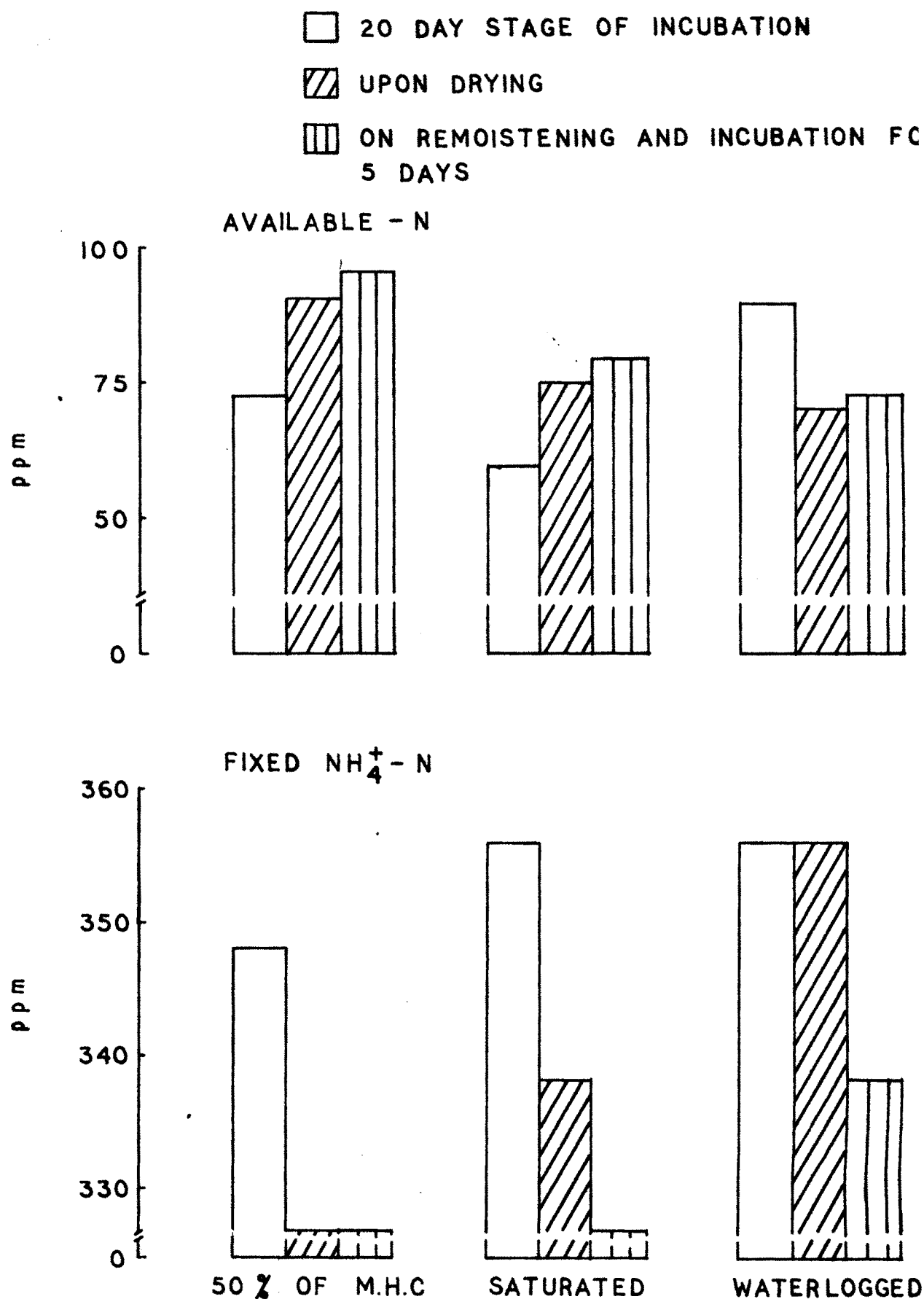


FIG. 6 EFFECT OF A SHORT PERIOD OF DRYING DURING INCUBATION ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N IN KALYANI SOIL

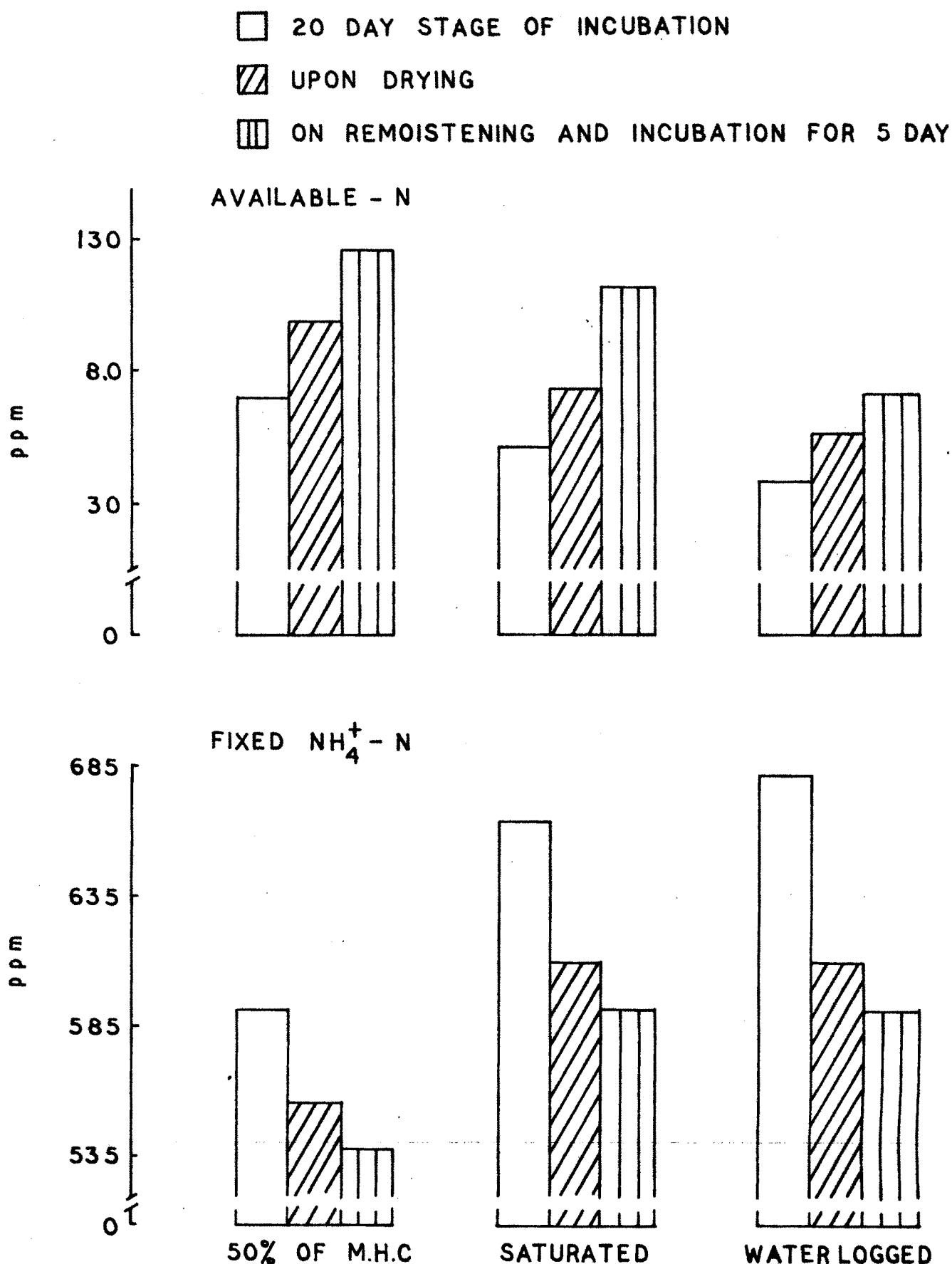


FIG. 7 EFFECT OF A SHORT PERIOD OF DRYING DURING INCUBATION ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N IN BANKURA SOIL

□ 20 DAY STAGE OF INCUBATION

▨ UPON DRYING

▤ ON REMOISTENING AND INCUBATION FOR 5 DAYS

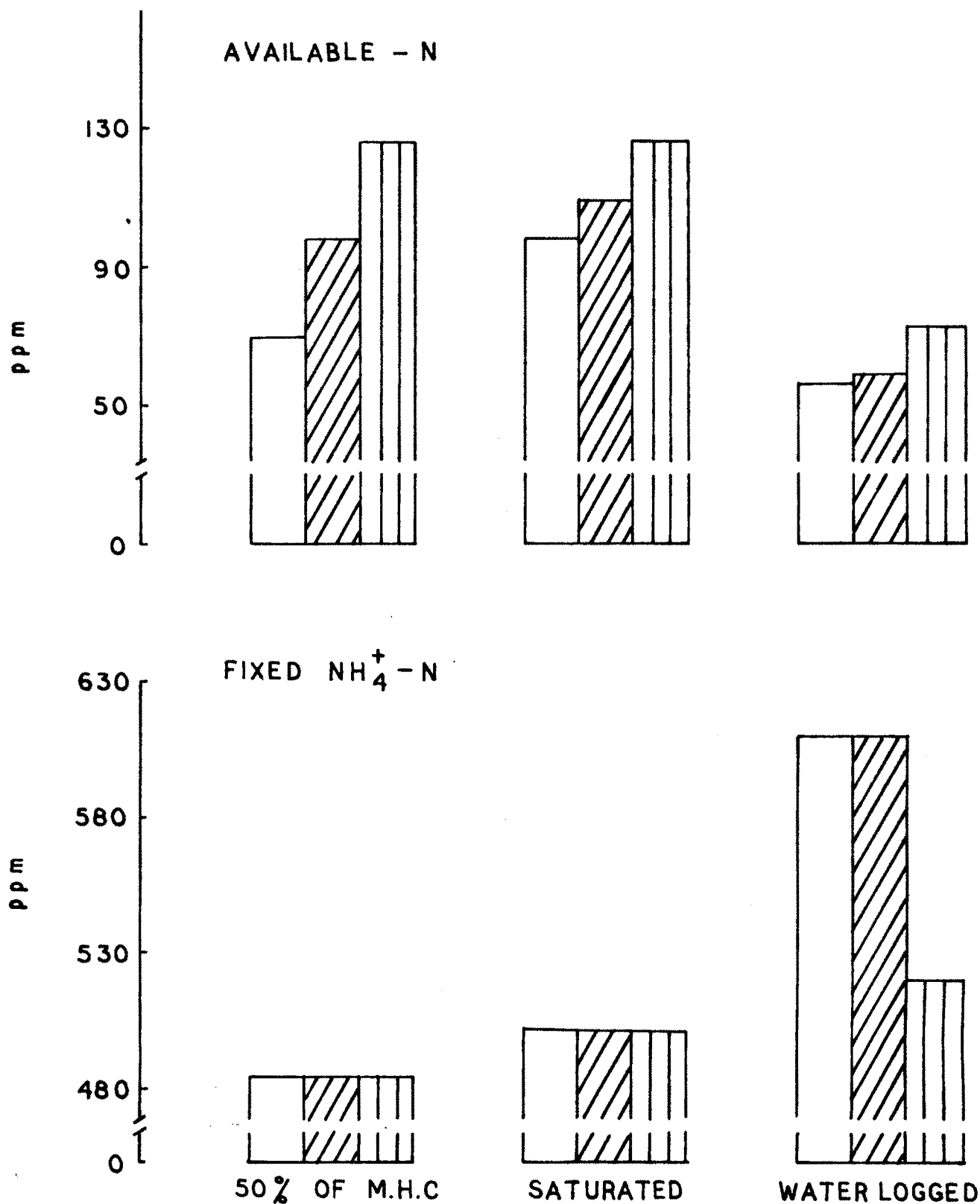


FIG. 8 EFFECT OF A SHORT PERIOD OF DRYING DURING INCUBATION ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N IN BAGDUBI SOIL

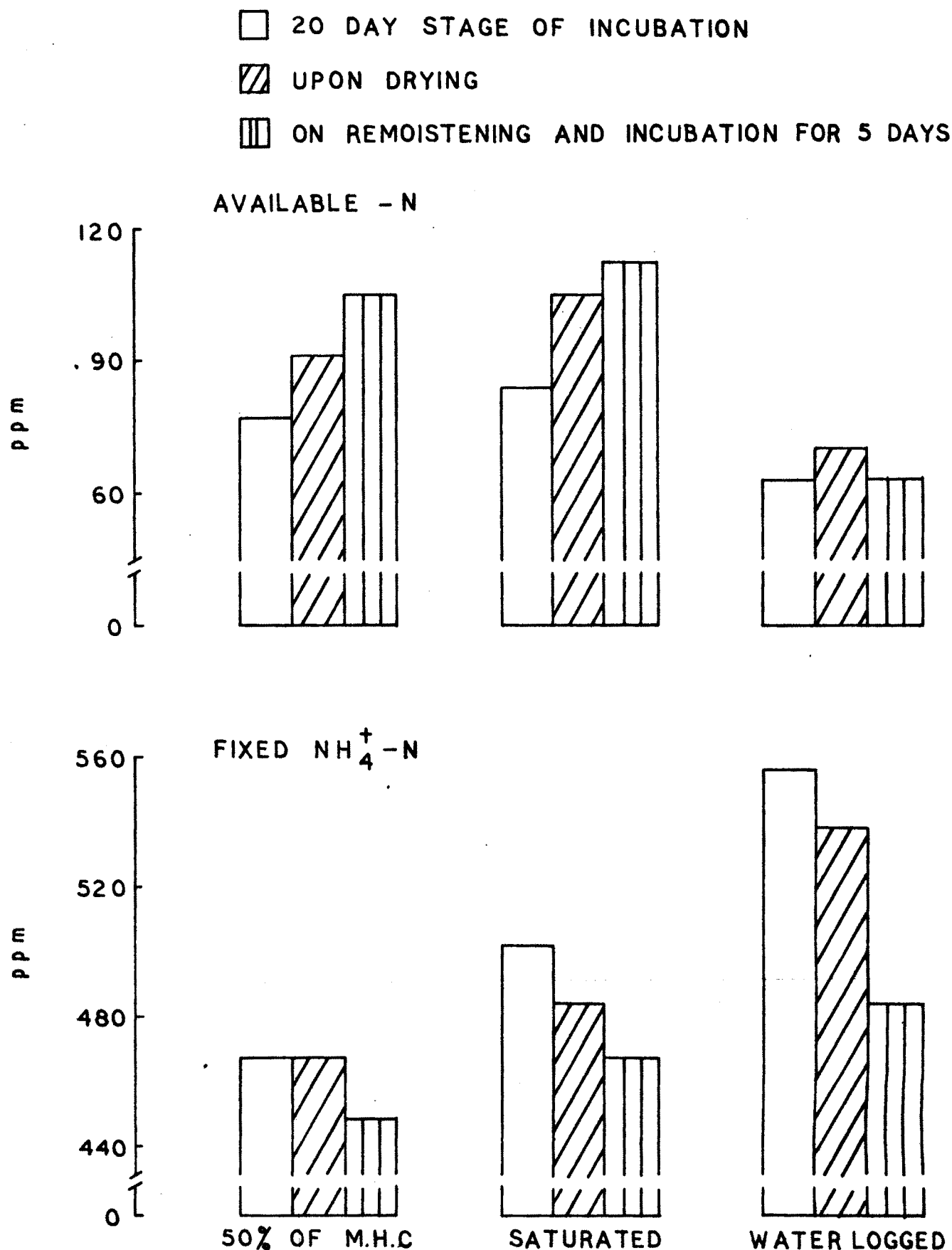
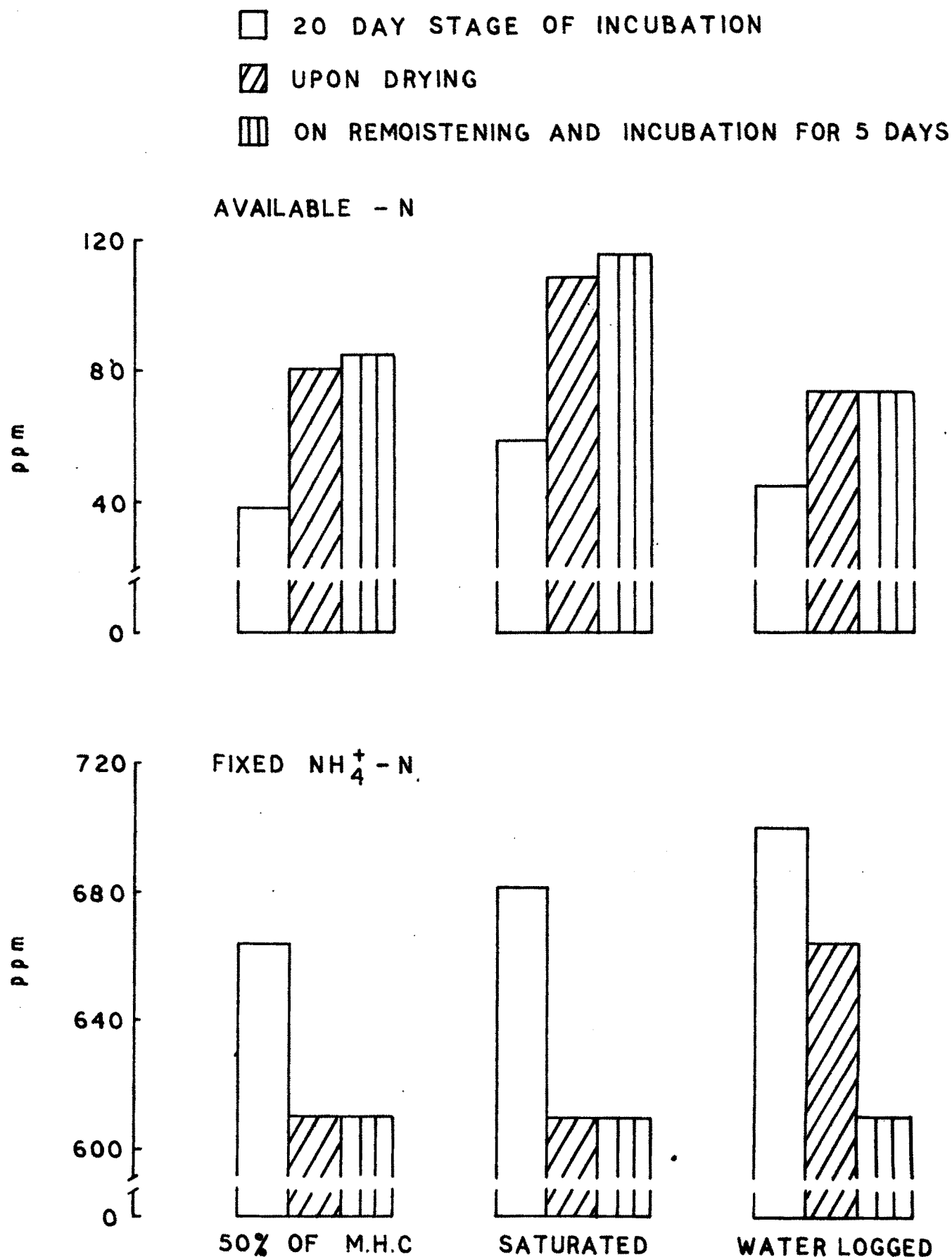


FIG. 9 EFFECT OF A SHORT PERIOD OF DRYING DURING INCUBATION ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N IN CANNING SOIL



of nitrogen due to drying also contributed to the observed release of mineral nitrogen in soil (Patrick and Wyatt 1964, Souliides and Allison, 1961; Takai and Harada, 1959). There are some reports to show that the solubility of soil organic matter increases as a result of drying (Birch 1959; Souliides and Allison, 1961). This may also contribute to the process. The release of fixed NH_4^+ due to drying has possibly occurred by the same process operative in the case of fixed potassium. Rich (1972) has suggested that the K-release due to drying is related to collapse of the expansible layer silicates. Besides change in the interlayer space, drying may change the rotation of the tetrahedral layer causing a change in K-O bond. Further, dehydration of cations may cause a redistribution of the interlayer cations allowing other cations to compete with the fixable cations at the wedge sites.

EXPERIMENT 3 : Effect of added $(\text{NH}_4)_2\text{SO}_4$ on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil incubated under three different but uniformly maintained moisture levels.

The management of soil moisture furnish a considerable possibility for increasing available nitrogen in soil. Very few workers (Broadbent and Tusneem, 1971; Bhattacharyya, 1971) have investigated transformation of mineral nitrogen with particular emphasis to the fixed ammonium as influenced by soil moisture levels. The present study was, therefore, conducted to

investigate the effect of 3 different soil moisture levels and added $(\text{NH}_4)_2\text{SO}_4$ on periodic changes in the amount of clay fixed ammonium, exchangeable ammonium and soluble nitrate nitrogen in a soil collected from Kalyani in West Bengal.

Results on the effect of added ammonium nitrogen on changes in the amount of different forms of mineral nitrogen including the fixed ammonium form over the corresponding amount in the soil without added $(\text{NH}_4)_2\text{SO}_4$ are presented in Table 4A. Results reveal that irrespective of the incubating soil moisture levels, the exchangeable ammonium decreased progressively. However, the magnitude of decrease was more pronounced under waterlogged (decreased from 195 ppm on 2nd day to 49 ppm on 20th day) and saturated soil (decreased from 202 to 57 ppm). The corresponding decrease of exchangeable ammonium under 50% of the moisture holding capacity was from 195 ppm to 104 ppm over 20 day period of incubation. It is of interest to note that the magnitude of decrease was almost same during the first 5 day period at all the three levels of moisture regimes under study. The difference due to soil moisture levels were pronounced on the 10th and 20th day period of incubation. The above observation was also found to be valid even when the sum of exchangeable NH_4 and NO_3 nitrogen in the soil were taken into consideration.

Analysis of the data in Table 4A indicate that the amount of clay fixed ammonium in the $(\text{NH}_4)_2\text{SO}_4$ added soil over the untreated control tended to increase with the increase of incubation period upto 10th day in the soils maintained at all

TABLE - 4A

Increase in the amount (ppm) of some mineral forms of nitrogen in Kalyani soil due to added ammonium sulphate during incubation for different periods at three moisture levels.

Moisture levels during incubation	Forms of inorganic nitrogen in soil	Incubation period in days			
		2	5	10	20
M ₁	Exchangeable NH ₄	195	128	132	104
	Soluble NO ₃	7	0	7	14
	Fixed NH ₄	2	36	54	90
M ₂	Exchangeable NH ₄	202	132	77	57
	Soluble NO ₃	7	7	35	70
	Fixed NH ₄	2	36	54	18
M ₃	Exchangeable NH ₄	195	125	83	49
	Soluble NO ₃	3	3	3	39
	Fixed NH ₄	2	54	105	18

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

the three moisture levels and upto 20th day in the soil at 50% of the moisture holding capacity. Closer examination of the data on fixed NH_4^+ - N in the soil separately for each of the soil moisture levels (Table 4A), show that only 1% of the added nitrogen (200 ppm) was found in the clay fixed ammonium form on 2nd day after addition of $(\text{NH}_4)_2\text{SO}_4$. On 5th day of incubation the value sharply increased to an amount equivalent to 18% of the added nitrogen under 50% of the moisture holding capacity and saturated condition, whereas, to 27% under waterlogged condition. The result thus suggest that an increased amount of added ammonium nitrogen became fixed under waterlogged condition than in the soils maintained at lower moisture levels. Clay fixation of ammonium equivalent to 52.5% of the added nitrogen was recorded on 10th day of incubation under waterlogged condition, whereas, the corresponding values recorded for the same soil kept under saturated and 50% of MHC were only 41.5 and 27% equivalent of the added ammonium nitrogen respectively. The result thus show that 10th day after ammonium fertilization, the magnitude of fixation of added ammonium increased with increase in the level of soil moisture. In an attempt to study the fate of ammonium nitrogen added as N^{15} tagged $(\text{NH}_4)_2\text{SO}_4$ to waterlogged Sacramento clay, Broadbent and Tusneem (1971) have also observed 53% of the added ammonium in the clay fixed form on 12th day after addition of fertilizer. But they restricted their study only to waterlogged soil condition.

Comparative evaluation of the decrease in the amount of added ammonium nitrogen in the exchangeable form and the

increase of the fixed form of NH_4^+ in the soil maintained at three moisture levels reveal that while there was a decrease in the amount of exchangeable NH_4^+ equivalent to 31.5, 62.5 and 56.0% of added nitrogen over the first 10 day period of incubation, there was an increase of 26.0, 26.0 and 51.5% equivalent in the form of clay fixed ammonium. The result thus suggest a possible transformation of exchangeable ammonium to fixed ammonium in the soil and such transformation was more pronounced under waterlogged condition than that in the soil at lower moisture levels. Although there is no available information on the effects of reduction and oxidation on ammonium fixation, such effects on similarly fixable K^+ ion in vermiculites and biotites were reported by Barshad and Kishk (1968, 1970); Gilkes *et al.* (1973) and Kishk and El-Sheemy (1974). Barshad and Kishk (1968) observed an increase (from 0-9 to 6-22 m.e/100 g) of potassium fixation in four vermiculite clays in the wet state.

In order to compare the relative influence of soil moisture levels on periodic changes in the amount of native clay fixed NH_4^+ the data in Table 2C and 4A are rearranged and are presented in Table 4C and Fig. 11. A similar table is also prepared for exchangeable ammonium and nitrate nitrogen and presented in Table 4B and graphically presented in Fig. 10.

It is evident from the data (Table 4C) that a considerable amount of the recently mineralised ammonium is incorporated into the clay fixed form in the soil and highest amount was incorporated

FIG. 10 INFLUENCE OF MOISTURE LEVELS DURING INCUBATION ON INCREASE IN THE AMOUNT (ppm) OF EXCHANGEABLE NH_4^+ -N IN N-FERTILIZED AND UNFERTILIZED KALYANI SOIL OVER THE INITIAL STAGE

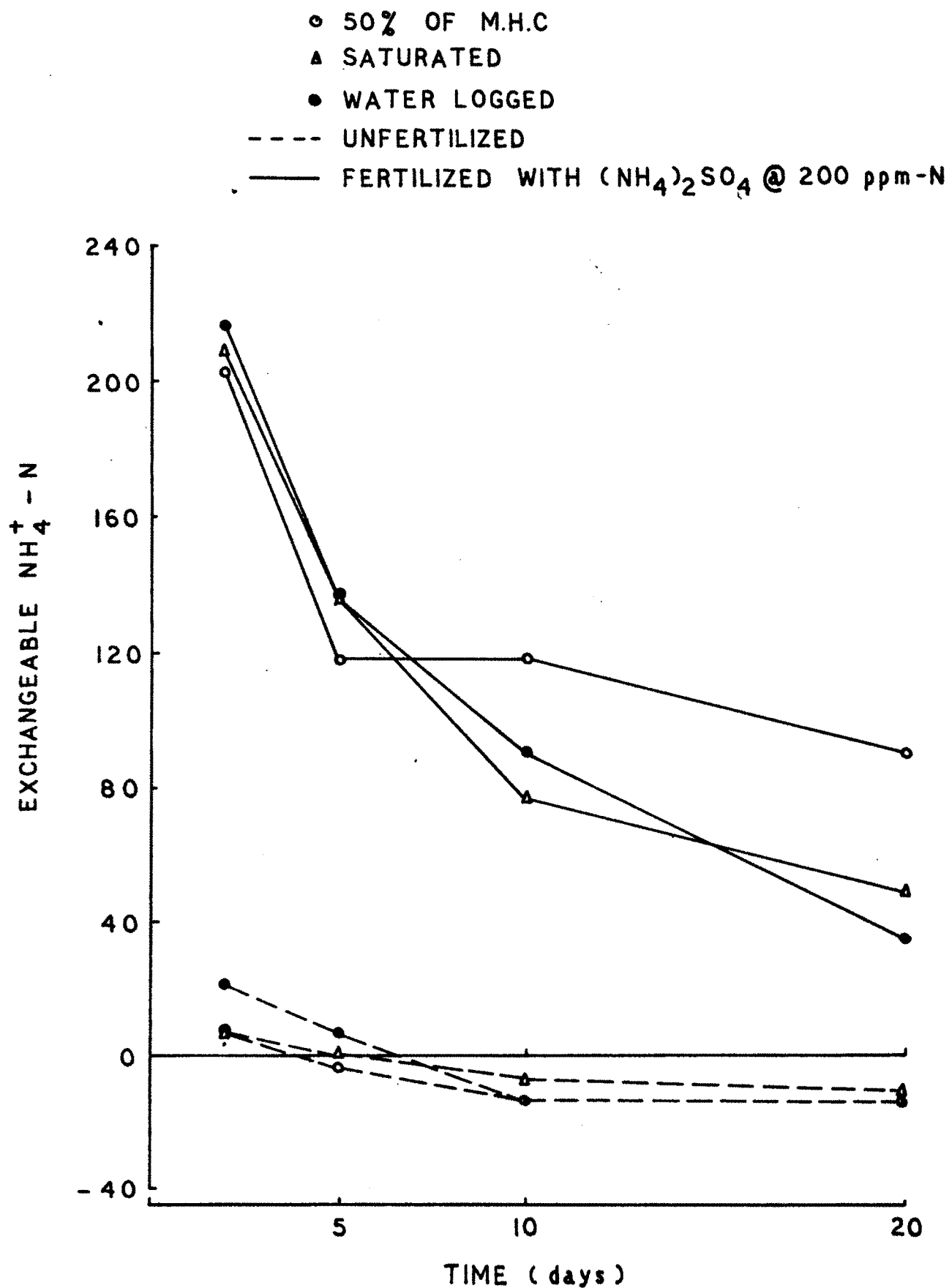


FIG. II INFLUENCE OF MOISTURE LEVELS DURING INCUBATION ON INCREASE IN THE AMOUNT (ppm) OF FIXED NH_4^+ -N IN N-FERTILIZED AND UNFERTILIZED KALYANI SOIL OVER THE INITIAL STAGE

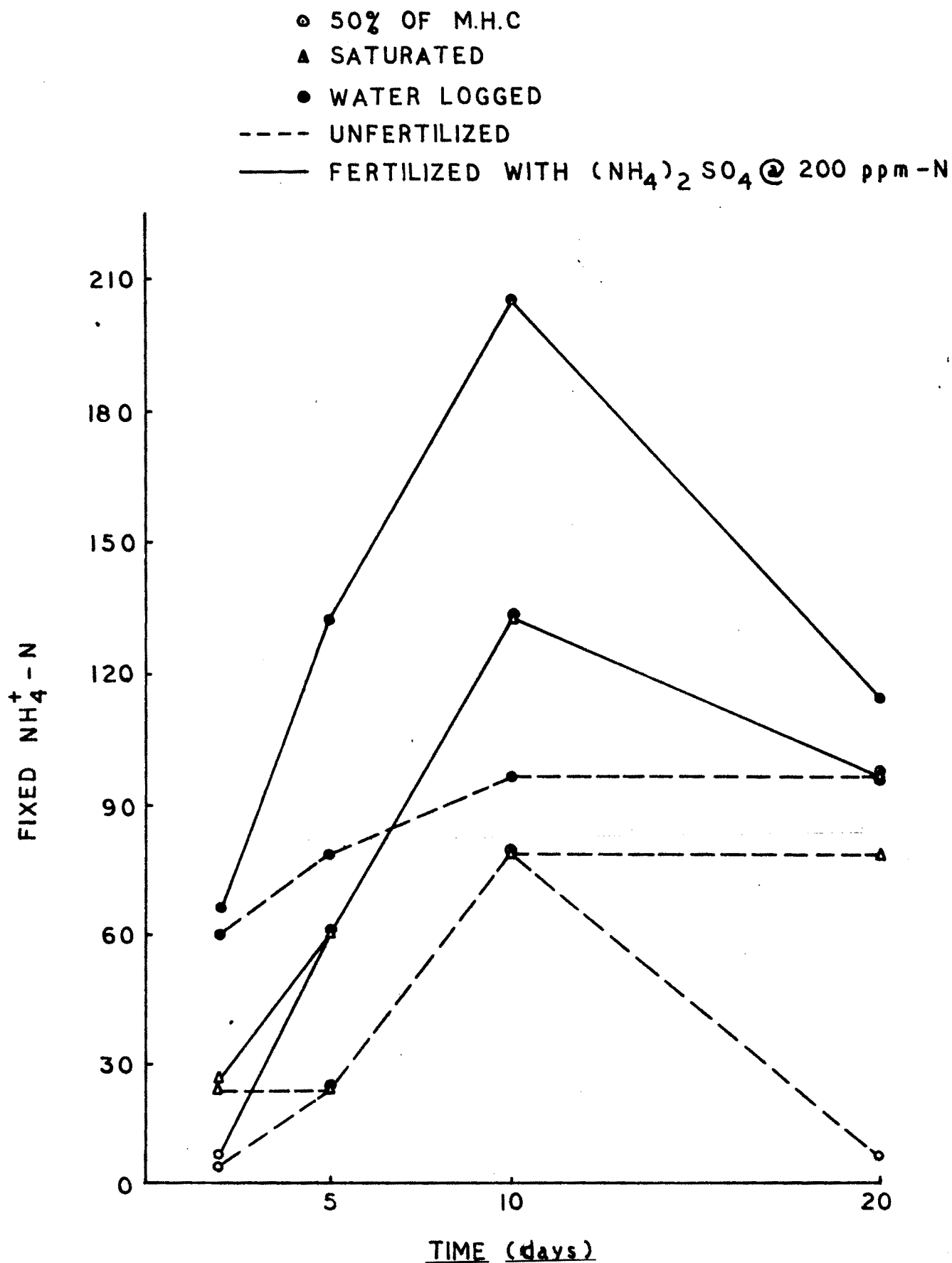


TABLE - 4B

Periodic increase in the amount (ppm) of exchangeable ammonium and soluble nitrate over the respective amounts on 0-day stage of incubation at three moisture levels in Kalyani soil treated with and without ammonium sulphate.

Moisture levels during incubation	Added $(\text{NH}_4)_2\text{SO}_4$	Incubation period in days												
		2				5				10				20
		Exch. NH_4	Soluble NO_3	Exch. NH_4	Soluble NO_3	Exch. NH_4	Soluble NO_3	Exch. NH_4	Soluble NO_3	Exch. NH_4	Soluble NO_3	Exch. NH_4	Soluble NO_3	
M_1	Without	7	7	-4	14	-14	14	-14	14	-14	14	-14	21	
	With	202	14	118	14	118	14	118	21	90	21	90	35	
M_2	Without	7	7	0	14	-8	14	-8	14	-11	14	-11	21	
	With	209	14	132	21	77	21	77	49	49	91	49	91	
M_3	Without	21	7	7	7	-14	7	-14	7	-14	7	-14	10	
	With	216	10	132	10	90	10	90	10	35	10	35	49	

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 4C

Periodic increase in the amount (ppm) fixed ammonium over the respective amounts on 0-day stage of incubation at three moisture levels in Kalyani soil treated with and without ammonium sulphate.

Moisture levels during incubation	Added $(\text{NH}_4)_2\text{SO}_4$	Incubation period in days			
		2	5	10	20
M_1	Without	4	24	78	6
	With	6(2)	60(36)	132(54)	96(90)
M_2	Without	24	24	78	78
	With	26(2)	60(36)	132(54)	96(18)
M_3	Without	60	78	96	96
	With	66(6)	132(54)	205(109)	114(18)

The values in parenthesis represent the amount over the corresponding native soil incubated under the same moisture level.

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

in the waterlogged soil. This is quite expected because the mineralisation of organic nitrogen in waterlogged soils is generally more rapid than in nonflooded soils (Patrick and Wyatt 1964, Borthakur and Mazumdar, 1968). While an increase of 96 ppm of ammonium nitrogen in the fixed form was observed after 10 days of waterlogging in the soil which did not receive any source of fertilizer nitrogen, only 78 ppm increase was noted in the corresponding soil maintained at moisture level equivalent to 50% of the moisture holding capacity. The observation suggest a possible conversion of a part of the mineralised ammonium to the fixed form. It is of further interest to note that out of the 200 ppm of NH_4^+ - N added as $(\text{NH}_4)_2\text{SO}_4$, 54 to 109 ppm NH_4^+ - N was fixed, whereas, during the same period 78 to 96 ppm NH_4^+ - N was fixed where no source of fertilizer nitrogen was added.

EXPERIMENT 4 : Effect of numbers of wetting and drying cycles after ammonium fertilizer addition on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil incubated under three different moisture levels.

No increase in the amount of fixed ammonium due to repeated wetting and drying cycles of soil over that to single air drying was observed by Allison et al. (1951). But Jansson (1958) reported higher percentage of added ammonium fixed in a Swedish soil due to three cycles of wetting and drying than that due to single drying (30°C). Thus contradictory reports exist as to

the effectiveness of wet and dry cycles on fixation of added ammonium. However, a recent report by Opuwaribo and Odu (1978) also indicated the effectiveness of wet and dry cycles on increase in the amount of added ammonium fixed in Nigerian soils. Most of the studies reported results on the amount of fixed ammonium in soils following the addition of fertilizer ammonium and subjecting the soils to different cycles of wetting and drying. But so far no studies reported changes, the recently fixed ammonium underwent when maintained under different moisture levels.

The present investigation was, therefore, conducted to study the changes in the amount of fixed ammonium, exchangeable NH_4 and soluble NO_3 form of nitrogen in soil after ammoniation separately through one and two cycles of wetting and air drying followed by washing of excess ammonium sulphate from the soil solution by distilled water.

Periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium form of nitrogen in soil during incubation under different moisture levels due to ammoniation separately through 1 and 2 cycles of wetting and drying are presented in Tables 5A, 5B and 5C respectively. The data presented in these tables are obtained by subtracting the corresponding values obtained in the same soil (Tables 2A, 2B and 2C respectively) not treated with any source of nitrogenous fertilizer.

During incubation at 50% of MHC, considerably higher amount of exchangeable ammonium was observed in the soil which underwent

TABLE - 5A

Periodic changes in the amount (ppm) of exchangeable ammonium in Haringhata soil during incubation under different moisture levels due to ammoniation separately through 1 and 2 cycles of wetting and drying.

Incubating moisture levels	Number of wetting and drying cycles prior to incubation	Incubation period in days			
		2	5	10	20
M ₁	1	22	46	4	-2
	2	66	80	48	11
M ₂	1	83	64	18	0
	2	76	47	14	-3
M ₃	1	100	24	21	-19
	2	64	17	-7	-23

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE - 5B

Periodic changes in the amount (ppm) of soluble nitrate in Haringhata soil during incubation under different moisture levels due to ammoniation separately through 1 and 2 cycles of wetting and drying.

Incubating moisture levels	Number of wetting and drying cycles prior to incubation	Incubation period in days			
		2	5	10	20
M ₁	1	14	14	43	26
	2	4	4	-3	-14
M ₂	1	21	17	13	13
	2	4	4	-14	-7
M ₃	1	-3	0	-3	0
	2	-3	4	0	-14

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE - 5C

Periodic changes in the amount (ppm) of fixed ammonium in Haringhata soil during incubation under different moisture levels due to ammoniation separately through 1 and 2 cycles of wetting and drying.

Incubating moisture levels	Number of wetting and drying cycles prior to incubation	Incubation period in days			
		2	5	10	20
M_1	1	65	53	54	61
	2	79	71	54	61
M_2	1	36	35	72	17
	2	60	71	89	71
M_3	1	0	36	89	35
	2	28	89	96	71

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

2 cycles of wetting and drying after ammoniation than the corresponding system with only one cycle. This was observed at all the 4 stages of analysis over the 20 day incubation period. Whereas when incubated under saturated and waterlogged condition lower amount of exchangeable ammonium was recorded in the soil with 2 than 1 cycles of wetting and drying. This trend of result was noted at all the stages of incubation period under study. Irrespective of the moisture levels at which incubation was conducted and the number of cycles of wetting and drying, however, the values of exchangeable ammonium tended to decrease with increase in the period of incubation. One cycle of wetting and drying following ammoniation resulted much higher amount of added ammonium in exchangeable form (83 to 100 ppm) in the soil incubated at higher moisture levels (saturated and waterlogged) than in the corresponding soil maintained at 50% of MHC (22 ppm), whereas, 2 cycles of wetting and drying resulted higher (86 ppm) amount of added ammonium in the exchangeable form in the soil incubated at 50% of MHC than under higher levels of soil moisture (76 ppm to 64 ppm). The trend was consistent over the complete period of incubation.

The increase in the amount of added ammonium entering the exchange phase in soil with increasing cycles of wetting and drying is possibly be due to the creation of more favourable condition for the added ammonium to replace other cations from the surface by mass action. Opuwaribo and Odu (1978) also reported that five alternate wet and dry cycles after ammoniation

brought about increase in the concentration of ammonium in exchange phase. Similar was the observation of Jansson (1958) and Harada and Kutsuna (1954). But under waterlogged and saturated soil the above effect could not be detected. This could possibly be the result of increasing amount of volatilisation and denitrification losses under the reduced environment of saturated and waterlogged conditions. Reddy and Patrick (1975b) have reported a loss of 63 per cent of added ammonium N due to denitrification under waterlogged condition. Patrik and Wyatt (1964) have observed that intermittent flooding of soils promotes losses by denitrification. Increasing amount of volatilization losses of added ammonium under waterlogged condition has also been reported by number of workers (Mitsui et al., 1954; MacRae and Ancajas, 1970; Ventura and Yoshida, 1977; Bouldin and Alimagno, 1976).

Increasing the number of cycles of wetting and drying resulted increasing amount of fixation of added ammonium in the soil. Irrespective of the moisture levels, distinctly higher amount of added ammonium was found to be fixed in the soil which underwent 2 cycles of wetting and drying than the corresponding system subjected to one cycle. At all the stages, except on 2nd day of incubation, the highest amount of added ammonium in the fixed form was observed under waterlogged condition and least under 50 per cent of the moisture holding capacity. A similar effect of moisture levels on clay fixed ammonium was also reported in another experiment of this section (Table 2C). The explanation furnished therein are equally applicable in the present case.

The result of the present investigation also support our previous observation (Table 2C) that fixation of added ammonium in soils maintained under saturated and waterlogged condition reaches its maximum value on 10th day after incubation and tends to decrease thereafter.

Analysis of the results presented in Table 5A and 5C and in Figs. 12 and 13 in general, show that on 10th day of incubation the amount of added ammonium in the exchangeable form decreased considerably while during the same period a distinct increase in the amount of fixed ammonium was noticed except in the soil maintained at 50 per cent of MHC. This observation possibly indicate partial conversion of the ammonium from the exchangeable to the fixed form.

It is of further interest to note that the decrease in the amount of fixed NH_4 on 20th day over 10th day was much more in the soil which passed through single cycle of wetting and drying after addition of ammonium sulphate than in the corresponding soil which underwent two such cycles. This observation indicates that increasing the number of cycles of wetting and drying possibly caused a decrease in availability of the recently fixed ammonium. This is of considerable practical significance. Further studies are, however, necessary to confirm the result.

FIG. 12 CHANGES IN THE AMOUNT (ppm) OF EXCHANGEABLE NH_4^+-N IN HARINGHATA SOIL DUE TO AMMONIATION THROUGH ONE AND TWO CYCLES OF WETTING AND DRYING PRIOR TO INCUBATION UNDER DIFFERENT MOISTURE LEVELS

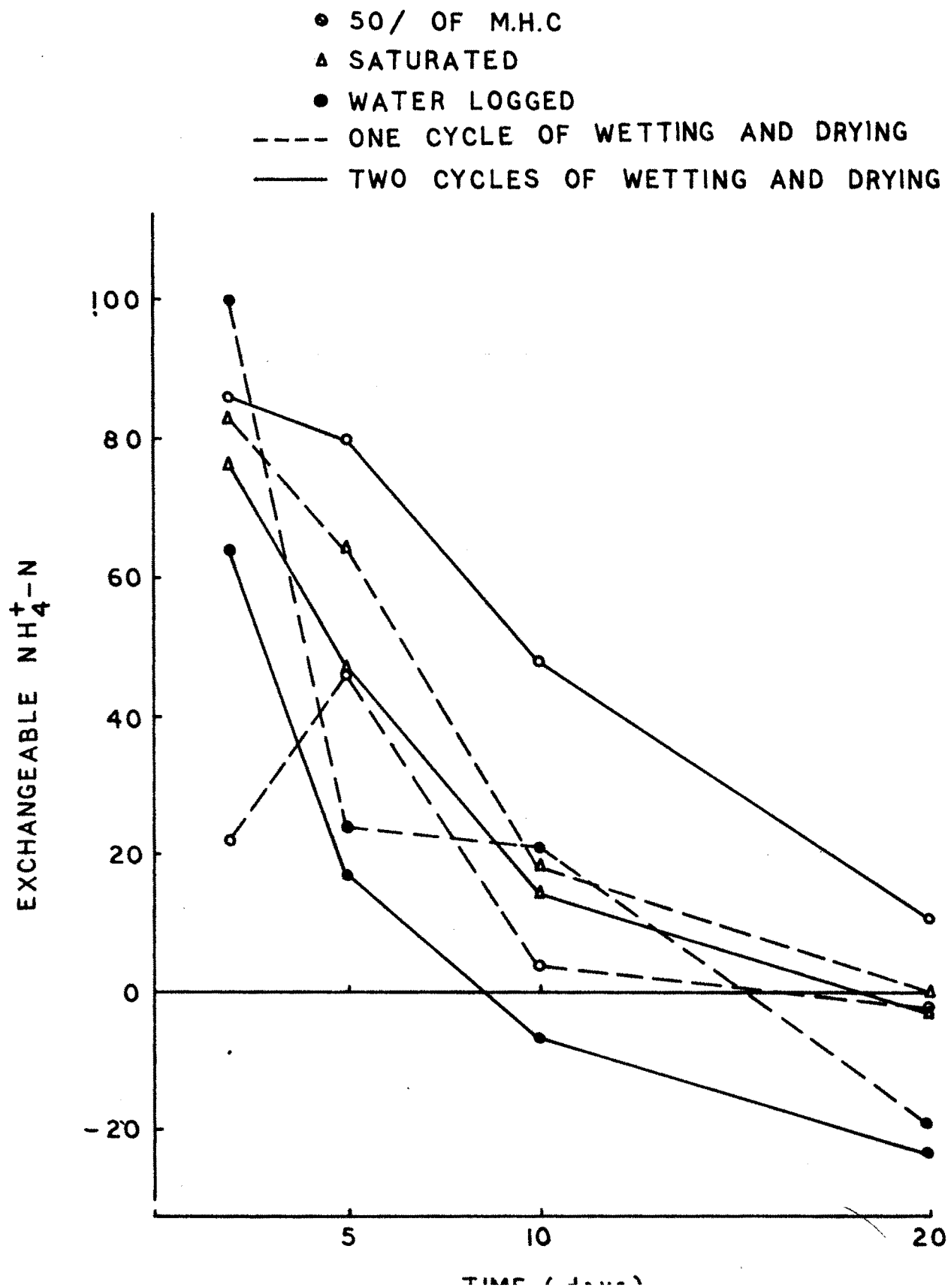
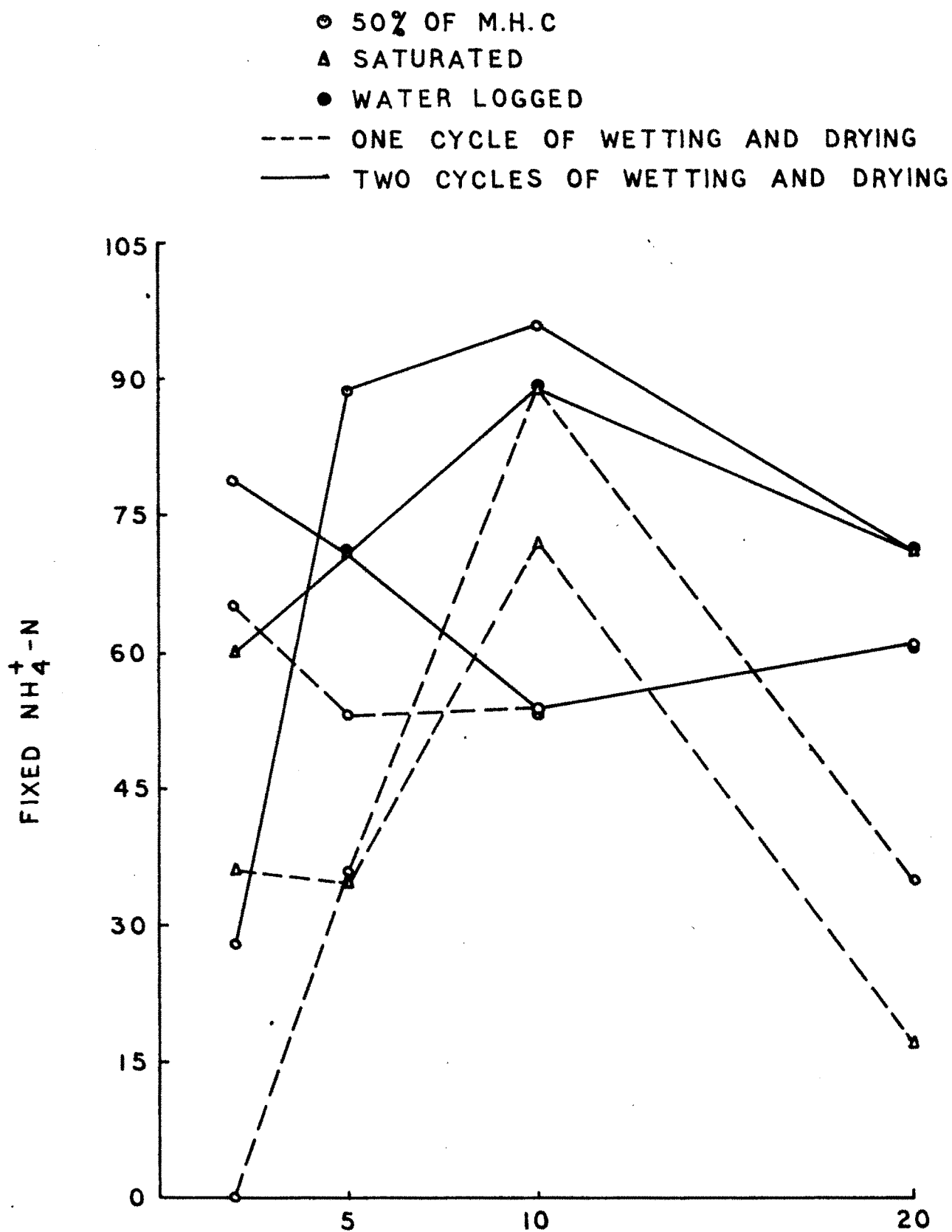


FIG. 13 CHANGES IN THE AMOUNT (ppm) OF FIXED $\text{NH}_4^+\text{-N}$ IN HARINGHATA SOIL DUE TO AMMONIATION THROUGH ONE AND TWO CYCLES OF WETTING AND DRYING PRIOR TO INCUBATION UNDER DIFFERENT MOISTURE LEVELS



EXPERIMENT 5 : Effect of different ammonium producing fertilizers on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in four soils incubated under different moisture levels.

Nitrogen is added in the field through different types of ammonium producing fertilizers. Results of most of the previous workers have indicated a measurable effect of anions associated with ammonium ion on fixation of the later by the soil (Stojanovic and Broadbent, 1960; Mukhopadhyay and Das, 1976).

The present investigation was conducted to study the effect of different ammonium yielding fertilizers on ammonium fixation in soils incubated under different moisture levels. Besides the determination of fixed ammonium-N in soil, the present study also included the analysis of the added nitrogen in the exchangeable ammonium and soluble nitrate forms.

The amount of exchangeable ammonium present in the soil treated with different nitrogenous fertilizer over the corresponding amount in the untreated control at four increasing periods of incubation under three different moisture levels are presented in Table 6A, 7A, 8A and 9A for the soils of Kalyani, Bankura, Bagdubi and Canning respectively. The corresponding results for soluble nitrate and fixed NH_4^+ forms, are presented in Table 6B, 7B, 8B, 9B, and 6C, 7C, 8C and 9C for the respective soils.

Analysis of the results reveal that irrespective of the nature of added nitrogenous fertilizers, in general, the amount

TABLE - 6A

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of exchangeable ammonium in Kalyani soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	195	122	132	104
	Urea	62	115	49	42
	Calcium ammonium nitrate	139	115	111	103
	Ammonium dihydrogen phosphate	153	150	160	153

M_2	Ammonium sulphate	202	132	85	60
	Urea	118	77	36	25
	Calcium ammonium nitrate	139	118	84	32
	Ammonium dihydrogen phosphate	167	153	147	94

M_3	Ammonium sulphate	195	125	104	49
	Urea	132	97	55	49
	Calcium ammonium nitrate	139	114	58	42
	Ammonium dihydrogen phosphate	167	153	153	67

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 7A

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of exchangeable ammonium in Bankura soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	209	209	216	209
	Urea	153	184	202	209
	Calcium ammonium nitrate	184	195	202	202
	Ammonium dihydro-gen phosphate	202	202	202	202
M_2	Ammonium phosphate	216	216	202	181
	Urea	202	191	188	167
	Calcium ammonium nitrate	193	202	188	167
	Ammonium dihydro-gen phosphate	209	209	209	209
M_3	Ammonium sulphate	195	202	205	209
	Urea	188	181	170	98
	Calcium ammonium nitrate	181	188	184	174
	Ammonium dihydro-gen phosphate	195	188	191	160

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 8A

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of exchangeable ammonium in Bagdubi soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	202	202	202	202
	Urea	181	191	181	167
	Calcium ammonium nitrate	195	195	188	195
	Ammonium dihydrogen phosphate	202	202	195	202

M_2	Ammonium sulphate	202	195	202	195
	Urea	160	153	160	111
	Calcium ammonium nitrate	174	195	202	188
	Ammonium dihydrogen phosphate	195	195	202	188

M_3	Ammonium sulphate	209	202	202	202
	Urea	174	167	167	104
	Calcium ammonium nitrate	202	195	202	167
	Ammonium dihydrogen phosphate	209	195	195	174

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 9A

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of exchangeable ammonium in Canning soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	195	195	167	178
	Urea	70	83	146	150
	Calcium ammonium nitrate	167	146	153	157
	Ammonium dihydro-gen phosphate	181	181	181	185

M_2	Ammonium sulphate	195	195	181	178
	Urea	167	153	153	108
	Calcium ammonium nitrate	167	174	174	157
	Ammonium dihydro-gen phosphate	195	209	181	192

M_3	Ammonium sulphate	188	188	181	190
	Urea	146	160	90	32
	Calcium ammonium nitrate	188	146	111	46
	Ammonium dihydro-gen phosphate	188	174	160	164

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 6B

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of soluble nitrate in Kalyani soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	7	0	7	20
	Urea	3	0	3	-7
	Calcium ammonium nitrate	188	209	209	195
	Ammonium dihydrogen phosphate	0	0	0	-21

M_2	Ammonium sulphate	7	7	35	70
	Urea	0	0	56	90
	Calcium ammonium nitrate	195	181	154	132
	Ammonium dihydrogen phosphate	7	0	7	63

M_3	Ammonium sulphate	3	3	3	39
	Urea	14	14	14	18
	Calcium ammonium nitrate	167	161	132	129
	Ammonium dihydrogen phosphate	0	7	7	39

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 7B

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of soluble nitrate in Bankura soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	0	0	-7	7
	Urea	0	0	-7	21
	Calcium ammonium nitrate	188	209	195	181
	Ammonium dihydrogen phosphate	0	0	-21	-7

M_2	Ammonium sulphate	-4	-4	0	7
	Urea	-7	0	-7	0
	Calcium ammonium nitrate	209	188	174	114
	Ammonium dihydrogen phosphate	-4	0	-7	-14

M_3	Ammonium sulphate	7	7	3	7
	Urea	7	7	14	14
	Calcium ammonium nitrate	174	170	139	139
	Ammonium dihydrogen phosphate	7	10	7	7

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 8B

Effect of different forms of NH_4 -yielding fertilizers on periodic changes in the amount (ppm) of soluble nitrate in Bagdubi soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	0	4	7	-14
	Urea	0	4	7	0
	Calcium ammonium nitrate	132	164	202	218
	Ammonium dihydrogen phosphate	-7	-4	0	14

M_2	Ammonium sulphate	7	4	4	7
	Urea	0	4	4	21
	Calcium ammonium nitrate	174	157	95	56
	Ammonium dihydrogen phosphate	0	0	4	7

M_3	Ammonium sulphate	10	10	7	0
	Urea	7	7	7	0
	Calcium ammonium nitrate	181	153	146	115
	Ammonium dihydrogen phosphate	0	7	0	-4

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 9E

Effect of different forms of NH_4 -yielding fertilizers on the periodic changes in the amount (ppm) of soluble nitrate in Canning soil during incubation under different moisture levels

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	14	7	4	3
	Urea	7	7	4	7
	Calcium ammonium	174	188	185	188
	Ammonium dihydrogen phosphate	10	3	4	17
M_2	Ammonium sulphate	0	0	0	7
	Urea	0	-4	0	14
	Calcium ammonium nitrate	206	202	202	139
	Ammonium dihydrogen phosphate	0	0	0	-14
M_3	Ammonium sulphate	10	0	0	3
	Urea	14	0	14	56
	Calcium ammonium nitrate	174	48	118	118
	Ammonium dihydrogen phosphate	10	-4	0	0

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged.

TABLE - 6C

Effect of different forms of NH_4 -yielding fertilizers on the periodic changes in the amount (ppm) of fixed ammonium in Kalyani soil during incubation under different moisture levels

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M ₁	Ammonium sulphate	6	36	54	90
	Urea	24	36	54	108
	Calcium ammonium nitrate	24	36	54	126
	Ammonium dihydrogen phosphate	96	108	94	126

M ₂	Ammonium sulphate	2	36	54	18
	Urea	18	108	72	18
	Calcium ammonium nitrate	38	108	144	90
	Ammonium dihydrogen phosphate	72	159	144	90

M ₃	Ammonium sulphate	2	54	105	18
	Urea	2	108	126	36
	Calcium ammonium nitrate	72	108	126	126
	Ammonium dihydrogen phosphate	72	123	194	162

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged.

TABLE - 7C

Effect of different forms of NH_4 -yielding fertilizers on the periodic changes in the amount (ppm) of fixed ammonium in Bankura soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	35	18	54	71
	Urea	89	72	108	71
	Calcium ammonium nitrate	125	108	108	71
	Ammonium dihydrogen phosphate	125	108	108	107

M_2	Ammonium sulphate	18	54	18	72
	Urea	18	54	18	108
	Calcium ammonium nitrate	36	54	18	108
	Ammonium dihydrogen phosphate	108	108	126	198

M_3	Ammonium sulphate	0	36	0	36
	Urea	36	54	70	38
	Calcium ammonium nitrate	54	72	70	108
	Ammonium dihydrogen phosphate	108	108	106	126

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 8C

Effect of different forms of NH_4 -yielding fertilizers on the periodic changes in the amount (ppm) of fixed ammonium in Bagdubi soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M_1	Ammonium sulphate	36	36	54	18
	Urea	36	36	90	35
	Calcium ammonium nitrate	90	54	100	53
	Ammonium dihydrogen phosphate	90	90	144	53

M_2	Ammonium sulphate	36	72	72	90
	Urea	36	72	180	90
	Calcium ammonium nitrate	36	90	180	108
	Ammonium dihydrogen phosphate	36	90	180	144

M_3	Ammonium sulphate	36	18	36	54
	Urea	36	18	36	126
	Calcium ammonium nitrate	36	36	68	126
	Ammonium dihydrogen phosphate	54	54	108	126

M_1 = 50% of the moisture holding capacity

M_2 = Saturated

M_3 = Waterlogged

TABLE - 9C

Effect of different forms of NH_4 -yielding fertilizers on the periodic changes in the amount (ppm) of fixed ammonium in Canning soil during incubation under different moisture levels.

Moisture levels during incubation	Forms of NH_4 yielding fertilizers added	Incubation period in days			
		2	5	10	20
M ₁	Ammonium sulphate	18	54	54	18
	Urea	54	72	54	18
	Calcium ammonium nitrate	72	108	72	54
	Ammonium dihydrogen phosphate	126	144	108	108

M ₂	Ammonium sulphate	0	72	72	18
	Urea	36	108	79	18
	Calcium ammonium nitrate	72	108	90	90
	Ammonium dihydrogen phosphate	72	108	90	90

M ₃	Ammonium sulphate	18	14	54	36
	Urea	18	50	54	72
	Calcium ammonium nitrate	18	50	115	90
	Ammonium dihydrogen phosphate	54	140	115	108

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

of clay fixed ammonium tended to increase with the period of incubation upto 10th day in all the four soils under investigation and upto 20th day in some soils particularly when incubated at lower moisture levels (M_1). It is of further interest to note that immediately after addition of fertilisers (2nd day of incubation), higher amount of added nitrogen was fixed in the soils incubated at M_1 moisture levels (50% of the moisture holding capacity) than those in the corresponding soils maintained at higher moisture levels (Table 9D). This was observed in all the four types of added ammonium fertilizers and in almost all the four soils under investigation. The result thus provide clear evidence in support of the hypothesis that immediately on addition of nitrogenous fertilizers supplying NH_4^+ - N, relatively higher amount of added ammonium nitrogen become fixed in the soils maintained at 50% of the moisture holding capacity than under saturated and waterlogged condition. On the other hand, on 5th, 10th and 20th day of incubation, higher amount of clay fixed ammonium is generally observed in saturated and waterlogged soil (Tables 9E, 9F, 9G). The later result also find support when comparison is made among the recorded highest value of clay fixed NH_4^+ attained over the 20 day period of incubation at the three increasing moisture levels (Table 9H and Fig. 14). It was observed that highest amount of fixation occurred either in the saturated or under waterlogged condition. Mineralisation of organic nitrogen in soil has been found to be more rapid under anaerobic environment than in the corresponding aerobic condition (Patrick and Wyatt, 1964; Borthakur and Mazumdar, 1968).

TABLE - 9D

Immediate increase in the amount (ppm) of clay fixed ammonium during incubation (2nd day) under three moisture levels due to addition of different ammonium yielding fertilizers to soils.

Soils	Incubating moisture levels	Forms of added ammonium yielding fertiliz			
		Ammonium sulphate	Urea	Calcium ammonium nitrate	Ammonium dihydroge phosphate
Kalyani	M ₁	6	24	24	96
	M ₂	2	18	38	72
	M ₃	2	2	72	72
Bankura	M ₁	25	89	125	126
	M ₂	18	18	36	108
	M ₃	0	36	36	108
Bagdubi	M ₁	36	36	90	90
	M ₂	36	36	36	36
	M ₃	36	36	36	54
Canning	M ₁	18	54	72	125
	M ₂	0	36	72	72
	M ₃	18	18	18	54

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE - 9E

Fixation of ammonium on 5th day due to addition of different ammonium yielding fertilizers to soils incubated under three increasing moisture levels.

Soils	Moisture levels	Different forms of NH_4 - fertilizers			
		Ammonium sulphate	Urea	Calcium ammonium sulphate	Ammonium dihydrogen phosphate
Kalyani	M ₁	36	36	36	108
	M ₂	36	108	108	159
	M ₃	54	108	108	123
Bankura	M ₁	18	72	108	108
	M ₂	54	54	54	108
	M ₃	36	54	72	108
Bagdubi	M ₁	36	36	54	90
	M ₂	72	72	90	90
	M ₃	18	18	36	54
Canning	M ₁	54	72	108	144
	M ₂	72	108	108	108
	M ₃	14	50	50	140

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE - 9F

Fixation of ammonium on 10th day due to addition of different ammonium yielding fertilizers to soils incubated under three increasing moisture levels.

Soils	Moisture levels	Different forms of NH_4 - fertilizers			
		Ammonium sulphate	Urea	Calcium ammonium sulphate	Ammonium dihydrogen phosphate
Kalyani	M ₁	54	54	54	94
	M ₂	54	72	144	144
	M ₃	105	126	126	194
Bankura	M ₁	54	108	108	108
	M ₂	18	18	18	126
	M ₃	0	70	70	106
Bagdubi	M ₁	54	90	100	144
	M ₂	72	180	180	180
	M ₃	36	36	68	108
Canning	M ₁	54	54	72	108
	M ₂	72	79	90	90
	M ₃	54	54	115	115

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged

TABLE-9 G

Fixation of ammonium on 20th day due to addition of different ammonium yielding fertilizers to soils incubated under three increasing moisture levels

Soils	Moisture levels	Different forms of NH_4 -fertilizers			
		Ammonium sulphate	Urea	Calcium ammonium nitrate	Ammonium dihydrogen phosphate
Kalyani	M ₁	90	108	126	196
	M ₂	18	18	90	90
	M ₃	18	36	126	162
Bankura	M ₁	71	71	71	107
	M ₂	72	108	108	198
	M ₃	36	38	108	126
Bagdubi	M ₁	18	35	53	53
	M ₂	90	90	108	144
	M ₃	54	126	126	126
Canning	M ₁	18	18	54	108
	M ₂	18	18	90	90
	M ₃	36	72	90	108

M₁ = 50% of the moisture holding capacity

M₂ = Saturated

M₃ = Waterlogged.

TABLE - 9H

Highest amount of clay fixed ammonium (ppm) recorded during 20 day period of incubation under three moisture levels in soils treated with different ammonium yielding fertilizers.

Soils	Moisture levels	Different forms of NH_4 - fertilizers			
		Ammonium sulphate	Urea	Calcium ammonium nitrate	Ammonium dihydrogen phosphate
Kalyani	M_1	90	108	126	126
	M_2	54	108	144	159
	M_3	105	126	126	194
Bankura	M_1	71	108	126	126
	M_2	72	108	108	198
	M_3	36	70	108	126
Bagdubi	M_1	54	90	100	144
	M_2	90	180	180	180
	M_3	54	126	126	126
Canning	M_1	54	72	108	144
	M_2	72	108	108	108
	M_3	54	72	115	140

M_1 = 50% of the moisture holding capacity

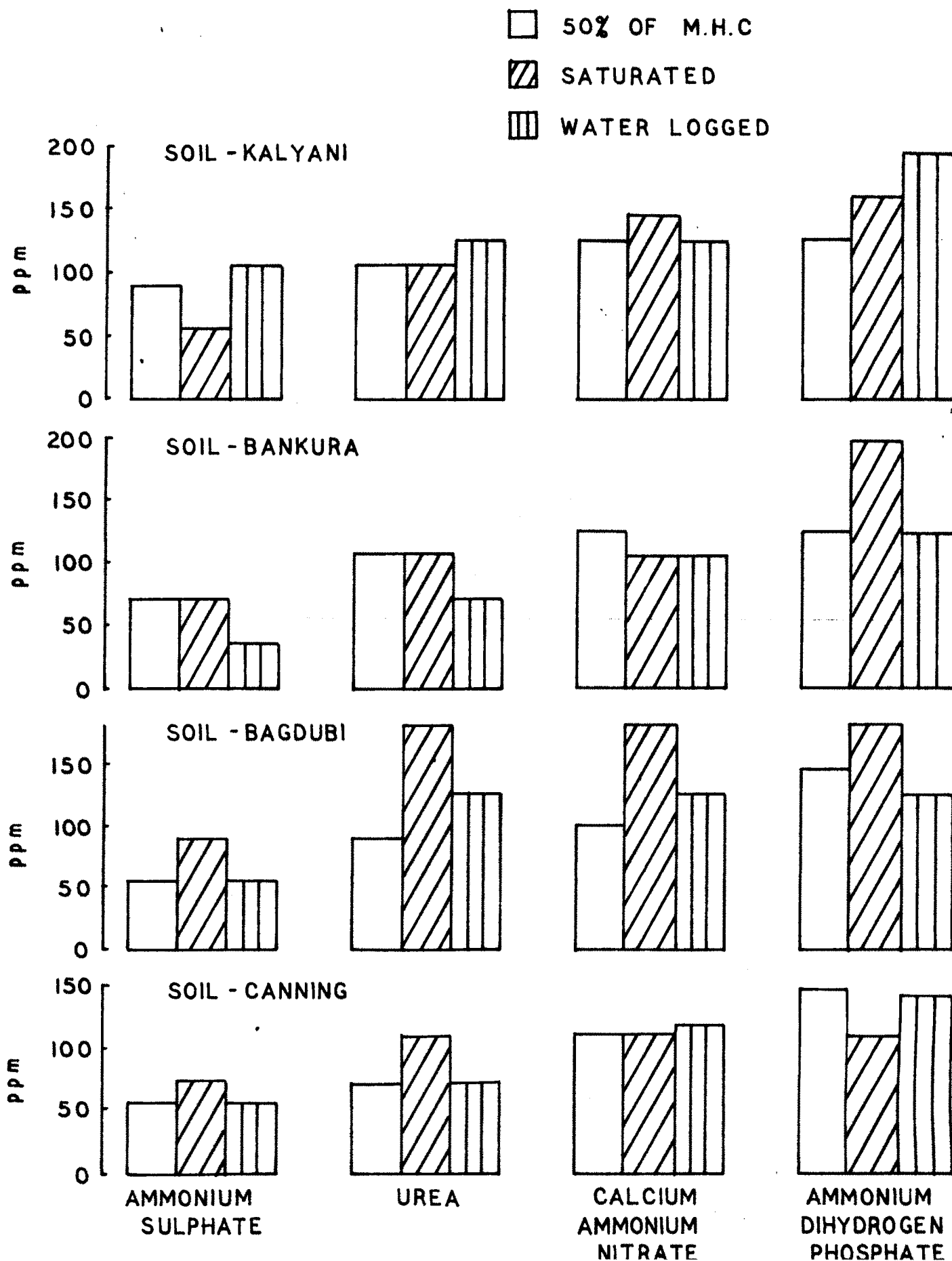
M_2 = Saturated

M_3 = Waterlogged

This is partly due to the lower nitrogen requirement of microbial population under anaerobic and partially aerobic soil condition and to their lower synthetic efficiency (Broadbent, 1979). Since exchange between fixed and non-fixed ammonium is possible (Stojanovic and Broadbent, 1960), it is quite likely that highest fixation would be observed under anaerobic and partially aerobic environment.

Critical analysis of the results presented in Tables 6C, 7C, 8C and 9C reveal that irrespective of the incubating soil moisture levels, clay fixation of the added ammonium from different ammonium containing or yielding nitrogenous fertilizers vary considerably. This observation was found to be consistent in all the four soils under which incubation experiment were carried out. When the same amount (200 ppm) of ammonium nitrogen was added separately in four forms of N-fertilizers, highest amount of ammonium fixation was observed in the ammonium dihydrogen phosphate treated soil and least in the ammonium sulphate added system. In general, the relative order of fixation from different types of ammonium fertilisers was found to be Ammonium dihydrogen phosphate > Calcium ammonium nitrate > Urea > Ammonium sulphate. The above order was also found on the 2nd day after addition of fertilisers (Table 9D) and was found to be equally valid when comparison is made among the recorded highest value of fixation of ammonium from added fertilizers in the soils (Table 9H).

FIG. 14 INFLUENCE OF DIFFERENT NH_4^+ PRODUCING FERTILIZERS ON THE RECORDED HIGHEST AMOUNT OF CLAY FIXED NH_4^+ -N (ppm) IN SOILS DURING INCUBATION AT THREE MOISTURE LEVELS



Although McBeth (1917) and Harada and Kutsuna (1954) have failed to observe any noticeable variation in the amount of clay fixed ammonium in soils following the addition of different forms of ammonium salts and have concluded that the fixation is independent of whether ammonium was added as sulphate or chloride, Legget (1958) reported distinct effect of associated anions on ammonium fixation. He has also observed highest ammonium fixation in diammonium hydrogen phosphate treated soil. He observed ammonium fixation due to addition of different ammonium salts followed the order; Diammonium hydrogen phosphate > Ammonium acetate > Ammonium chloride > Ammonium tartarate > Ammonium sulphate > Ammonium citrate. Although he used quite a wide range of inorganic and organic ammonium salts in his investigation, the results support the observation that ammonium fixation was least in ammonium sulphate added soil and highest in diammonium hydrogen phosphate treated system. Using isotopically labelled ammonium, Stojanovic and Broadbent (1960) have also observed measurable effect of anion associated with ammonium in its fixation. Though he has not actually determined the amount of clay fixed ammonium and restricted only to the recovery of added ammonium by two extraction procedures, use of N^{15} in their study furnished a conclusive evidence in favour of the associated anion's effect on ammonium fixation. Tamini et al. (1963) observed much higher (2.66 m.e/100 g) amount of ammonium fixation in soil from diammonium hydrogen phosphate than that from ammonium chloride (1.33 m.e/100 g) which they attributed to the high capacity of the large amount

of colloidal hydrated oxides of Fe and Al present in the soil to fix phosphate. In a leaching study, Kanehiro et al. (1960) also found higher sorption of NH_4^+ ion when applied as $\text{NH}_4\text{H}_2\text{PO}_4$ or $(\text{NH}_4)_2\text{HPO}_4$ than when applied as $(\text{NH}_4)_2\text{SO}_4$ or NH_4Cl .

The observed variation among different ammonium containing or yielding fertilizers on ammonium fixation in soils appear to be a result of a number of reactions occurring in soils following fertilizer addition. These may include the effect of anion on the adsorption capacity of the associated cation. However, if the highest fixation from diammonium hydrogen phosphate be attributed to the precipitation of colloidal hydrated oxides of Fe and Al by reacting with the added phosphate forming a compound such as ammonium tarnakite, then strictly such fixation cannot be termed as clay fixed ammonium.

EXPERIMENT 6 : Effect of a short period of drying during incubation under different moisture levels on periodic changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in a soil treated with different forms of ammonium producing fertilizers.

The importance of a short period of drying between different but uniformly maintained moisture conditions on the transformation of different inorganic forms of nitrogen in the soil has been emphasized in the earlier section (Experiment 2, Section A). The result of the experiment presented in that section clearly indicated that a short period of drying caused an increase in

the amount of exchangeable ammonium from the native source of nitrogen. This was accompanied by a general decrease in the amount of clay fixed ammonium.

Since the above experiment was conducted with soils which did not receive any source of nitrogenous fertilizers, the informations obtained were restricted to the changes under native soil conditions. In order to know whether the observed effect is also valid in the transformation of the different inorganic forms of added fertiliser nitrogen to the soil under similar conditions, an experiment was conducted with one soil (Bankura) but with 4 different types of added ammonium containing or yielding fertilizers. Besides addition of different forms of ammonium yielding fertilizers, this experiment was conducted at the three incubating moisture levels as was done for the previous experiment.

Results in Table 10 represent changes in the amount of clay fixed ammonium, exchangeable ammonium and soluble nitrate forms of nitrogen from the four different forms of fertilizers added soil over the corresponding unfertilized system due to a short period of drying between moist incubation. A short period of drying caused a decrease in the amount of added ammonium in exchangeable and fixed form in the rehydrated soil while no noticeable change in the nitrate content was observed (Table 10). The trend of the result was same irrespective of the moisture levels and nature of the added nitrogenous fertilizers. In spite of the observed decrease in the amount of clay fixed ammonium upon drying and on

TABLE 10

Effect of a short period of drying during incubation under different moisture levels on increase in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium in Bankura soil due to addition of different forms of nitrogenous fertilizers.

Moisture levels during incubation	Different forms of added nitrogenous fertilizers	Exchangeable ammonium			Soluble nitrate			Fixed ammonium		
		A	B	C	A	B	C	A	B	C
M ₁	Ammonium sulphate	209	188	174	7	7	0	71	35	17
	Urea	209	174	160	21	21	0	71	35	17
	Calcium ammonium nitrate	202	181	160	181	181	160	71	35	17
	Ammonium dihydrogen phosphate	202	174	149	-7	-7	14	107	35	35
M ₂	Ammonium sulphate	181	181	167	7	14	14	72	72	18
	Urea	167	167	132	0	0	7	108	72	18
	Calcium ammonium nitrate	167	167	132	114	181	174	108	83	83
	Ammonium dihydrogen phosphate	209	188	188	-14	-14	0	198	134	90
M ₃	Ammonium sulphate	209	174	167	7	46	-3	36	36	0
	Urea	98	83	176	14	14	-3	38	36	0
	Calcium ammonium nitrate	174	160	167	139	164	134	108	36	18
	Ammonium dihydrogen phosphate	160	174	167	7	11	7	126	90	72

A = Prior to drying (20th day of incubation); B = Upon drying; C = 5th day after remoistening; M₁ = 50% of the moisture holding capacity; M₂ = Saturated; M₃ = Waterlogged.

rehydration, highest amount of clay fixed ammonium, in general, was observed in the ammonium dihydrogen phosphate treated soil. Even on rehydration after a short period of drying, the amount of clay fixed ammonium in the ammonium dihydrogen phosphate treated soil over the corresponding unfertilized soil was higher than the amount in the soil treated with other forms of ammonium yielding fertilizers. The result thus suggest that neither drying nor post drying rehydration could influence the intrinsic variation due to differences in the type of added ammonium fertilizers.

Closer examination of the data (Table 10) on the amount of clay fixed ammonium in the rehydrated soil also corroborate our previous findings (Table 6C, 7C, 8C and 9C). On 5th day of incubation after rehydration at three moisture regimes, highest value of fixed ammonium (90 ppm) was observed under saturated condition and least (35 ppm) under 50 per cent of the moisture holding capacity.

Explanation furnished there in (Experiment 2) for the progressive decrease in the amount of clay fixed ammonium due to drying and subsequent remoistening seems to be equally applicable in the present situation. Upon drying, a general decrease in the amount of exchangeable ammonium was observed in the fertilized soil, while an increase in this form of nitrogen was noticed in unfertilized native soil under similar situation. Obviously, the increase, in the amount of exchangeable ammonium in the soil due to drying was more a function of the concentration of the

exchangeable ammonium present. In the native soil, the concentration was much lower than the corresponding nitrogenous fertilizer added soil.

EXPERIMENT 7 : Effect of liming soil of acidic reaction on changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen under independent and simultaneous presence of added $\text{NH}_4\text{-N}$, K and organic matters of varying nitrogen content.

Review of previous research investigations on ammonium fixation in soil do not show any ambiguity with respect to the following : (i) K^+ and NH_4^+ are similarly fixable cations and presence of one competes with another for occupying the same fixing sites, (ii) Under N-stress situation, addition of easily oxidisable organic material of wide C/N ratio to the soil, cause considerable release of fixed ammonium due to increased microbial activity in the soil (Nommik, 1957), (iii) Rate of remineralisation of organically bound nitrogen is considerably higher if sufficient amount of nitrogen is available to the microbes during decomposition (Broadbent and Mikkelsen, 1968, Koyama and Niamsrichand, 1973; Onikura et al., 1975).

But considerable differences in opinions exist regarding the effect of liming on fixation of ammonium. Ammonium produced through mineralisation of soil organic nitrogen is a microbiological process and the so produced NH_4^+ can also serve, as the source of clay fixed NH_4^+ is appreciably controlled by the microbiological activity of the soil. Higher microbial activity

in limed over the corresponding unlimed soil of acidic reaction is, therefore, expected to cause variation in the amount of ammonium fixation as well as release of the recently fixed ammonium in the soils.

The present investigation was, therefore, carried out to study the effect of liming soil of acidic reaction on ammonium fixation in presence and absence of added K, added NH_4^+ form of nitrogen and easily decomposable N free added organic matter as well as organic matter with wide C/N ratio.

Results on the effect of added organic matters on changes in the amount of fixed NH_4^+ , exchangeable NH_4^+ and soluble NO_3^- forms of nitrogen in an acid soil collected from Bagdubi (pH 5.40) and in the corresponding limed soil are presented in Table 11A and graphically presented in Fig. 15. On both the 5th and 15th day of incubation, virtually no difference in the amount of exchangeable ammonium could be detected due to liming in either the starch or rice straw added soil. However, in the soil in which no source of carbonaceous matter was added, much less amount of exchangeable ammonium was observed in the limed (40 and 34 ppm on 5th and 15th day respectively) than in the corresponding unlimed soil (88 and 61 ppm). Whereas, in presence of added organic matter, the amount of exchangeable ammonium in the limed and unlimed soil was less than the soil not treated with organic matter. Addition of easily decomposable organic matter in the soil possibly caused an increased immobilisation of readily available exchangeable ammonium, resulting its lower

TABLE - 11A

Effect of two sources of added organic matter on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and clay fixed ammonium during incubation of limed and unlimed Bagdubi soil.

Organic matter added to soil	Addition of lime	Amount of the forms of nitrogen in soil on					
		5th day			15th day		
		Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3	Fixed NH_4
No organic matter	Unlimed	88	14	523	61	7	506
	Limed	40	14	573	34	14	540
Starch	Unlimed	27	14	506	34	7	489
	Limed	27	7	523	34	7	455
Rice Straw	Unlimed	40	14	523	40	7	506
	Limed	34	7	573	34	7	540

concentration in the exchange phase. When no source of organic matter was added, presence of lower concentration of exchangeable NH_4^+ in the limed than unlimed soil could also be attributed to the greater biological utilization of available nitrogen by the increased microbial population under limed condition.

Much higher amount of clay fixed ammonium was observed on 5th day period of incubation in the limed than in the unlimed soil. The above observation was also found to be true even on 15th day of incubation except in the starch added system where, lesser amount of fixed ammonium was noted in the limed than in the corresponding unlimed soil. Least amount of clay fixed ammonium was noted in the starch added soil. This was observed irrespective of the stages of incubation and lime treatment.

During the three month period allowed for the added lime to react, the rate of mineralisation of the native organically bound nitrogen was likely to be higher in the limed than unlimed soil. A part of the increased amount of mineralised ammonium might have been fixed by the soil. It is of further interest to note that irrespective of the addition of rice straw as organic matter to the soil, the increase of fixed NH_4^+ in limed soil over the corresponding unlimed system amounted to 50 ppm on 5th and 34 ppm on 15th day of incubation. Lesser amount of fixation in the unlimed acidic soil may be due to (i) the presence of H^+ ion with relatively higher replacing power to influence the state of equilibrium between exchangeable NH_4^+ and fixed NH_4^+ ; (ii) A higher concentration of hydrogen ion (low pH) would lead

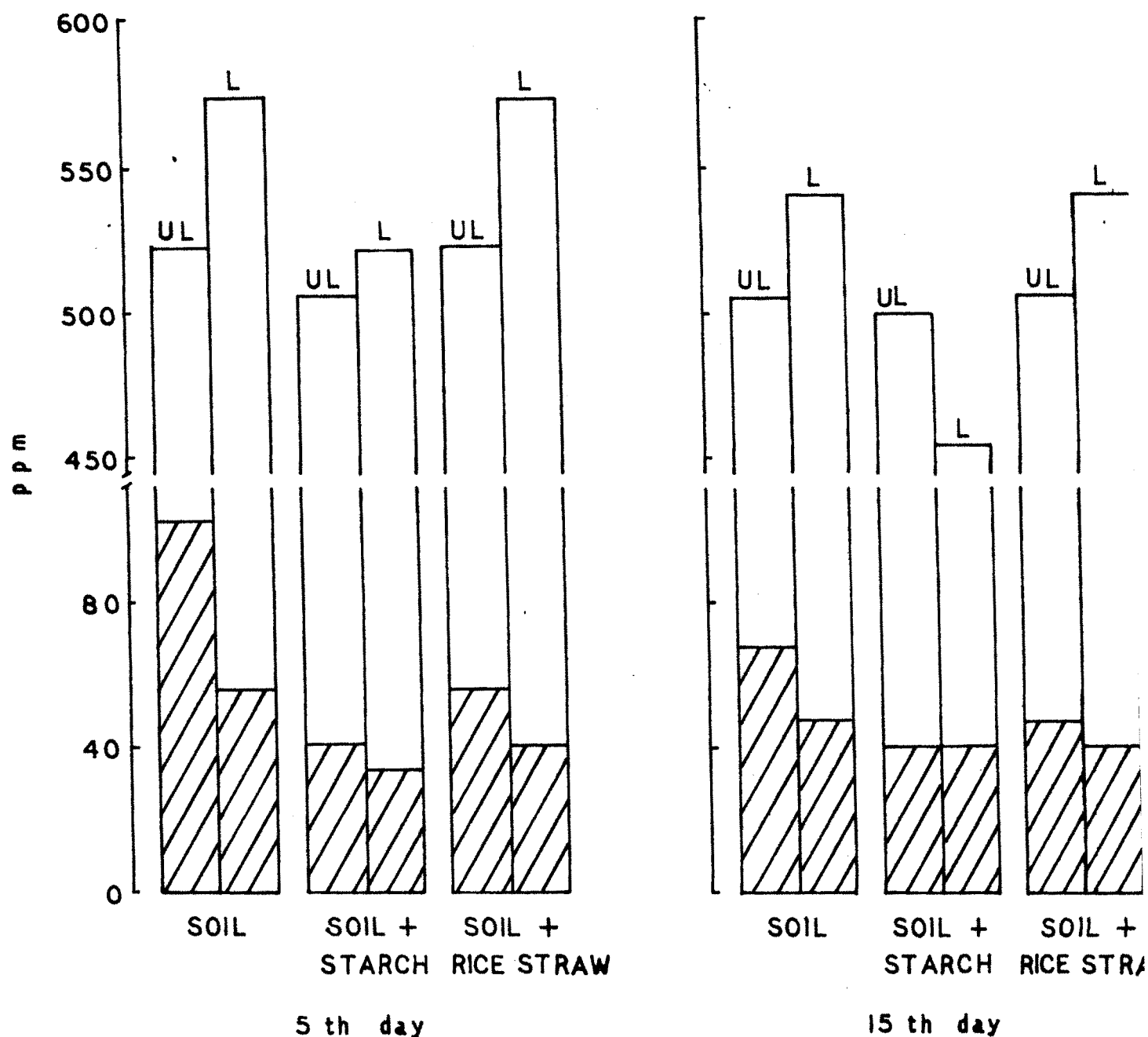
FIG. 15 EFFECT OF LIMING ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N DUE TO ADDED ORGANIC MATTERS DURING INCUBATION IN BAGDUBI SOIL

UL - UNLIMED

L - LIMED

□ FIXED NH_4^+ -N

▨ AVAILABLE -N=(EXCHANGEABLE NH_4^+ + SOLUBLE NO_3^-)



to the occupation of larger number of interlattice fixing sites by H^+ (H_3O^+) resulting the clay crystal in somewhat expanded state (Barshad, 1954b) so that subsequently added ammonium could neither effectively replace the strongly bound H^+ (H_3O^+) ion in the crystal lattice nor contract the crystal lattice. Moreover, in such an expanded state, the absorbed NH_4^+ is more accessible to a strongly replacing cation; (iii) The third possible factor may be that under highly acidic environment, interlattice space of 2:1 clay minerals may partially be filled by $Fe(OH)_3$ or, $Al(OH)_3$. All this factors might have caused the reduction in the amount of ammonium fixation under acidic soil system.

In the starch added system, much lower amount (34 ppm) of fixed NH_4^+ was, however, observed on 15th day of incubation in the limed than in unlimed soil. Moreover, irrespective of liming, the magnitude of fixed ammonium in the starch added soil was much less than either the rice straw treated soil or no organic matter added situation. Although during the three month reaction period following the addition of lime caused considerable mineralisation of the native organic nitrogen, much of this mineralised fraction had possibly been microbiologically immobilised during the subsequent decomposition of the added N-free starch under favourable environment in the limed soil. Relatively higher amount of stress for available nitrogen was created under limed soil with higher density of microbial population than under unlimed situation. This might have prompted the heterotrophic microbes to utilize

a considerable amount of fixed ammonium from the soil resulting a decrease in its amount under limed condition.

Comparison of the data of fixed NH_4^+ on 5th and 15th day of incubation under limed and unlimed soil reveal that irrespective of the added organic matter, higher amount of decrease was noted on 15th day in the limed over the unlimed soil and the order of decrease was highest in starch added limed soil (68 ppm).

Much higher amount of added ammonium was found in the exchangeable form in unlimed than in the limed soil (Table 11B and Fig. 16). Of the 400 ppm of ammonium nitrogen added to the soil, 371 ppm was found in exchangeable form on 5th day in the unlimed soil not treated with any organic matter. The corresponding values for rice straw and starch treated soil are 344 and 249 ppm. While much lower (304, 194 and 122 ppm respectively) amount of added NH_4^+ - N in the exchangeable ammonium form over the no nitrogen added control was observed in the limed soil. This is a likely effect of increased microbial utilization of added ammonium in limed soil due to an increased microbial activity. Least amount of increase in exchangeable ammonium (122 ppm) from the added nitrogen was noted in the starch added limed soil. This provides an additional support to the said explanation. The differences between limed and unlimed soil widened with increase in the period of incubation upto 15th day.

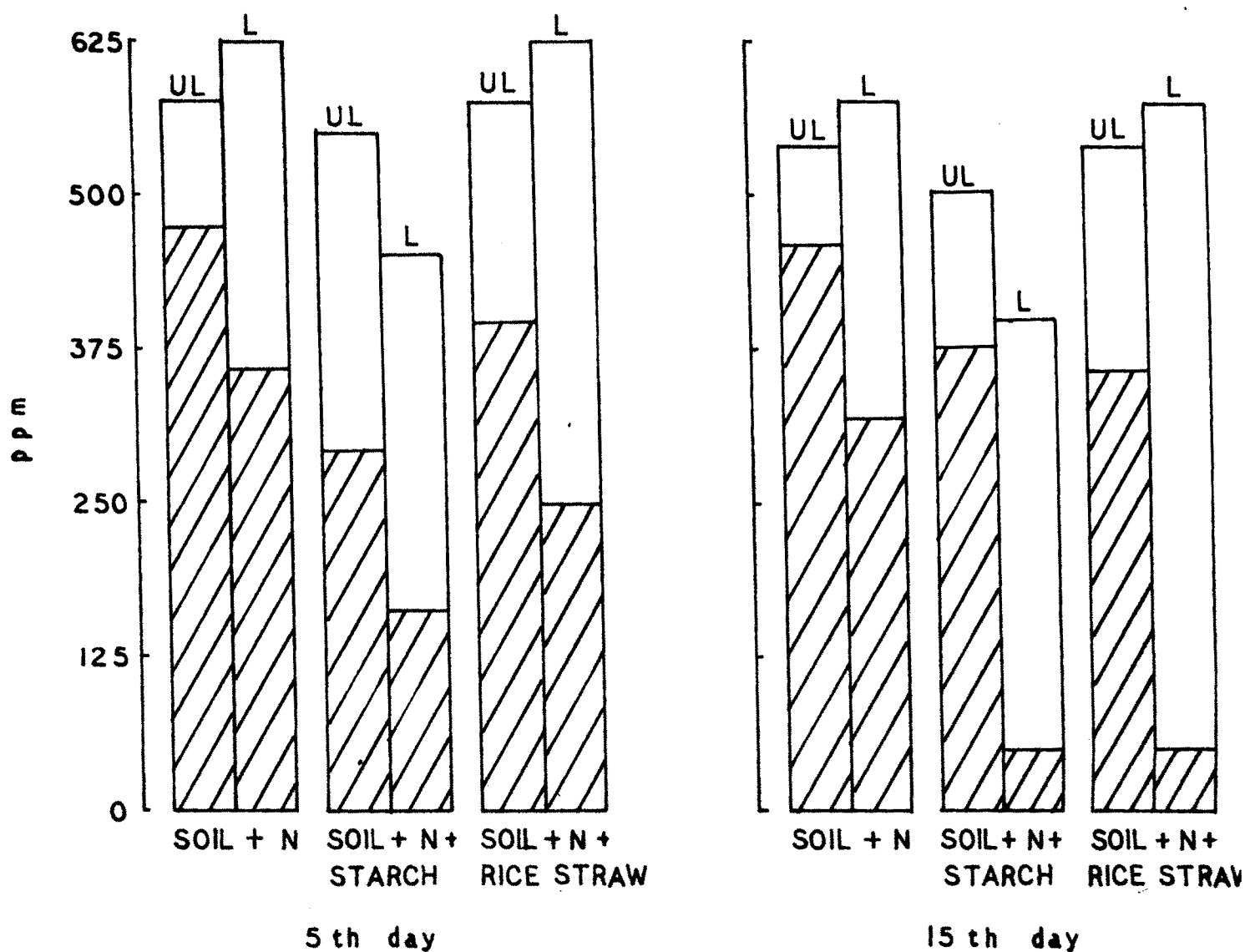
TABLE - 11B

Effect of two sources of added organic matter on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and clay fixed ammonium during incubation of limed and unlimed Bagdubi soil due to 400 ppm N addition as $(\text{NH}_4)_2\text{SO}_4$.

Organic matter added to soil	Addition of lime	Amount of the forms of nitrogen in soil on					
		5th day			15th day		
		Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3	Fixed NH_4
No organic matter	Unlimed	371	0	50	384	7	34
	Limed	304	0	51	216	53	33
Starch	Unlimed	249	0	50	330	7	17
	Limed	122	6	-73	0	7	-51
Rice straw	Unlimed	244	0	50	303	7	34
	Limed	194	13	51	0	7	33

FIG. 16 EFFECT OF LIMING ON CHANGES IN THE AMOUNT (ppm) OF AVAILABLE AND FIXED NH_4^+ -N DUE TO ADDED ORGANIC MATTERS AND INORGANIC N DURING INCUBATION OF BAGDUBI SOIL

UL - UNLIMED
 L - LIMED
 □ FIXED NH_4^+ -N
 ▨ AVAILABLE -N = (EXCHANGEABLE NH_4^+ + SOLUBLE NO_3^-)



Possibility of higher amount of volatilization loss from the added ammonium under limed than unlimed condition cannot, however, be totally excluded. This might also partly be responsible for the presence of decreased amount of exchangeable ammonium in the limed soil. But the actual loss has not been determined in the present experiment.

Irrespective of added organic matter and liming, the data (Table 11B) indicate that the increase in the amount of fixed ammonium due to ammonium fertilization was almost same (50 ppm) on the 5th day of incubation. The observation made on 5th day of incubation was also found to be valid on 15th day except in the starch added soil. Although considerable effect of liming soils of acidic reaction was noted on the fixation of the recently mineralised ammonium (Table 11A); no variation due to liming could be detected in the amount of added ammonium fixed following the addition of ammonium fertilizer to a limed soil.

Most of the previous studies by other workers have assessed the significance of the degree of N-saturation of soil and clay minerals on their capacity to fix NH_4 and K (Hauser, 1941; Martin et al., 1946; Attoe, 1947; Wiklander, 1950; Harada and Kutsuna, 1954; Nommik, 1957; Ghildyal and Singh, 1961; Raju and Mukhopadhyay, 1976). They have in general pointed out a direct positive correlation between pH and ammonium fixing capacity of soil. Wiklander and Andersson (1959) have observed increased NH_4^+ fixing ability of the limed soil after analysing soils 22 years

after application of lime. This was also observed in the results of present and previous experiment (Tables 11B and 11A).

Although no effect of liming was observed on the amount of added ammonium fixed by the soil, the amount of fixed ammonium present in the limed soil, in general, exceeded that in the unlimed condition. Similarly, the decrease in the amount of fixed ammonium on 15th day over that on the 5th day period was also found to be higher in the limed than the corresponding unlimed soil and least amount of fixed ammonium was noted in both the limed and unlimed starch added soil. The explanations furnished in the earlier section are equally applicable in the present case.

Effect of potassium on fixation of
added ammonium in presence and
absence of organic matters

In order to assess the effect of subsequently added K^+ on the release of recently fixed ammonium and fixation of added ammonium by the limed and unlimed soils, an experiment was conducted with and without K addition (200 ppm) to the same treatments as in Table 11A and 11B. The results are presented in Table 11C.

Comparative analysis of the data of clay fixed NH_4^+ for both 5 and 15 day incubation period after K application (Table 11C) with those in the corresponding treatments with no K addition

TABLE - 11C

Effect of added potassium on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium during incubation in limed and unlimed Bagdubi soil treated with and without organic matters.

Treatment materials added to soil	Addition of lime	Amount of the forms of nitrogen in soil on					
		5th day			15th day		
		Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3	Fixed NH_4
Control	Unlimed	88	14	523	61	7	506
	Limed	40	14	573	34	14	540
K	Unlimed	61	14	506	67	7	506
	Limed	34	14	573	27	14	557
Starch + K	Unlimed	27	14	506	54	7	489
	Limed	27	7	523	40	14	455
Rice straw + K	Unlimed	27	14	523	47	14	506
	Limed	27	14	573	40	7	540

(Table 11A) failed to indicate any effect of added K on the amount of fixed NH_4^+ present in either the limed or unlimed soil. No source of NH_4 was added simultaneously with or after K addition to the soil, the observed increase in the amount of fixed NH_4^+ in the limed over the unlimed soil was considered to be the result of increased mineralisation of organic nitrogen. Since potassium was added to the limed soil i.e. after the changes in the amount of fixed ammonium have occurred due to increased mineralisation of nitrogen in the limed soil, it is quite logical not to observe any inhibitory influence of similarly fixable K^+ ion on NH_4^+ fixation in the soil. Moreover, irrespective of K addition, the magnitude of decrease in the amount of fixed NH_4^+ on 15th day from that on 5th day period remained the same. This also suggest that addition of K did not have any influence either on the availability of fixed NH_4^+ to heterotrophic micro-organisms or other forms of release.

In order to assess the effect of added K (200 ppm) on the fixation of simultaneously added $\text{NH}_4\text{-N}$ (400 ppm) in the same soil, under both the limed and unlimed condition, a similar experiment was also conducted where the amount of fixed ammonium was determined in presence and absence of added NH_4 to soils simultaneously fertilized with and without potassium. Result of the experiment are presented in Table 11D. In absence of added ammonium virtually no effect of added potassium was observed in either the limed or unlimed soil. However, in presence of the simultaneously

TABLE - 11D

Effect of added potassium on changes in the amount (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium during incubation in limed and unlimed Bagdubi soil treated with and without $(\text{NH}_4)_2\text{SO}_4$.

Treatment materials added to soil	Addition of lime	Amount of the forms of nitrogen in soil on					
		5th day			15th day		
		Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3	Fixed NH_4
Control	Unlimed	88	14	523	61	7	506
	Limed	40	14	573	34	14	540
K	Unlimed	61	14	506	67	7	506
	Limed	34	14	573	27	14	557
Starch+K	Unlimed	459	14	573	465	14	540
	Limed	344	40	624	250	67	573
Rice straw+K	Unlimed	492	14	540	479	67	506
	Limed	371	27	573	243	14	523

added ammonium, addition of K resulted in a much lower amount of ammonium fixation in both the limed and unlimed soil. A similar observation has also been made by various other workers (Jansson, 1958; Raju and Mukhopadhyay, 1973, 1976). But the interesting observation of the present investigation is that the decrease in the amount of the added ammonium fixed due to simultaneous K fertilization was more in limed than in unlimed soil.

Results on the effect of simultaneous addition of potassium with ammonium in the limed and unlimed soil treated with either starch or rice straw are presented in Table 11E. The differential effect of added K on fixation of added NH_4 in limed and unlimed soil observed in absence of added organic matter (Table 11D) could not be observed in the organic matter added soil. On the contrary, the reduction in the amount of ammonium fixation due to the presence of potassium was found to be more in unlimed than in the corresponding limed soil. And the said effect was prominent in the easily decomposable starch added system than in the corresponding rice straw added soil. Obviously, the presence of the added organic matter played some role. Further studies in detail would, however, be necessary to explain the phenomena.

TABLE - 11E

Effect of simultaneous addition of K and NH_4 on changes in the amount of (ppm) of exchangeable ammonium, soluble nitrate and fixed ammonium during incubation in limed and unlimed Bagdubi soil treated with starch or rice straw.

Treatment materials added to soil	Addition of lime	Amounts of the forms of nitrogen in soil on					
		5th day			15th day		
		Exch. NH_4	Soluble NO_3	Fixed NH_4	Exch. NH_4	Soluble NO_3	Fixed NH_4
Starch + NH_4	Unlimed	337	14	573	391	14	523
	Limed	162	20	500	34	7	439
Starch + NH_4 + K	Unlimed	344	14	506	351	7	455
	Limed	175	20	506	34	14	455
Rice straw + NH_4	Unlimed	432	14	573	364	14	540
	Limed	226	27	624	34	7	573
Rice straw + NH_4 + K	Unlimed	452	14	540	412	7	523
	Limed	250	14	607	40	7	557

EXPERIMENT 8 : Effect of liming soils of acidic reaction on changes in the amount of different forms of organic nitrogen and exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in soils.

While explaining the increase in the amount of fixed ammonium during incubation with increase in the levels of soil moisture in experiments presented in earlier section (Table 2C), it was pointed out that a considerable amount of ammonium produced through mineralisation of native soil organic nitrogen was converted to clay fixed form. A similar explanation has also been furnished to explain the increase in the amount of fixed ammonium in limed over that in unlimed soil (Table 11A). In order to provide further experimental evidences in support of the above explanation, it was considered necessary to follow changes in both the mineral and organic forms of nitrogen in the limed and unlimed soil.

Results of analysis for changes in pH, exchange acidity, fixed ammonium, 2M KCl extractable ammonium and nitrate due to liming in three soils of acidic reaction are presented in Table 12A. The corresponding changes in the amount of different forms of organic nitrogen are presented in Table 12B.

Results (12A) show an increase in pH due to liming. This was associated with a marked increase in the amount of fixed ammonium, exchangeable NH_4 and soluble NO_3 in the limed over the corresponding unlimed soils. Examination of the data (Table 12B) show that although liming soils of acidic reaction led to a

TABLE - 12A

Changes in pH, exchange acidity and different forms of inorganic nitrogen occurred in soils due to liming.

Soils	Addition of lime	pH	Exchange acidity (me/ 100g)	Fixed ammo- nium (ppm)	Exchange- able ammonium (ppm)	Soluble nitrate (ppm)
Bankura	Unlimed	5.50	4.76	541	28	7
	Limed	7.40	1.87	593	63	35
Bagdubi	Unlimed	5.40	3.27	530	35	14
	Limed	7.50	0.84	547	42	28
Arabari	Unlimed	5.30	4.86	702	28	14
	Limed	7.40	1.31	737	49	14

TABLE - 12B

Effect of liming soils of acidic reaction on changes in the amount (ppm) of different fractions of hydrolysable organic nitrogen.

Forms of hydrolysable organic nitrogen	Soils					
	Bankura		Bagdubi		Arabari	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
Total organic nitrogen	877	759	674	641	810	742
Ammonium nitrogen	219	202	185	185	169	202
Hexosamine nitrogen (Amino-Sugar -N)	34	51	0	34	84	51
Serine & threonine nitrogen (Hydroxy amino acid-N)	84	76	51	57	67	67
Amino acid nitrogen	371	324	168	148	283	202
Unidentified form	253	182	321	274	264	287

marked decrease in the amount of total hydrolysable organic nitrogen due possibly to its mineralisation, it generally had little effect on the distribution of its constituent forms except the amino acid fraction. The distribution of different forms of organic nitrogen for the individual soil shows that the only detectable consistent trend due to liming was the decrease in the amount of amino acid-N in all the soils under investigation. The result thus indicates that it is the amino acid-N forms of organic nitrogen which is most susceptible to mineralisation. A similar conclusion was also drawn by Keeney and Bremner (1966). The decrease in the amount of total hydrolysable organic nitrogen due to liming over the unlimed soil was, however, closely compensated by the sum of the corresponding increase in the mineral forms of nitrogen representing fixed ammonium, exchangeable ammonium and soluble nitrate. The decrease in the amount of total hydrolysable organic nitrogen in the limed over the corresponding unlimed soil amounted to 118, 33 and 78 ppm in Bankura, Bagdubi and Arabari soils respectively. The corresponding increase in the sum of fixed NH_4^+ , exchangeable NH_4^+ and soluble NO_3^- forms of nitrogen in the soils amounted to $115 = (52 + 35 + 28)$, $33 = (17+7+14)$ and $56 = (35+21+0)$ ppm. The observed parallelity of the decrease of the amount of organic forms of nitrogen with increase in the amount of mineral forms of nitrogen including fixed NH_4^+ , thus possibly provides an experimental evidence in support of the hypothesis that a considerable portion of the mineralised ammonium was converted to the clay fixed form.

AVAILABILITY OF FIXED NH_4^+ TO CROPSEXPERIMENT 9 : Availability of native fixed NH_4^+ to crops

Changes in the amount of exchangeable NH_4^+ , soluble nitrate and fixed NH_4^+ forms of nitrogen in the native unfertilized soil during growth of maize plants at two densities are respectively presented in Table 15A, 15B and 15C. The mean data of the ten replicates show that the level of the available forms of mineral nitrogen (exchangeable NH_4^+ and soluble NO_3^-) and the fixed form of NH_4^+ - nitrogen in soil during the growth of first crop of maize were significantly higher in the low density treatment than in the soils of the corresponding plots with high density cropping. This observation was noted at all the three stages of sampling. Irrespective of cropping densities, the amount of exchangeable ammonium and soluble nitrate tended to decrease upto 70th day following which an increasing trend was noted but even on 95th day the mean values were less than the amount observed on 30th day. On the other hand, the corresponding values of fixed ammonium in the soil increased steadily with increase in the period of crop growth. Relatively lesser amount of all the three forms of mineral nitrogen (Tables 15A, 15B, 15C and Fig. 17) under high density cropping was possibly the result of higher degree of exhaustion of soil nitrogen to meet the increased demand of larger number of plants per unit area.

TABLE - 15A

Periodical changes in the amount (ppm) of exchangeable ammonium in an unfertilized soil growing maize at two densities

Replica- tions	Days after sowing of seeds					
	30		70		95	
	Density of planting		Density of planting		Density of planting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	39	32	22	22	33	32
R ₂	38	34	22	19	31	32
R ₃	32	32	25	19	33	29
R ₄	36	35	23	23	32	21
R ₅	38	38	24	20	29	20
R ₆	39	41	31	26	23	21
R ₇	35	32	34	26	27	24
R ₈	39	34	30	21	24	24
R ₉	35	35	21	19	24	23
R ₁₀	35	35	22	23	24	19
Mean	36.5	34.8	25.4	21.8	28.0	24.5

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 15B

Periodical changes in the amount (ppm) of soluble nitrate in an unfertilized soil growing maize at two densities.

Replica- tions	Days after sowing of seeds					
	30		70		95	
	Density of planting	Density of planting	Density of planting	Density of planting	Density of planting	Density of planting
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	18	17	12	10	20	16
R ₂	17	17	16	9	13	14
R ₃	17	14	15	12	13	13
R ₄	18	17	13	13	13	11
R ₅	18	17	11	11	21	16
R ₆	20	14	16	13	16	16
R ₇	18	18	13	13	20	17
R ₈	20	14	16	13	13	10
R ₉	18	14	16	13	17	16
R ₁₀	20	17	13	13	16	13
Mean	18.4	15.9	14.1	12.0	16.2	14.2

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 15C

Periodical changes in the amount (ppm) of fixed ammonium in an unfertilized soil growing maize at two densities.

Replica- tions	Days after sowing of seeds					
	30		70		95	
	Density of planting		Density of planting		Density of planting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	470	465	499	496	504	497
R ₂	468	463	492	485	498	497
R ₃	467	464	495	489	496	495
R ₄	468	461	500	497	506	505
R ₅	470	462	492	492	501	498
R ₆	464	464	496	484	502	498
R ₇	473	463	498	483	500	499
R ₈	469	462	491	490	504	502
R ₉	471	467	501	496	503	501
R ₁₀	465	462	497	481	501	500
Mean	468.5	463.3	496.1	489.3	501.5	499.2

D₁ = 28 plants per plot

D₂ = 68 plants per plot

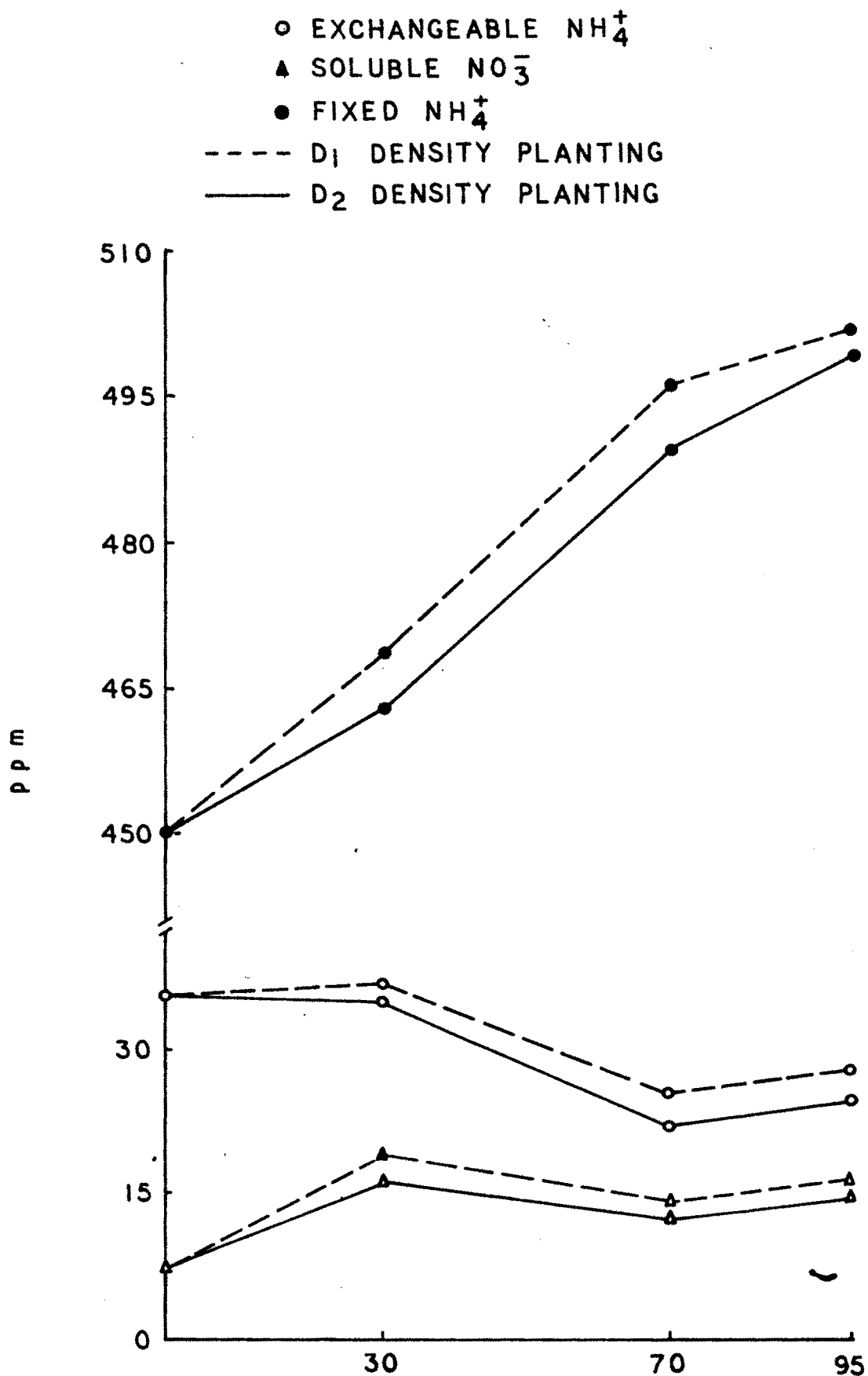
Increase in the amount of fixed ammonium with increasing period of cropping suggest that a considerable portion of the recently mineralised ammonium occupied the fixing sites in the soil as no source of nitrogen was added. Since the relative demand of crops for available nitrogen per unit area was more in D_2 than in D_1 density plots, lesser amount of recently mineralised ammonium could find entry and become fixed in the high density cropped plots. This could possibly explain the result that in spite of increase in the amount of fixed ammonium in the soil with increasing period of crop growth, lesser amount of fixed ammonium was noted in D_2 than in D_1 plots.

Native fixed ammonium is generally considered of very low solubility and biologically only slowly available (Walsh and Murdock, 1963; Martin et al., 1970; Black and Waring, 1972; Osborne, 1976; Kowalenko and Cameron, 1976; Mohammed, 1979). The results on changes in the amount of fixed ammonium in an unfertilized cropped field (native) under two densities of planting are quite in agreement with the previous views. In the present situation, the amount of fixed ammonium tended to increase with the growing period.

In order to assess the rhizosphere effect of both the low and high density cropped plots, total microbial count was determined in both the rhizosphere and remote soils of the D_1 and D_2 plots on 45th and 75th day stage of crop growth. The results are presented in Table 15D and 15E respectively. Analysis of the result clearly indicate that the mean counts of microbial

FIG. 17

CHANGES IN THE AMOUNT (ppm) OF EXCHANGEABLE NH_4^+ , SOLUBLE NO_3^- AND FIXED NH_4^+ FORMS OF NITROGEN DURING PLANT GROWTH AT TWO DENSITY TREATMENTS



population of remote soils were much less than those of rhizosphere samples. This observation was found to be consistent on both 45th and 75th day samples and in both the low and high density cropped plots. It is also evident from the data that the bacterial population of rhizosphere soil of high density D_2 plots were much higher than the corresponding values of D_1 plots. While the mean bacterial counts in D_1 rhizosphere samples was 63.5×10^5 counts/g of soil on 45th day stage of crop growth, it was almost 3 times (179.25×10^5 counts/g of soil) in the corresponding D_2 rhizosphere soil. Similarly, on 75th day stage of crop growth the value of D_2 plot was 274.25×10^5 counts/g of soil, whereas, the corresponding value for D_1 plot was of smaller order (160×10^5 counts/g of soil). The above observations were also found to be statistically significant. Increase in the total microbial counts of rhizosphere over the remote soil is an well known phenomenon. Such an increase may be attributed to the effect of the presence of higher amount of root exudates due to increased root activity in the rhizosphere than in remote soils (Vuurde and Delange, 1978). For the same reason, the microbial population was much higher in high density (D_2) than in the low density (D_1) plots. Because of the presence of higher microbial population in high density cropped plots, it is expected that the rate of microbial decomposition of the available soil organic matter would also be higher in D_2 than in D_1 plots. Therefore, not only the rate of nitrogen mineralisation but also the microbial utilization of nitrogen released through mineralisation would also be higher in D_2 over D_1

TABLE - 15D

Effect of rhizosphere on bacterial population ($\times 10^5$ per g) in soil on 45th day stage of crop growth planted at two densities.

Treatments	Replications				Mean
	R ₁	R ₂	R ₃	R ₄	
Rhizosphere (D ₁)	59	60	88	55	63.50
Remote (D ₁)	28	26	38	40	33.00
Rhizosphere (D ₂)	127	160	180	250	179.25
Remote (D ₂)	30	39	45	50	41.00

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 15E

Effect of rhizosphere on bacterial population ($\times 10^5$ per g)
in soil on 75th day stage of crop growth planted at two
densities.

Treatments	Replications				Mean
	R ₁	R ₂	R ₃	R ₄	
Rhizosphere (D ₁)	170	155	150	165	160.00
Remote (D ₁)	127	135	132	122	129.00
Rhizosphere (D ₂)	190	253	300	250	174.25
Remote (D ₂)	126	167	120	130	135.75

D₁ = 28 plants per plot

D₂ = 68 plants per plot

plots. In spite of these, the amount of mineral forms of nitrogen were found to be less in high plant density plots than in the corresponding low density plots. This could possibly be attributed to the fact that the demand for nitrogen by the larger population of crops and microorganisms per unit area in D_2 plots exceeded its supply through the process of N-mineralisation.

Effect of the density of planting on nitrogen uptake was also determined. The results are presented in Table 15F, 15G and 15H respectively for 30th, 70th and 95th day of crop growth. The results are quite in agreement with the previous observations. Percentage of nitrogen in the plants (mean of ten plots) in low density D_1 plots were higher than those of D_2 plots. Although the nitrogen percentage decreased with the age of plants, higher percentage of nitrogen in crops of low density plots was observed over the corresponding high density plots. This was also found to be consistent at all the three stages of crop growth. Since the number of plants for D_1 plot was 28 as against 68 in D_2 plots, it is quite likely that in spite of the higher rate of N-mineralisation in D_2 , the demand for nitrogen of 68 plants per plot could not possibly be supplied by the soil at the same rate as in the case of 28 plants per plot. For the same reason the dry matter yield per plant of D_2 plots were less than the corresponding D_1 plots. Obviously therefore, the total uptake of nitrogen per plot (i.e. product of percentage of nitrogen and dry matter yield of plants per plot) was found to be much higher in D_2 than in D_1 plots. The results thus indicate that the exhaustion of nitrogen

TABLE - 15F

Effect of density of plant population on nitrogen percentage and dry matter yield of plant and total nitrogen uptake by maize crop on 30th day growth stage.

Replica- tions	Percentage of nitrogen in plant		Dry matter yield per plant in gm		Nitrogen uptake in kg/ha	
	Density of planting		Density of planting		Density of planting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	2.66	2.38	10.04	8.77	14.95	23.33
R ₂	2.83	2.16	9.41	7.30	14.91	21.44
R ₃	2.75	2.25	8.65	7.92	13.32	24.23
R ₄	2.97	2.50	4.83	3.90	8.03	13.26
R ₅	2.54	2.42	8.80	7.68	12.52	25.27
R ₆	2.81	2.50	8.82	8.41	13.88	28.59
R ₇	3.02	2.38	7.85	8.02	13.27	25.95
R ₈	2.80	2.68	8.07	9.02	12.65	32.87
R ₉	2.92	2.63	4.43	2.80	7.24	10.01
R ₁₀	3.28	3.04	3.25	3.88	5.97	16.04
Mean	2.85	2.49	7.41	6.77	11.67	22.60

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 15G

Effect of density of plant population on nitrogen percentage and dry matter yield of plant and total nitrogen uptake by maize crop on 70th day growth stage.

Replica- tions	Percentage of nitrogen in plant		Dry matter yield per plant in gm		Nitrogen uptake in kg/ha	
	Density of planting		Density of planting		Density of planting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	0.87	0.86	32.00	25.40	15.59	29.70
R ₂	0.76	0.72	30.60	21.00	13.02	20.56
R ₃	0.76	0.72	36.30	14.80	15.44	14.49
R ₄	0.79	0.64	61.70	42.50	27.29	37.49
R ₅	1.09	0.68	38.50	39.00	23.50	36.06
R ₆	0.83	0.78	26.50	32.90	12.32	34.90
R ₇	0.69	0.72	39.50	22.40	15.26	21.93
R ₈	0.84	0.89	33.00	18.70	15.52	22.63
R ₉	1.02	0.86	36.30	14.80	20.73	17.31
R ₁₀	0.79	0.67	43.00	18.20	19.02	16.58
Mean	0.84	0.75	37.74	24.94	17.76	25.17

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 15H

Effect of density of plant population on nitrogen percentage and dry matter yield of plant and total nitrogen uptake by maize crop on 95th day growth stage.

Replica- tions	Percentage of nitrogen in plant		Dry matter yield per plant in gm		Nitrogen uptake in kg/ha	
	Density of planting		Density of planting		Density of planting	
	D ₁	D ₂	D ₁	D ₂	D ₁	D ₂
R ₁	0.56	0.42	40.90	32.30	12.82	18.45
R ₂	0.46	0.31	33.20	28.70	8.55	12.09
R ₃	0.30	0.31	54.50	19.40	9.15	8.18
R ₄	0.41	0.40	45.00	20.40	10.33	11.09
R ₅	0.38	0.31	42.50	25.00	9.04	10.54
R ₆	0.43	0.29	31.50	23.80	7.58	9.38
R ₇	0.34	0.36	53.00	11.10	10.09	5.43
R ₈	0.49	0.32	47.40	30.60	13.00	13.31
R ₉	0.42	0.38	33.00	49.80	7.76	25.73
R ₁₀	0.34	0.27	76.50	30.40	14.56	11.16
Mean	0.41	0.33	45.75	27.15	10.28	12.53

D₁ = 28 plants per plot

D₂ = 68 plants per plot

resources in soil was more in D_2 than in D_1 plots. A sharp decrease in the uptake of nitrogen was recorded on 95th day of crop growth. This was the result of some external factors. After 65 day of crop growth the cropped fields were repeatedly attacked by parrots and monkeys. Besides, considerable number of matured cobs were stolen by some offenders of the locality. These factors caused a considerable loss of high nitrogen containing plant parts of both the D_1 and D_2 plots.

The differences in the percentage of nitrogen in the plants, dry matter yield per plant and total nitrogen uptake (kg/ha) values of high and low density cropped plots were found to be statistically significant at all the three stages of crop growth. (Appendix Tables X, XI, XII, XIII, XIV, XV, XVI, XVII and XVIII). Similarly, differences in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium nitrogen in the high and low density cropped fields were also found to be statistically significant at all the three stages of crop growth (Appendix Tables I, II, III, IV, V, VI, VII, VIII and IX).

Most of the previous reports (Allison et al, 1951, 1953a; b; Bower, 1950; Nommik 1957; Raju and Mukhopadhyay, 1974), have indicated that the native fixed ammonium is biologically only slowly available. Even under intensive cropping, small but insignificant amount of native fixed ammonium was released (Black and Waring, 1972). The result of the present investigation is in agreement with the above mentioned views. If the fixed ammonium nitrogen

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present in the unfertilized soils be called native fixed ammonium, the amount did not decrease at any stage of the crop growth, even under intensive high density cropping (vide Table 15C). On the other hand, the value of native fixed ammonium tended to increase due possibly to fixation of a part of the recently mineralised ammonium form of nitrogen in the soil.

EXPERIMENT 10 : Availability of recently fixed NH_4^+ to crops

Results (mean of the replicates) on changes in the amount of exchangeable NH_4^+ , soluble NO_3^- and fixed NH_4^+ forms of nitrogen in the field soil cropped with maize at two densities and fertilized separately with ammonium and nitrate forms of nitrogenous fertilizers are presented in Tables 16A, 16B and 16C respectively and graphically presented in Figures 18 and 19. Changes (mean of replicates) in the nitrogen percentages, dry matter yield and nitrogen uptake of the crop at two stages of growth are presented in Tables 16D. During the first 7 day period following fertilization, no effect of planting density is expected. The nutrition of the germinated seedlings during this period was possibly restricted primarily to its supply from the stored material in the seed with least support from the soil sources. Hence no effect of density of plant population on changes in the forms of nitrogen in soil are observed between 0 and 7 day stages (Tables 16A, 16B and 16C).

Based on the assumption that increase over control of the forms of nitrogen present in the soil during the first 7 day period have been derived from the applied fertilizer, analysis of the result (Table 16A, 16B and 16C) reveal that following addition of ammonium sulphate fertilizer at the low rate (60 kg/ha), 94% and 76% were recovered in the available mineral form (sum of exchangeable NH_4^+ and soluble NO_3^-) after 0 and 7th day respectively. While the corresponding percentage recovery from the applied nitrate fertilizer at the same rate were 80 and 71. Whereas, at 300 kg level of nitrogen application, the percentage recovery values obtained were 81 and 64 after 0 and 7 days of ammonium sulphate addition and 79 and 50 after the addition of nitrogen in the form of $\text{Ca}(\text{NO}_3)_2$ respectively. Thus, irrespective of the levels of N-application, relatively lower recovery percentages in the said forms were observed following the application of nitrate fertilizer than at the corresponding level of nitrogen applied in the form of ammonium fertilizer. The results further show that at both the rate of fertilization by nitrate fertilizer, the amount of fixed ammonium nitrogen did not change from its native level. In such a short period after sowing of seeds nitrogen uptake by plant was quite unlikely. Microbial immobilisation of ammonium and nitrate could be possible (Jansson, 1958) to explain the result. A considerable part of the added ammonium fertilizer nitrogen was, however, found in the fixed form. This amounted to 17 and 8.6 per cent immediately after application at the rate of 60 and 300 kg of N/ha. The corresponding values, however,

TABLE - 16A

Effect of density of plant population and forms of N-fertilization on periodic changes in exchangeable ammonium content (ppm) in soil

(Mean of three replicates)

Treatments	Density of plant population	Days after sowing of seeds				
		0	7	30	60	85
Control	D ₁	23.50	23.16	20.16	29.33	30.33
	D ₂			25.33	31.33	23.00
Ammonium sulphate @ 60 kg N/ha	D ₁	46.00	35.16	23.33	32.33	24.66
	D ₂			29.00	28.33	25.00
Calcium nitrate @ 60 kg N/ha	D ₁	22.66	23.33	25.00	26.66	26.33
	D ₂			26.33	33.00	23.00
Ammonium sulphate @ 300 kg N/ha	D ₁	145.66	99.83	30.66	32.00	25.00
	D ₂			35.66	28.66	27.33
Calcium nitrate @ 300 kg N/ha	D ₁	22.66	26.16	25.00	30.66	24.33
	D ₂			24.66	34.33	23.33

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 16B

Effect of density of plant population and forms of N-fertilization on periodic changes in soluble nitrate content (ppm) in soil

(Mean of three replicates)

Treatments	Density of plant popula- tion	Days after sowing of seeds				
		0	7	30	60	85
Control	D ₁	29.83	26.16	16.00	18.00	30.33
	D ₂			15.33	26.00	29.66
Ammonium sulphate @ 60 kg N/ha	D ₁	34.00	36.83	16.33	16.33	24.66
	D ₂			18.66	16.66	25.00
Calcium nitrate @ 60 kg N/ha	D ₁	52.83	47.66	35.66	25.66	26.33
	D ₂			18.00	19.33	23.00
Ammonium sulphate @ 300 kg N/ha	D ₁	29.66	35.66	20.33	22.33	25.00
	D ₂			23.00	22.66	27.33
Calcium nitrate @ 300 kg N/ha	D ₁	148.83	119.83	100.66	78.33	24.66
	D ₂			37.33	31.66	23.33

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 16C

Effect of density of plant population and forms of N-fertilization on periodic changes in fixed NH_4 content (ppm) in soil

(Mean of three replicates)

Treatments	Density of plant population	Days after sowing of seeds				
		0	7	30	60	85
Control	D ₁	505.66	511.50	538.00	555.66	559.66
	D ₂			528.00	553.00	548.66
Ammonium sulphate @ 60 kg N/ha	D ₁	510.83	525.83	531.66	581.00	600.66
	D ₂			526.66	562.66	564.33
Calcium nitrate @ 60 kg N/ha	D ₁	505.00	508.83	521.00	555.66	567.00
	D ₂			518.66	535.66	532.66
Ammonium sulphate @ 300 kg N/ha	D ₁	518.83	563.83	625.66	645.00	681.33
	D ₂			593.00	611.66	640.66
Calcium nitrate @ 300 kg N/ha	D ₁	506.00	510.00	517.00	548.66	576.00
	D ₂			512.66	558.33	575.66

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 16D

Effect of plant population and added N-fertilizers on periodic changes in N percentage and dry matter yield of plant and total nitrogen uptake by maize crop

(Mean of three replicates)

Treatment	Density of plant population	Percentage of N		Dry matter yield per plant (g)		N-uptake (kg/ha)	
		Plant growth stages in days					
		30	60	30	60	30	60
Control	D ₁	1.70	1.03	35.86	76.10	34.35	43.90
	D ₂	1.47	0.91	39.10	80.66	77.96	100.72
Ammonium sulphate @ 60 kg N/ha	D ₁	1.99	1.25	45.93	78.03	50.96	54.76
	D ₂	1.61	1.02	47.30	80.23	101.13	109.76
Calcium nitrate @ 60 kg N/ha	D ₁	2.12	1.50	51.33	84.30	60.92	70.88
	D ₂	1.74	1.20	56.40	92.63	133.46	151.17
Ammonium sulphate @ 300 kg N/ha	D ₁	2.36	1.95	48.10	72.23	63.53	79.10
	D ₂	2.12	1.71	54.36	78.90	156.72	183.48
Calcium nitrate @ 300 kg N/ha	D ₁	2.60	1.99	56.76	85.90	83.25	100.72
	D ₂	2.36	1.77	63.90	96.25	204.61	231.69

D₁ = 28 plants per plant

D₂ = 68 plants per plant

increased to 48 and 34.6 per cent after 7 days of fertilizer application. The above observations thus indicate the following:

(a) Fixation of the recently added ammonium increased with increase in the period of reaction upto 7th day with soil. This observation is similar to the results obtained by Legget and Moodie (1962) and Harada and Kutsuna (1954). Such increase in the amount of added ammonium fixed may be aided by wetting and drying cycles in the field which have been shown to increase fixation (Jansson, 1958).

(b) Relative increase in the amount of fixed ammonium in the soil treated with 300 kg of nitrogen as $(\text{NH}_4)_2\text{SO}_4$ per hectare (52.2 ppm and 13 ppm after 70 and 0 day of fertilization) was found to be higher than the corresponding 60 kg level of nitrogen addition (14.3 and 5.2 ppm after 7 and 0 day of fertilization). This is very much expected as the amount of exchangeable ammonium nitrogen was also higher at the 300 kg level of N-application (Table 16A). As the concentration of added ammonium in soil solution increases, the amount of fixed ammonium in the soil would also increase (Nommik, 1957; Mele Mela, 1962).

(c) Almost complete recovery of added fertilizer nitrogen (96 to 100%) in the mineral form could be accounted if the percentage of recently added ammonium fixed be pooled with the total percent recovery of the available mineral forms of nitrogen (exchangeable NH_4^+ + soluble NO_3^-). It is, therefore, suggested

FIG. 18 EFFECT OF DENSITY OF PLANT POPULATION AND ADDED NH_4 AND NO_3 FORMS OF FERTILIZER @ 300 Kg N/ha LEVEL ON CHANGES IN EXCHANGABLE AMMONIUM CONTENT (ppm) IN THE FIELD

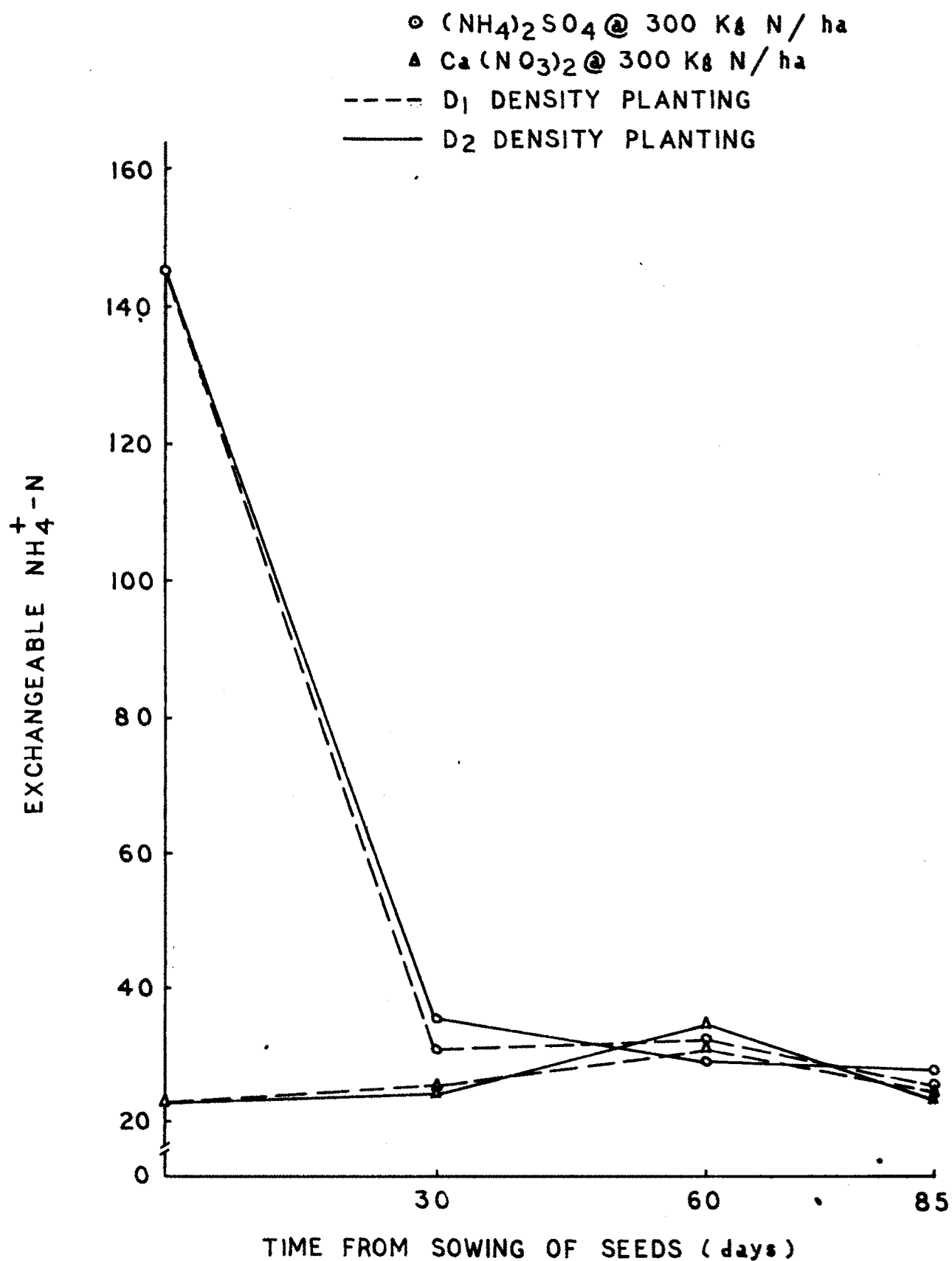
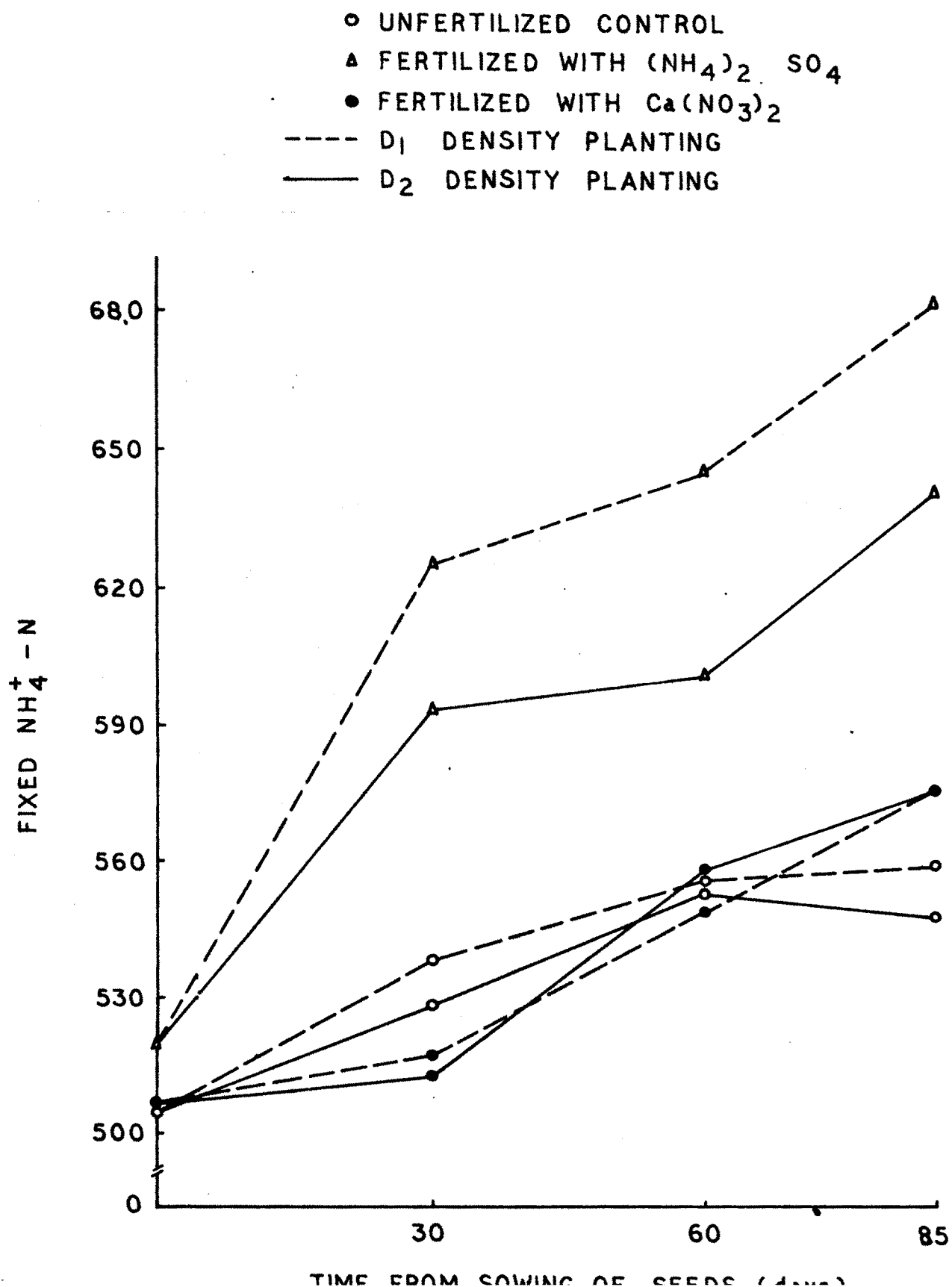


FIG. 19 EFFECT OF DENSITY OF PLANT POPULATION AND ADDED NH_4 AND NO_3 FORMS OF FERTILIZER @ 300 Kg N / ha LEVEL ON CHANGES IN FIXED AMMONIUM CONTENT (ppm) IN THE FIELD



that the fixation of recently added ammonium may be treated as conservation of the added fertilizer nitrogen than loss from the soil system.

The amount of fixed NH_4^+ in the soil increased with increasing period of crop growth. This was observed in all the treatments under investigation. Analysis of the results in Table 17 reflects the order of increase under different treatments. Irrespective of levels of N-fertilization, the amount of fixed NH_4^+ ~~was~~ in the ammonium sulphate treated soil was found to be higher than those in the calcium nitrate added system. Relatively higher amount of fixed NH_4^+ was found in the soil with low density cropping (D_1) than in the corresponding treatment with high density plant population (D_2). Since, nitrate cannot be chemically converted to NH_4^+ form in the soil, and clay fixation of NH_4^+ was, therefore, higher in the ammonium than nitrate fertilizer added soil. Since, nitrogen requirement of higher plant population per unit area (D_2) is more than that of the lesser number of plants (D_1), more exhaustive utilization would be expected under D_2 than in D_1 planting. This may possibly be the reason for observing lesser amount of fixed NH_4^+ in the soil under D_2 than in D_1 plots.

The ($D_1 - D_2$) values of fixed NH_4^+ in the soil treated with ammonium sulphate was found to increase with increase in the period of crop growth. With age of crop, the demand for nitrogen also increased, more so in D_2 than D_1 density plots. This was possibly the reason for widening the difference in the amount of

TABLE - 17

Effect of density of plant population and forms of N-fertilization on the periodic increase (ppm) in fixed ammonium content in soil over 0 day

Treatment	Density of plant population	Days after sowing of seeds			
		7	30	60	85
Control	D ₁	5.84	32.34	50.00	54.00
	D ₂		22.34	47.34	43.00
Ammonium sulphate @ 60 kg N/ha	D ₁	15.00	20.83	70.17	93.83
	D ₂		15.83	51.83	53.50
Calcium nitrate @ 60 kg N/ha	D ₁	3.83	16.00	50.66	62.00
	D ₂		13.66	30.66	27.00
Ammonium sulphate @ 300 kg N/ha	D ₁	45.00	106.83	126.17	162.50
	D ₂		74.17	92.83	121.83
Calcium nitrate @ 300 kg N/ha	D ₁	4.00	11.00	42.66	70.00
	D ₂		6.66	52.33	69.66

D₁ = 28 plants per plant

D₂ = 68 plants per plant

fixed ammonium content in the soil of D₂ and D₁ plots with increasing period of crop growth.

Critical examination of the data in Table 17, however, raises some very pertinent questions. Interpretation of the results shall possibly remain incomplete if these questions are not properly highlighted. What could possibly be the reason for the increase in the amount of fixed ammonium in the calcium nitrate treated and unfertilized control soil ? Since no source of ammonium was added, the observed phenomenon therefore logically indicate that mineralisation of native soil organic nitrogen could have resulted the change. Conclusive evidence can, however, be obtained by tracing the change in mineralisation of N¹⁵ tagged soil organic matter. If the hypothesis furnished above is considered as a valid one, at least two important consideration emerge out of the result of the present investigation. One, under both the unfertilized control and N fertilized soils, fixation of the recently mineralised ammonium contributed a significant role in N-transformation in presence of growing plants, since no variation could be detected till 7th day period. Even on 30th day stage of crop growth the said contribution was found to be of much lower order than what was observed on 60th or 85th day stages. Further work in this line is, however, needed to place the hypothesis on a firm basis. Secondly, the rate of N-mineralisation of soil organic matter was found to be faster in the unfertilized control soil during the initial period of crop growth (even upto

60th day stage) than in the NO_3^- fertilized soil. But during the later stage of crop growth (85th day stage) N-mineralisation was found to be faster in the NO_3^- fertilized soil than in the unfertilized control.

Using the data in Table 17, the difference in the amount of increase of fixed ammonium in the NH_4 and NO_3^- fertilizer treated soils were computed and presented in Table 18. Assuming that the rate of N-mineralisation would be same under both the NH_4 and NO_3^- fertilizer added soil, the computed data in Table 18 therefore, represent the amount fixed from the added ammonium fertilizers. The result (Table 18) reveal that at 60 kg N/ha level of added ammonium fertilizer, the clay fixation of NH_4^+ increased from 30th to 60th day stage of crop growth. This increase after 30th day may be added by the movement of ammonium through the soil making more fixation sites available. On the other hand, at 300 kg N/ha level of applied $(\text{NH}_4)_2\text{SO}_4$, maximum fixation of the added ammonium was found on 30th day stage (95.83 and 67.51 ppm at D_1 and D_2 density cropped plots) which decreased considerably on 60th day stage and subsequently increased on 85th day stage of crop growth. But the observed value on 85th day were also lower than the corresponding value on 30th day. A similar result of substantial decline in the amount of recently fixed ammonium nitrogen after 40 days at the high rate of ammonium sulphate application (500 ppm) was also reported by Black and Waring (1972) in a pot culture study. Irrespective of the levels of added fertilizer ammonium and stages

TABLE - 18

Effect of addition of $(\text{NH}_4)_2\text{SO}_4$ over $\text{Ca}(\text{NO}_3)_2$ on the periodic increase (ppm) in the amount of fixed NH_4^+ in soil over a day after fertilization.

$(\text{NH}_4)_2\text{SO}_4$ and $\text{Ca}(\text{NO}_3)_2$ when applied @	Density of plant population	Days after sowing of seeds		
		30	60	85
60 kg N/ha	D ₁	4.83	19.51	27.83
	D ₂	1.17	21.07	25.50
300 kg N/ha	D ₁	95.83	83.51	92.50
	D ₂	67.51	39.40	51.17

D₁ = 28 plants per plot

D₂ = 68 plants per plot

of crop growth, the amount of fixation under D_2 was found to be less than that under D_1 treatment. The recently fixed ammonium nitrogen values at the final harvest of the first crop indicate that a single cropping cannot completely remove all the recently fixed ammonium nitrogen from the soil.

Assuming herbage nitrogen to be soil extractable nitrogen taken up by the plant, an increase in the amount of total extractable nitrogen plus fixed ammonium nitrogen in the soil was calculated for each of the two crop density treatments for 30th day period over 0 day stage after N-fertilization. The results of the computed data are presented in Table 19. The increase in the total extractable nitrogen in D_2 over D_1 along with its different constituent forms were also computed and presented in the same Table. A similar computations for 60th day period over 0 day stage were also done and are presented in Table 20. The results in Table 19 and 20 may thus help to integrate at least some of the important individual processes of nitrogen transformations in a soil-plant system.

Analysis of the results in Table 19 indicate that during the first 30 day period after addition of ammonium sulphate @ 60 kg N/ha, an additional amount of 28.08 ppm of soil extractable nitrogen including fixed ammonium was recorded in D_2 and D_1 treatment. Analysis of the individual forms, however, fail to indicate any contribution of fixed ammonium form of nitrogen to this increased amount. Exchangeable NH_4^+ content in D_2 exceeded

TABLE - 19

Increase in the amount (ppm) of total soil extractable nitrogen including fixed ammonium on 30th day after fertilization over the corresponding 0 day stage.

(Mean of three replicates)

Treatments	Density of plant population	Increase in total soil extractable N on 30th day over 0 day of fertilization	Amount of increase in total soil extractable -N in D ₂ over D ₁ density of plant population	Increase in the amount of constituent forms of soil extractable-N in D ₂ over D ₁ density of planting during the first 30 day period of crop growth			
				Exch. NH ₄ ⁺	Sol. NO ₃ ⁻	Fixed NH ₄ ⁺	Uptake
Ammonium sulphate @ 60 kg N/ha	D ₁	5.97	28.08	+5.67	+2.33	-5.00	+25.08
	D ₂	34.05					
Calcium nitrate @ 60 kg N/ha	D ₁	31.63	17.60	+1.33	-17.66	-2.34	+36.27
	D ₂	49.63					
Ammonium sulphate @ 300 kg N/ha	D ₁	14.92	21.61	+5.00	+2.67	-32.66	-46.60
	D ₂	36.53					
Calcium nitrate @ 300 kg N/ha	D ₁	6.79	0.00	-0.34	-63.33	-4.34	+60.68
	D ₂	-0.54					

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 20

Increase in the amount (ppm) of total soil extractable nitrogen including fixed ammonium on 60th day after fertilization over the corresponding 0 day stage.

(Mean of three replicates)

Treatments	Density of plant population	Increase in total soil extractable N on 60th day over 0 day of fertilization	Amount of increase in total soil extractable -N in D ₂ over D ₁ density of plant population	Increase in the amount of constituent forms of soil extractable-N in D ₂ over D ₁ density of planting during the first 60 day period of crop growth			
				Exch. NH ₄ ⁺	Sol. NO ₃ ⁻	Fixed NH ₄ ⁺	Uptake
Ammonium sulphate @ 60 kg N/ha	D ₁	66.21					
	D ₂	71.70	5.49	-4.00	+0.33	-19.34	+27.50
Calcium nitrate @ 60 kg N/ha	D ₁	62.93					
	D ₂	83.08	20.15	+6.34	-6.33	-20.00	+40.14
Ammonium sulphate @ 300 kg N/ha	D ₁	45.39					
	D ₂	61.23	15.84	-3.34	+0.33	-33.34	+52.19
Calcium nitrate @ 300 kg N/ha	D ₁	30.52					
	D ₂	62.67	32.15	+3.67	-46.67	+9.67	+65.48

D₁ = 28 plants per plot

D₂ = 68 plants per plot

by about 5 ppm over D_1 and fixed NH_4^+ content in D_1 exceeded by 55 ppm over D_2 . Hence no contribution of fixed ammonium form could possibly be accounted for the total increase in D_2 over D_1 , whereas, during the same period after addition of ammonium sulphate @ 300 kg N/ha, an additional amount of 21.61 ppm of extractable nitrogen was recorded in D_2 over D_1 treatment. But at this higher rate of nitrogen application, considerable amount of the recently fixed ammonium (32.66 ppm) was found to contribute for the 46.60 ppm of nitrogen uptake by maize tops. The corresponding analysis of the results in the NO_3^- fertilizer added soil reveal that the increased uptake of nitrogen by the growing plants in D_2 over D_1 treatment upto 30 days was mainly from the applied NO_3^- fertilizers as evidenced from the results of the decrease in NO_3^- content in D_2 over D_1 , vis-a-vis, the difference in the amount of nitrogen uptake by plants. The results in Table 19 thus point out that within 30 day period of plant growth, the recently fixed ammonium form of nitrogen hardly become released for meeting the requirement of nitrogen of the growing plants. The corresponding results in Table 20, however, indicate that over the 60 day growing period, a considerable amount of the recently fixed ammonium was utilized by the crops planted at D_2 density over those planted at lower density (D_1). At the rate of 60 kg N/ha of $(\text{NH}_4)_2\text{SO}_4$ applied to soil, nitrogen uptake by maize tops in D_2 treatment exceeded by 27.5 ppm over those in D_1 , which is found to be largely compensated by a decrease of 19.34 ppm of fixed NH_4^+ and 4 ppm of

exchangeable NH_4^+ in the soil i.e., a total of 23.34 ppm. Similarly at 300 kg N/ha level of application in the form of $(\text{NH}_4)_2\text{SO}_4$, the nitrogen taken up by crops in D_2 treatment over D_1 amounted to 52.19 ppm. During the same period a decrease of 33.34 ppm of fixed ammonium and 3.24 ppm of exchangeable ammonium was recorded in D_2 over D_1 treatment i.e. a net decrease of 36.68 ppm. This decrease in the amount of exchangeable and fixed ammonium form of nitrogen in D_2 plots over D_1 was likely the effect of the increased nitrogen uptake by crops in D_2 over D_1 . The result (Table 24) therefore, points out that over the 60 day growing period, a considerable portion of the recently fixed ammonium was utilized by the growing plant population to meet their nitrogen demand. This was consistently observed at both the levels of NH_4^+ fertilization. From the trend of result it was also quite evident that with increase in the period of growing plants, demand for nitrogen also increased and with the development of increasing stress of the readily available forms of nitrogen (exchangeable NH_4^+ + soluble NO_3^-), the plants did utilize a considerable amount of the recently fixed ammonium present in the soil. Result of the investigations carried out by Kowalenko and Cameron (1978) and Black and Waring (1972) have also led them to arrive at a similar conclusion.

Nitrogen uptake

Rate of nitrogen uptake calculated in terms of kg/ha/day for two stages of growth by maize crop planted at two densities are presented in Table 21. Data in Table 21 clearly indicate

that nitrogen fertilization resulted in increased N-uptake by maize herbage (herbage in this study is defined as total above ground plant material) over the cropped control treatment. This was observed irrespective of crop densities and forms and levels of nitrogen fertilization. Similar observation was also recorded by Kowalenko and Cameron (1978) in a field study with N^{15} tracer nitrogen.

It was further observed that the rate of nitrogen uptake was very rapid during the first 30 day period of growth of maize than in the period between 30 to 60 days. This was also a general observation and found in both the fertilized and unfertilized soil and at both the densities of cropping. The rate of dry matter production was relatively lower than the rate of N-accumulation during the initial growth period. The result of the present investigation closely corroborates the observations of Kowalenko and Cameron (1978).

Closer examination of the data reveal that irrespective of fertilizations and stages of crop growth, rate of nitrogen uptake by herbage (kg/ha/day) was faster in high density plots (D_2) than in the corresponding low density plots (D_1). Obviously this is the result of larger plant population in D_2 over D_1 . It was of further interest to note that at the corresponding levels of N-fertilization, higher rates of N-uptake by maize crop was recorded in $Ca(NO_3)_2$ fertilized plots than in the $(NH_4)_2SO_4$ treated plots. This difference was, however, narrowed down during 30 to 60 day period of growth. A number of authors have also reported relatively

TABLE - 21

Effect of density of plant population and forms of N-fertilization on the rate of nitrogen uptake (kg/ha/day) by maize crop at two growth stages.

Fertilizer treatment	Density of plant population	Rate of nitrogen uptake at growth stages between	
		0 to 30 days	30 to 60 days
No fertilizer	D ₁	1.450	0.318
	D ₂	2.598	0.758
Ammonium sulphate @ 60 kg N/ha	D ₁	1.698	0.126
	D ₂	3.371	0.287
Calcium nitrate @ 60 kg N/ha	D ₁	2.031	0.332
	D ₂	4.456	0.590
Ammonium sulphate @ 300 kg N/ha	D ₁	2.117	0.519
	D ₂	5.224	0.892
Calcium nitrate @ 300 kg N/ha	D ₁	2.775	0.582
	D ₂	6.820	0.902

D₁ = 28 plants per plot

D₂ = 68 plants per plot

lower nitrogen uptake by plant over a short growing period from ammonium than nitrate fertilized plots (Nommik, 1957; Jansson, 1958). Recently Black and Waring (1972) have also demonstrated less nitrogen uptake by wheat tops from ammonium compared with nitrate sources. This could possibly be due mainly to the increased fixation of added ammonium in the $(\text{NH}_4)_2\text{SO}_4$ added soil than in the corresponding $\text{Ca}(\text{NO}_3)_2$ treated plots. Similar hypothesis was also suggested by Black and Waring (1972). Walsh and Murdock (1963) concluded that fixation caused reduced nitrogen uptake from ammonium fertilizer.

Nitrogen mineralisation

In low density cropped plots, the control soil (0-15 cm) obtained 72.32 kg extractable (exchangeable) NH_4^+ + soluble NO_3^-) nitrogen per hectare at harvest after 30 days and if the herbage nitrogen (34.35 kg/ha) is assumed as soil extractable nitrogen taken up by the plant, the total comes to 106.67 kg/ha. Initially the soil contained 106.66 kg/ha of extractable nitrogen which means that there was no increase in extractable nitrogen over the 30 day period. However, during the same period the fixed ammonium content in the soil was found to increase by 64.68 kg/ha. If this increase was assumed to be entirely due to mineralisation of native organic nitrogen of the soil as no other source of nitrogen was added, then a net rate of N-mineralisation of 2.12 kg/ha/day (Table 22) occurred. A similar calculation for the ammonium form of fertilizer added soils show a net rate of N-mineralisation at 0.464 kg/ha/day and 4.28 kg/ha/day when applied @ 60 and 300 kg of N/ha respectively,

TABLE - 22

N-mineralisation rates at different stages and densities of crop growth in unfertilized and fertilized soils.

Fertilizer application	Density of cropping	Net N mineralisation rate at two crop growth stage ^{unit}			
		30 day		60 day	
		A	B	A	B
No fertilizer control	D ₁	2.12	0.00	2.20	0.52
	D ₂	3.26	1.78	3.39	1.81
Ammonium sulphate @ 60 kg N/ha	D ₁	0.46	0.00	2.20	0.00
	D ₂	2.26	1.21	2.39	0.66
Ammonium sulphate @ 300 kg N/ha	D ₁	4.28	0.00	0.00	0.00
	D ₂	5.72	0.78	3.68	0.59

D₁ = 28 plants per plot

D₂ = 68 plants per plot

A = Net N mineralisation rate calculated by including the change in the amount of fixed NH_4^+ in soil.

B = Net N mineralisation rate calculated by excluding the change in the amount of fixed NH_4^+ - N in soil.

assuming no part of the added fertilizer nitrogen was lost from the soil.

Whereas, in the high density cropped plots, the net rate of N-mineralisation was found to be higher than the corresponding low density cropped plots. In the control soil the net rate was found to be 2.36 kg/ha/day. When fertilized with $(\text{NH}_4)_2\text{SO}_4$ @ 60 kg N/ha, the rate of N-mineralisation was found to be 2.26 kg/ha/day. At the higher level of $(\text{NH}_4)_2\text{SO}_4$ application, the corresponding value was 5.72 kg/ha/day.

Analysis of the net rate of mineralisation under both the fertilized and unfertilized field soils thus reveal that when the change in the fixed ammonium content in the soil was included in the calculation, the mineralisation rate was found to be higher than when the said form of nitrogen was excluded from the calculation. This observation also points out that a considerable part of the recently mineralised ammonium was converted to clay fixed form during crop growth. Unless the portion of the fixed ammonium that has actually come from the fertilizer source be estimated the extent derived from recently mineralised ammonium cannot possibly be accounted for. However, comparison of the net mineralisation rate (calculated by excluding the change in fixed ammonium content in the soil) between unfertilized and $(\text{NH}_4)_2\text{SO}_4$ fertilized soil reveal that irrespective of the density of cropping, the mineralisation rate was lower in the fertilized than in unfertilized soil and the rate was less in the plot which received 300 kg N/ha

(0.78 kg/ha/day) than under 60 kg N/ha (1.21 kg/ha/day). In general, a similar trend of results varying only in degree, were obtained when calculation for the 60 day stage of crop growth was done in a similar manner (Table 22).

The analysis thus suggest that more the fertilizer nitrogen is available for the crop growth, less the amount of nitrogen made available from the native soil organic matter. Irrespective of fertilization, higher rates of N mineralisation was recorded in the high density cropped plots than in the corresponding low density plots. This is quite expected because higher root activity in the high density cropped plots is likely to release larger amount of root exudates favouring increased microbial activity and thereby causing increased rate of mineralisation (Mishra and Das, 1975). This observation also finds support from the results of total microbial counts in rhizosphere and remote soils determined after 30 and 65 days of crop growth (Table 23). Analysis of the data in Table 23 clearly indicate that irrespective of fertilization and stages of crop growth, significantly higher microbial population was observed in D_2 over D_1 . This was observed in both the remote and rhizosphere soils.

TABLE - 23

Effect of rhizosphere and forms of N-fertilization on the periodic changes in bacterial population ($\times 10^5$ per g) in soil cropped with maize at two densities.

(Mean of three replicates)

Treatments	Density of plant popula- tion	Days after sowing seeds			
		30		65	
		Remote	Rhizosphere	Remote	Rhizosphere
Control	D ₁	59.23	105.00	47.33	230.33
	D ₂	125.00	156.66	181.00	394.00
Ammonium sulphate @ 60 kg N/ha	D ₁	86.65	147.33	57.00	173.33
	D ₂	164.33	211.66	290.33	264.00
Calcium nitrate @ 60 kg N/ha	D ₁	120.00	165.00	82.66	223.33
	D ₂	152.33	167.33	105.33	376.66
Ammonium sulphate @ 300 kg N/ha	D ₁	111.66	144.00	101.66	187.33
	D ₂	110.33	180.00	232.00	239.33
Calcium nitrate @ 300 kg N/ha	D ₁	142.66	178.00	264.33	376.66
	D ₂	148.33	219.00	216.00	323.33

D₁ = 28 plants per plot

D₂ = 68 plants per plot

EXPERIMENT 11 : Availability of residual fixed NH_4^+ to crops

In order to study the residual effect of the different treatments in experiment 10, maize crop was grown in the same field with two densities of planting but without any source of N-fertilizer addition. The plots corresponding to D₁ and D₂ densities were maintained as in the previous experiment. The changes in the amount of exchangeable ammonium, soluble nitrate and fixed ammonium forms of nitrogen in the soil and nitrogen percentage and dry matter yield of plant and nitrogen uptake by maize crop in the experiment were determined and the results are presented in Tables 24A, 24B, 24C, 24D, 24E and 24F respectively.

Changes in the amount of exchangeable NH_4^+ in the soil

Results in Table 24A indicate a decline in the amount of exchangeable ammonium in soil during the first 20 day period of plant growth. This declining trend was generally observed in both the residual N-fertilized and unfertilized soils. Since, during the same period, no increase in nitrate (Table 24B) or fixed NH_4^+ (Table 24C) content of the soil was observed, the decrease in the amount of exchangeable ammonium was possibly the result of utilization of available nitrogen by the growing maize crop. The amount of exchangeable NH_4^+ form of nitrogen was, however, found to increase with the growing period beyond 20 day stage. The amount of the said increase between 20 and 50 day stage ranged between 17 to 27 ppm in low density cropped plots and

TABLE - 24A

Periodic changes in the amount of exchangeable ammonium (ppm) in soil as influenced by density of plant population and residual effect of added N-fertilizers.

(Mean of three replicates)

Treatments applied in the cropped 2nd experiment	Density of plant population				
		0	20	35	50
Control	D ₁	30.66	27.33	29.66	54.33
	D ₂		22.33	24.66	31.66
Ammonium sulphate @ 60 kg N/ha	D ₁	31.00	20.00	35.00	51.33
	D ₂		22.33	24.00	55.00
Calcium nitrate @ 60 kg N/ha	D ₁	33.00	25.66	23.33	43.66
	D ₂		21.66	21.33	47.00
Ammonium sulphate @ 300 kg N/ha	D ₁	42.66	24.00	31.00	49.00
	D ₂		28.00	21.00	52.33
Calcium nitrate @ 300 kg N/ha	D ₁	28.33	24.66	23.33	41.33
	D ₂		28.33	23.00	44.00

D₁ = 28 plants per plot

D₂ = 68 plants per plot

between 9 to 33 ppm in the high density cropped fields. It was of further interest to observe that at harvest of the crops on 50th day, the amount of exchangeable form of ammonium was more in D_2 than in D_1 plot in the residual N-fertilized soil and higher in soil of D_1 than D_2 unfertilized plots.

Changes in the amount of 2M KCl
extractable NO_3 in the soil

In general, the change in the amount of soluble nitrate in the soil (Table 24B) followed almost a similar trend as was observed for exchangeable ammonium (Table 24A).

Changes in the amount of fixed
 NH_4^+ in the soil

Results in Table 24C and Fig. 20 reveal that the amount of fixed ammonium in the soil decreased with the increase in age of the growing plants and the magnitude of decrease was relatively higher in plots with high density planting than in the corresponding plots with low plant density. Comparison of decrease in the amount of fixed ammonium nitrogen in D_1 and D_2 density plots reveal that maximum utilization of residual fixed ammonium nitrogen was observed in plots which were fertilized with NO_3 form of nitrogen ($D_1 - D_2$ values was 41 at both the 60 and 300 kg N/ha). Whereas, the corresponding value was 31 ppm in plots which were fertilized with ammonium sulphate. The relatively higher amount release of residual fixed ammonium form of nitrogen from the NO_3 fertilised plots, suggest that the recently fixed ammonium derived from mineralisation of soil organic matter was

TABLE - 24B

Periodic changes in the amount of soluble nitrate (ppm) in soil as influenced by density of plant population and residual effect of added N-fertilizers.

(Mean of three replicates)

Treatments applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds			
		0	20	35	50
Control	D ₁	28.33	23.33	14.33	25.33
	D ₂		17.66	17.66	21.00
Ammonium sulphate @ 60 kg N/ha	D ₁	28.00	23.33	16.66	25.66
	D ₂		19.66	17.66	21.00
Calcium nitrate @ 60 kg N/ha	D ₁	23.33	18.33	15.00	15.00
	D ₂		23.00	19.66	26.00
Ammonium sulphate @ 300 kg N/ha	D ₁	35.66	19.33	17.33	25.66
	D ₂		19.33	15.33	15.00
Calcium nitrate @ 300 kg N/ha	D ₁	23.33	20.66	17.00	15.66
	D ₂		19.66	12.66	28.00

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 24C

Periodic changes in the amount of fixed ammonium (ppm) in soil as influenced by density of plant population and residual effect of added N-fertilizers.

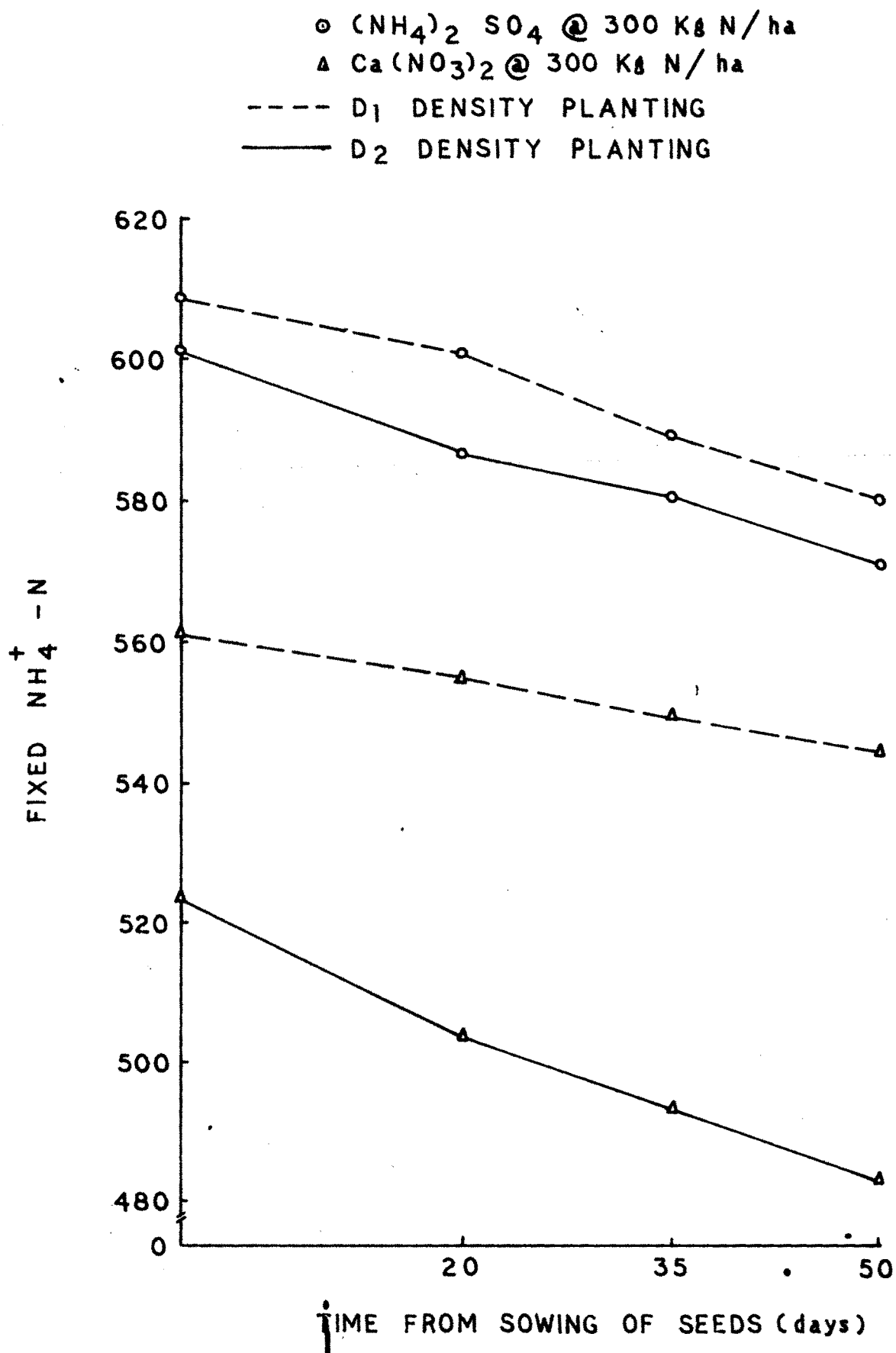
(Mean of three replicates)

Treatment applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds			
		0	20	35	50
Control	D ₁	569.66	564.00	560.66	551.00
	D ₂	567.33	559.00	554.66	548.00
Ammonium sulphate @ 60 kg N/ha	D ₁	589.66	588.66	585.00	580.00
	D ₂	559.66	551.66	541.66	528.63
Calcium nitrate @ 60 kg N/ha	D ₁	502.66	499.66	495.66	490.66
	D ₂	494.66	479.66	475.00	453.00
Ammonium sulphate @ 300 kg N/ha	D ₁	608.66	600.66	589.66	580.00
	D ₂	601.00	586.66	580.00	570.66
Calcium nitrate @ 300 kg N/ha	D ₁	560.00	554.66	549.66	544.00
	D ₂	523.66	503.66	492.66	482.66

D₁ = 28 plants per plot

D₂ = 68 plants per plot

FIG. 20 EFFECT OF PLANT DENSITY ON CHANGES IN THE AMOUNT (ppm) OF RESIDUAL FIXED NH_4^+ -N IN THE FIELD FERTILIZED DURING PREVIOUS CROPPING



more accessible to growing plants and microbes than where the source of nitrogen was ammonium sulphate fertilizer. In all previous experiments, the amount of fixed ammonium in the soil progressively increased with increasing period of crop growth, while, in the present experiment, the said form decreased progressively with increasing period of crop growth. The field selected for the 3 experiments in succession remained fallow (without any cultivation) for more than 10 years. Considerable increase in microbial activity was observed immediately the land was put to cultivation with the addition of fertilizer nutrient. This might have caused release of a considerable amount of exchangeable ammonium through mineralisation, resulting fixation of a part of this form by the clay colloids present in the soil. But during the third cropping of maize crop, the soil might have reached a stage of equilibrium. The above explanation may help to understand the said deviation in the trend of result (Table 24C) in the present experiment.

Lower amount of fixed ammonium form of nitrogen in the soil under D_2 density of planting than in D_1 was due to more exhaustive utilization of the said form to meet the higher demand of larger plant population per unit area.

Changes in N percentage and total nitrogen uptake by growing maize plant with age of crop

Results presented in Table 24D reveal the expected decrease in N percentage in the growing maize plant with increasing age of the crop. This was observed at both the plant densities

TABLE - 24D

Periodic changes in the nitrogen percentage of plant as influenced by density of plant population and residual effect of added N-fertilizers.

(Mean of three replicates)

Treatments applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds		
		20	35	50
Control	D ₁	3.09	1.68	0.73
	D ₂	2.54	1.34	0.74
Ammonium sulphate @ 60 kg N/ha	D ₁	2.34	1.25	0.82
	D ₂	1.89	1.24	0.76
Calcium nitrate @ 60 kg N/ha	D ₁	2.53	1.55	0.93
	D ₂	2.57	1.33	0.80
Ammonium sulphate @ 300 kg N/ha	D ₁	2.66	1.38	0.85
	D ₂	2.44	1.09	0.81
Calcium nitrate @ 300 kg N/ha	D ₁	3.09	1.25	0.95
	D ₂	2.87	1.33	0.89

D₁ = 28 plants per plot

D₂ = 68 plants per plot

under investigation. In general, nitrogen percentage of the crop planted at high density was found to be lower than those in the corresponding treatment planted at D_1 density. This observation was consistently noted at all the three stages of sampling. The result is in agreement with what was observed in the two previous experiments (Tables 15F, 15G, 15H of experiment 9 and Tables 16D of experiment 1C). Explanation furnished therein are equally applicable in the present situation.

Changes in total nitrogen uptake by the crop with increase in age of plant (24F) indicate that much higher amount of nitrogen was extracted from the soil by the crop planted at high density (D_2) than at the corresponding low density planting. From the analysis of results presented in Tables 24A, 24B and 24C, it was observed that during the 50 day period of crop growth, exchangeable ammonium content in the soil increased while the amount of clay fixed ammonium decreased.

Changes in the amount of KObR
extractable nitrogen in the
soil

Interpretation of the results on changes in the above mentioned forms of nitrogen in soil also finds support from the changes in the amount of KObR extractable nitrogen in the soil with the age of growing plants (Table 24G). Analysis of the result (Table 24G) show a decrease in the amount of KObR extractable nitrogen with the age of growing plants. This was observed at both densities of planting and in the treatments with and

TABLE - 24E

Periodic changes in the dry matter yield per plant (g) as influenced by density of plant population and residual effect of added N-fertilizers.

(Mean of three replicates)

Treatment applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds		
		20	35	50
Control	D ₁	6.88	17.95	37.54
	D ₂	6.50	16.00	36.21
Ammonium sulphate @ 60 kg N/ha	D ₁	6.57	16.05	34.20
	D ₂	6.56	17.92	29.86
Calcium nitrate @ 60 kg N/ha	D ₁	7.18	22.95	46.16
	D ₂	7.63	24.45	28.87
Ammonium sulphate @ 300 kg N/ha	D ₁	6.72	19.60	35.30
	D ₂	7.08	18.95	33.98
Calcium nitrate @ 300 kg N/ha	D ₁	7.53	28.71	38.66
	D ₂	7.86	28.13	31.66

D₁ = 28 plants per plot

D₂ = 68 plants per plot

TABLE - 24F

Periodic changes in the total N uptake (kg/ha) by plant as influenced by density of plant population and residual effect of added N-fertilizers.

(Mean of three replicates)

Treatments applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds		
		20	35	50
Control	D ₁	11.90	16.81	15.49
	D ₂	22.44	29.10	36.58
Ammonium sulphate @ 60 kg N/ha	D ₁	9.41	11.25	15.82
	D ₂	16.73	29.96	30.91
Calcium nitrate @ 60 kg N/ha	D ₁	10.16	19.80	24.04
	D ₂	20.65	44.20	32.82
Ammonium sulphate @ 300 kg N/ha	D ₁	10.06	15.16	16.83
	D ₂	23.61	28.30	37.19
Calcium nitrate @ 300 kg N/ha	D ₁	13.07	20.26	21.21
	D ₂	30.69	51.03	38.32

D₁ = 28 plants per plot

D₂ = 68 plants per plot

• without added ammonium sulphate. Difference between the amount of potassium hypobromite extractable nitrogen of the soil before and after cropping for 50 days, indicate that irrespective of nitrogen fertilization, much higher amount of decrease occurred in the soil with high than low density planting. Since this fraction of extractable nitrogen represent easily oxidisable labile organic forms of nitrogen and exchangeable ammonium form of nitrogen (Silva and Bremner, 1966), higher nitrogen uptake by plants grown in D_2 over D_1 plots was to a large extent supplied by this fraction. Mohammed (1979) in his study on the availability of fixed ammonium nitrogen to barley seedlings, suggested that about 38% of the total fixed ammonium nitrogen and about 70% of the potassium hypobromite extractable nitrogen of the soil were available when grown under conditions of high plant density. The results of the present investigation thus find support from his work.

TABLE - 24G

Periodic changes in the amount (ppm) of KBr extractable nitrogen with the age of growing plants

(Mean of three replicates)

Treatments applied in the cropped 2nd experiment	Density of plant popula- tion	Days after sowing of seeds		
		20	35	50
Control	D ₁	88	88	68
	D ₂	117	98	68
Ammonium sulphate @ 60 kg N/ha	D ₁	117	107	98
	D ₂	137	127	68
Ammonium sulphate @ 300 kg N/ha	D ₁	107	107	78
	D ₂	107	78	68

D₁ = 28 plants per plot

D₂ = 68 plants per plot

SUMMARY AND CONCLUSION

In view of rapid increase in the use of nitrogenous fertilizers in agricultural soils, clay fixation of applied ammonium assumes importance of practical significance in the nitrogen transformation in high ammonium fixing soils. For efficient utilization of nitrogenous fertilizers, it is, therefore, necessary to understand the dynamics of fixed ammonium along with exchangeable ammonium and soluble nitrate in soils. The present investigation was, therefore, conducted to observe the effect of some important but less studied factors on fixation of ammonium in some soils of West Bengal. In all these experiments, periodic changes were simultaneously monitored for fixed ammonium, exchangeable ammonium and soluble nitrate forms of nitrogen in the soil. Results of these experiments revealed the following facts.

The amount of exchangeable ammonium increased with increase in the level of incubating soil moisture in the range from 50% of the moisture holding capacity to waterlogged state. In general, the highest amount of fixed ammonium was observed in waterlogged soil and least in the soil maintained at 50% of the moisture holding capacity. The amount of fixed ammonium tended to increase upto 10th day of incubation, thereafter the amount tended to decrease. The result suggested that a part of the mineralised ammonium was chemically fixed by the clay colloids.

• A short period of drying between uniformly maintained moisture conditions caused an increase in the amount of exchangeable NH_4^+ on remoistening the soil to predrying moisture level. This was observed not only under waterlogged condition but also in soils maintained at lower moisture levels. However, the net increase in the amount of mineral nitrogen due to drying was more in soils incubated at 50% of the moisture holding capacity and saturated state than under waterlogged condition. Upon drying, a general decrease in the amount of fixed ammonium nitrogen was observed in all the soils and at all moisture levels. It is suggested that a part of increase in the amount of mineral nitrogen was due to the release of fixed NH_4^+ - N in soil. Increased mineralisation of nitrogen due to drying also contributed to the said increase in the amount of mineral nitrogen in the soil. A short period of drying between different but uniformly maintained moisture conditions in soil therefore caused an increase in the amount of exchangeable ammonium accompanied by a general decrease in the amount of clay fixed ammonium from the native source of nitrogen. But, a general decrease in the amount of both the exchangeable and fixed NH_4^+ nitrogen was observed in the ammonium-N fertilized soil.

A considerable amount of the recently added ammonium nitrogen was incorporated during incubation in the clay fixed form in the soils. The percentage of added ammonium nitrogen (200 ppm) fixed by the soil was maximum under waterlogged condition (27.0% and 52.5% on 5th and 10th day of incubation)

and least at moisture levels equivalent to 50% of the moisture holding capacity (18.0% and 27.0% on 5th and 10th day of incubation). While there was a decrease in the amount of exchangeable NH_4^+ during the first 10 day period of incubation equivalent to 31.5, 62.5 and 56.0 per cent of the added nitrogen, there was an increase of clay fixed ammonium in the soil equivalent to 26.0, 26.0 and 51.5 per cent respectively. A possible transformation of the recently added ammonium nitrogen from the exchangeable to clay fixed form is suggested.

Irrespective of the moisture levels in which the ammoniated soils were incubated, distinctly higher amount of added ammonium was converted to fixed form in the soil which underwent two cycles of wetting and drying than one cycle prior to incubation. During the same period, higher amount of exchangeable ammonium was observed in the soil maintained at 50% of the moisture holding capacity which underwent two cycles of wetting and drying, whereas, under waterlogged condition it was noticed in the corresponding system which underwent one cycle of wetting and drying.

When the same amount of ammonium nitrogen (200 ppm) was added separately through four forms of N-fertilizers, the highest amount of ammonium fixation was observed in the ammonium dihydrogen phosphate treated soil and least in the ammonium sulphate added system. In general, the relative order of NH_4^+ fixation from

different types of ammonium fertilizers was found to be Ammonium dihydrogen Phosphate > Calcium ammonium nitrate > Urea > Ammonium sulphate.

Comparatively higher amount of clay fixed ammonium and lower amount of exchangeable ammonium were observed in the limed over the unlimed soil. Whereas, much lower amount of clay fixed ammonium was observed in the starch added limed than in the corresponding unlimed soil. Irrespective of liming, magnitude of fixed ammonium in the starch added soil was much less than either the rice straw treated or no organic matter added soil. In absence of added ammonium, no effect of added potassium was observed in either the limed or unlimed soil. But much lower amount of ammonium fixation was observed in both the limed and unlimed soil due to added potassium when simultaneously present with added ammonium.

Liming soils of acidic reaction caused a definite decrease in the amount of hydrolysable amino acid nitrogen in all the soils under investigation suggesting that this fraction of organic nitrogen is most susceptible to mineralisation. The amount of decrease in the organic forms of nitrogen of the soil was found to be closely associated with increase in the amount of mineral forms of nitrogen including fixed ammonium form. Experimental evidences led to the hypothesis that a considerable portion of the mineralised ammonium was converted to clay fixed form.

• Most of our knowledge on the availability of fixed NH_4^+ to crops was largely due to laboratory and green house oriented studies. Hence relevance to field situation was difficult to extrapolate. In order to study the effect of cropping on the release of native fixed NH_4^+ - N and availability of the recently fixed NH_4^+ in soils of West Bengal, three field experiments in succession were conducted in a field at Kalyani. Results of these experiments revealed the following facts.

The amount of exchangeable ammonium, soluble nitrate and fixed ammonium forms of nitrogen in the native unfertilized soil growing maize crop were significantly lower in the high density cropped plots than in the corresponding plots with low density planting. The amount of native fixed NH_4^+ in the soil tended to increase with increase in the period of crop growth due possibly to the fixation of a part of the recently mineralised ammonium nitrogen in the soil. Bacterial population of the rhizosphere soil of high density cropped plots, were also found to be significantly higher than the corresponding low density plots.

Irrespective of the levels of N-fertilization, the amount of fixed ammonium in the ammonium sulphate treated soil were found to be higher than those in the corresponding calcium nitrate added system. In the N-fertilized soil, higher amount of fixed ammonium was observed in the low density cropped plots. The recently fixed ammonium form of nitrogen was not found to be

available to meet the nitrogen requirement during the first 30 day period of crop growth. However, over the 60 day growing period, a considerable amount of the recently fixed ammonium was utilized by the maize crop planted at high density.

The residual effect of the different treatments shows a considerable utilization of clay fixed ammonium nitrogen by the maize crop in both the nitrate and ammonium fertilizer added soil. During the 50 day period of crop growth, much higher order of decrease in the amount of KBr extractable nitrogen occurred in the soil with high than low density planting. This fraction represent more labile forms of organic nitrogen and exchangeable ammonium present in the soil. Higher nitrogen uptake by plants grown in D_2 over D_1 density of cropping thus suggest that this fraction was considerably responsible for the supply of available nitrogen to crops.

FUTURE SCOPE OF RESEARCH

The results of the present laboratory and field studies have indicated that a substantial amount of recently mineralised ammonium get fixed in the soil. Besides, during incubation of soil, a considerable part of the recently fixed ammonium have possibly been converted to exchangeable form. Field studies indicated that a good portion of the recently fixed NH_4^+ was utilized by the growing crops. This led us to conclude that recently fixed ammonium may be considered as conservation against loss of the applied ammonium nitrogen from the soil.

Further work therefore is needed in the similar lines with more number of soils to establish the said hypothesis applying N^{15} labelled organic matter and $(\text{NH}_4)_2\text{SO}_4$ to soil. If crops of different root types are grown with and without the above treatments, the study shall furnish more conclusive evidences in support of the hypothesis.

These studies will, therefore, be of great practical significance in N-transformations in high NH_4^+ - fixing soils.

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APPENDIX

TABLE - I

Analysis of variance table for exchangeable ammonium content in soil on 30th day growth stage during 1st cropping.

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	9	14.45	1.605	0.38
Treatment	1	89.05	89.050	21.63*
Error	9	37.05	4.116	
Total	19	140.55		

* Significant at 5% level of significance

C.D. value at 5% level = 2.050

Treatment = Density of plant population.

TABLE - II

Analysis of variance table for exchangeable ammonium content in soil on 70th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	9	28.8	3.20	0.774
Treatment	1	207.2	207.20	50.133*
Error	9	37.2	4.13	
Total	19	237.2		

* Significant at 5% level of significance

C.D. value at 5% level = 2.053

Treatment = Density of plant population.

TABLE - III

Analysis of variance table for exchangeable ammonium content in soil on 95th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{calculated}
Replication	9	26.45	2.938	1.388
Treatment	1	315.05	315.050	148.889*
Error	9	19.05	2.116	
Total	19	360.55		

*Significant at 5% level of significance

C.D. value at 5% level 0 1.470

Treatment = Density of plant population

TABLE - IV

Analysis of variance table for soluble nitrate content in soil on 30th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{calculated}
Replication	9	31.25	3.472	1.344
Treatment	1	14.05	14.050	5.439*
Error	9	23.25	2.583	
Total	19	68.55		

* Significant at 5% level of significance

C.D. value at 5% level = 1.624

Treatment = Density of plant population.

TABLE - V

Analysis of variance table for soluble nitrate content in soil on 70th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^F calculated
Replication	9	22.05	2.45	0.982
Treatment	1	30.45	30.45	12.209*
Error	9	22.45	2.49	
Total	19	74.95		

* Significant at 5% level of significance

C.D. value at 5% level = 1.594

Treatment = Density of plant population

TABLE - VI

Analysis of variance table for soluble nitrate content in soil on 95th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^F calculated
Replication	9	20.0	2.20	1.22
Treatment	1	128.2	128.2	71.22*
Error	9	17.0	1.8	
Total	19	165.2		

* Significant at 5% level of significance

C.D. value at 5% level = 1.356

Treatment = Density of plant population.

TABLE - VII

Analysis of variance table for fixed ammonium content in soil on 30th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	56.8	6.311	1.502
Treatment	1	135.2	135.200	32.190*
Error	9	37.8	4.200	
Total	19	229.8		

* Significant at 5% level of significance

C.D. value at 5% level = 2.071

Treatment = Density of plant population

TABLE - VIII

Analysis of variance for fixed ammonium content in soil on 70th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	279.2	31.022	1.91
Treatment	1	231.2	231.200	14.27*
Error	9	145.8	16.200	
Total	19	656.2		

* Significant at 5% level of significance

C.D. value at 5% level = 4.042

Treatment = Density of plant population.

TABLE - IX

Analysis of variance for fixed ammonium content on 95th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	139.1	15.44	2.005
Treatment	1	26.5	26.50	3.440*
Error	9	70.0	7.70	
Total	19	182.6		

* Significant at 5% level of significance

C.D. value at 5% level = 2.804

Treatment = Density of plant population

TABLE - X

Analysis of variance for percentage of nitrogen in plant on 30th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	0.1340	0.0148	1.026
Treatment	1	0.1768	0.1768	11.946*
Error	9	0.1298	0.1442	
Total	19	0.4406		

* Significant at 5% level of significance

C.D. value at 5% level = 0.384

Treatment = Density of plant population.

TABLE ~~XI~~

Analysis of variance table for percentage of nitrogen in plant on 70th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{calculated}
Replication	9	0.0405	0.0045	0.5102
Treatment	1	0.1273	0.1273	14.4300*
Error	9	0.0794	0.0088	
Total	19	0.2472		

* Significant at 5% level of significance

C.D. value at 5% level = 0.095

Treatment = Density of plant population

TABLE-XII

Analysis of variance table for percentage of nitrogen in plant on 95th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{Calculated}
Replication	9	0.0288	0.0032	1.285
Treatment	1	0.0546	0.0546	21.927*
Error	9	0.0224	0.0024	
Total	19	0.1059		

*Significant at 5% level of significance

C.D. value at 5% level = 0.049

Treatment = Density of plant population.

TABLE - XIII

Analysis of variance table for dry matter yield per plant on 30th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	9	30.2114	3.3568	1.3673
Treatment	1	18.5059	18.5059	7.5380*
Error	9	22.0951	2.4550	
Total	19	70.8124		

* Significant at 5% level of significance

C.D. value at 5% level = 1.584

Treatment = Density of plant population.

TABLE - XIV

Analysis of variance table for dry matter yield per plant on 70th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	9	815.365	90.596	1.7142
Treatment	1	1248.245	1248.245	23.6191*
Error	9	475.640	52.848	
Total	19	2539.250		

* Significant at 5% level of significance

C.D. value at 5% level = 7.347

Treatment = Density of plant population.

TABLE - XV

Analysis of variance for dry matter yield for plant on 95th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	26.2676	2.8075	0.0675
Treatment	1	170.4106	170.4106	4.0988*
Error	9	374.1754	41.5750	
Total	19	374.1754		

* Significant at 5% level of significance

C.D. value at 5% level = 6.517

Treatment = Density of plant population

TABLE - XVI

Analysis of variance for plant uptake of nitrogen on 30th day growth stage during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	265.9419	29.5491	1.1831
Treatment	1	440.3911	440.3911	17.6321*
Error	9	224.7912	24.9768	
Total	19	931.1242		

* Significant at 5% level of significance

C.D. value at 5% level = 5.051

Treatment = Density of plant population.

TABLE - XVII

Analyses of variance table for plant uptake of nitrogen on 70th day growth stage during 1st cropping

Sources of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	274.0955	30.4550	0.921
Treatment	1	585.6568	585.6568	17.728*
Error	9	297.3169	33.0352	
Total	19	1157.0692		

*Significant at 5% level of significance

C.D. value at 5% level = 5.809

Treatment = Density of plant population

TABLE - XVIII

Analysis of variance table for plant uptake of nitrogen on 95th day growth stage during 1st cropping

Sources of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	9	25.2676	2.8075	0.0675
Treatment	1	170.4106	170.4106	4.0988*
Error	9	374.1754	41.5750	
Total	19	374.1754		

* Significant at 5% level of significance

C.D. value at 5% level = 6.517

Treatment = Density of plant population

TABLE - XIX

Analysis of variance table for microbial counts on 45th day stage of crop growth during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	3	3395.19	1131.73	1.765
Treatment	3	55161.69	18387.23	28.677*
Error	9	5770.56	641.17	
Total	15	64327.44		

* Significant at 5% level of significance

C.D. value at 5% level = 40.465

Treatment = Density of plant population and effect of rhizosphere.

TABLE - XX

Analysis of variance table for microbial counts on 75th day stage of crop growth during 1st cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	3	336.5	112.16	0.3048
Treatment	3	54134.5	18044.83	49.0508*
Error	9	3311.0	367.88	
Total	15	57782.0		

* Significant at 5% level of significance

C.D. value at 5% level = 30.651

Treatment = Density of plant population and effect of rhizosphere.

TABLE - XXI

Analysis of variance table for exchangeable ammonium content in soil on 30th day growth stage during 2nd cropping

Sources of variation	D.F.	S.S.	M.S.S.	F ^F calculated
Replication	2	1.87	0.935	0.035
Treatment	9	519.33	57.703	2.166*
Error	18	479.47	26.630	
Total	29	1000.67		

* Significant at 5% level of significance

C.D. value at 5% level = 8.848

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXII

Analysis of variance table for exchangeable ammonium content in soil on 60th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^F calculated
Replication	2	1.667	0.8335	0.1793
Treatment	9	153.333	17.0370	3.6653*
Error	18	83.667	4.6482	
Total	29	238.667		

* Significant at 5% level of significance

C.D. value at 5% level = 3.697

Treatment = Levels and forms of N-fertilizers and density of plant population.

TABLE - XXIII

Analysis of variance table for fixed ammonium content in soil on 30th day growth state during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	161.0	80.50	0.776
Treatment	9	37859.8	4206.64	40.055*
Error	18	1894.4	105.02	
Total	29	39911.2		

* Significant at 5% level of significance

C.D. value at 5% level = 17.571

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXIV

Analysis of variance table for fixed ammonium content in soil on 60th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	483.5	241.75	2.020
Treatment	9	29705.2	3300.57	27.583*
Error	18	2154.0	119.66	
Total	29	33222.7		

* Significant at 5% level of significance

C.D. value at 5% level = 18.756

Treatment = Levels and forms of N-fertilizers and density of plant population.

TABLE - XXV

Analysis of variance table for plant uptake of nitrogen on 30th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	512.94	256.47	2.43
Treatment	9	76529.57	8503.28	80.51*
Error	18	1901.26	105.62	
Total	29	78943.77		

* Significant at 5% level of significance

C.D. value at 5% level = 17.621

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXVI

Analysis of variance table for plant uptake of nitrogen on 50th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	86.47	43.235	0.220
Treatment	9	95737.03	10637.447	54.175*
Error	18	3534.38	196.354	
Total	29	99357.88		

* Significant at 5% level of significance

C.D. value at 5% level = 24.026

Treatment = Levels and forms of N-fertilizers and density of plant population.

TABLE - XXVII

Analysis of variance table for microbial counts of remote soil on 30th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	468.87	234.435	0.5409
Treatment	9	27792.53	3088.058	7.1258*
Error	18	7800.47	433.359	
Total	29	36061.87		

* Significant at 5% level of significance

C.D. value at 5% level = 35.694

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXVIII

Analysis of variance table for microbial counts of rhizosphere soil on 30th day growth stage during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	639.80	319.900	1.558
Treatment	9	29574.53	3286.058	16.008*
Error	18	3694.87	205.271	
Total	29	33909.20		

* Significant at 5% level of significance

C.D. value at 5% level = 24.566

Treatment = Levels and forms of N-fertilizers and density of plant population.

TABLE - XXIX

Analysis of variance table for microbial counts of remote soil on 65th day stage of crop growth during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{calculated}
Replication	2	22.87	11.4350	0.118
Treatment	9	216773.37	24085.93	248.717*
Error	18	1743.13	96.8405	
Total	29	218539.37		

* Significant at 5% level of significance

C.D. value at 5% level = 16.873

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXX

Analysis of variance table, for microbial counts of rhizosphere soil on 65th day stage of crop growth during 2nd cropping

Source of variation	D.F.	S.S.	M.S.S.	F ^{calculated}
Replication	2	387.30	193.65	0.6926
Treatment	9	183304.80	20367.20	72.8544*
Error	18	5032.10	279.56	
Total	29	188724.20		

* Significant at 5% level of significance

C.D. value at 5% level = 28.668

Treatment = Levels and forms of N-fertilizers and density of plant population.

TABLE - XXXI

Analysis of variance table for fixed ammonium content
on 20th day growth stage during 3rd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	554.8	277.4	1.905
Treatment	9	45965.1	5107.2	35.101*
Error	18	2620.6	145.5	
Total	29	49140.5		

* Significant at 5% level of significance

C.D. value at 5% level = 20.682

Treatment = Levels and forms of N-fertilizers and density
of plant population

TABLE - XXXII

Analysis of variance table for fixed ammonium content in
soil on 35th day growth stage during 3rd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	385.1	192.55	0.792
Treatment	9	45600.8	5066.75	20.853*
Error	18	4373.6	242.97	
Total	29	50359.5		

* Significant at 5% level of significance

C.D. value at 5% level = 26.726

Treatment = Levels and forms of N-fertilizers and density
of plant population.

(xxxx)

TABLE - XXXIII

Analysis of variance table for plant uptake of nitrogen
on 20th day growth stage during 3rd cropping

Sources of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	9.3331	4.6666	1.2482
Treatment	9	1637.3457	181.9273	48.6632*
Error	18	67.2939	3.7385	
Total	29	1713.9727		

* Significant at 5% level of significance

C.D. value at 5% level = 3.315 1.96

Treatment = Levels and forms of N-fertilizers and density
of plant population.

TABLE - XXXIV

Analysis of variance table for fixed ammonium content in soil
on 30th day growth stage during 3rd cropping

Source of variation	D.F.	S.S.	M.S.S.	F calculated
Replication	2	116.9	58.45	0.6592
Treatment	9	51752.8	5750.31	64.8653*
Error	18	1595.8	88.65	
Total	29	53465.5		

* Significant at 5% level of significance

C.D. value at 5% level = 16.144

Treatment = Levels and forms of N-fertilizers and density
of plant population.

TABLE - XXXV

Analysis of variance table for plant uptake of nitrogen on 35th day growth stage during 3rd cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	2	34.833	17.416	0.2742
Treatment	9	4428.692	492.076	7.7465*
Error	18	1143.397	63.522	
Total	29	5606.922		

* Significant at 5% level of significance

C.D. value at 5% level = 13.665 / 8.05

Treatment = Levels and forms of N-fertilizers and density of plant population

TABLE - XXXVI

Analysis of variance table for plant uptake of nitrogen on 50th day growth stage during 3rd cropping

Source of variation	D.F.	S.S.	M.S.S.	F ¹ calculated
Replication	2	5.939	2.9695	0.2117
Treatment	9	2328.266	258.696	18.4492*
Error	18	252.398	14.022	
Total	29	2586.603		

* Significant at 5% level of significance

C.D. value at 5% level = 6.421 / 3.78

Treatment = Levels and forms of N-fertilizers and density of plant population.