EFFECT OF PLACEMENT AND CONCENTRATION OF APPLIED NH₄⁺-N ON NITROGEN LOSS FROM FLOODED SOIL

K. R. REDDY AND W. H. PATRICK, JR.

Laboratory of Flooded Soils and Sediments, Agronomy Department, Louisiana Agricultural Experiment Station, Louisiana State University, Baton Rouge, Louisiana 70803

Received for publication January 13, 1976

ABSTRACT

The effect of placement and concentration of NH₄⁺-N in a flooded soil on nitrogen (N) loss was investigated under laboratory conditions. Applied ¹⁵ΝH⁺₄-N was rapidly lost from the soil system during a 4-month incubation period regardless of where NH₄⁺-N was applied in the soil column. Nitrogen loss was lower when N was placed in the anaerobic zone than where placed at the aerobic surface. Addition of rice straw decreased N loss where N was applied to the soil, but did not show any difference where N was applied to the overlying floodwater. Increasing the concentration of NH₄⁺-N in the soil increased the N loss and also the thickness of the aerobic soil layer. Measurement of N distribution in the soil column showed that increasing the amount of NH₄⁺-N applied in the anaerobic soil layer increased the accumulation of NO₃⁻-N in the aerobic layer; however, the total accumulation of NO₃⁻-N was very little as compared to the NH₄⁺-N disappearance.

INTRODUCTION

Applied NH₄⁺-N losses in flooded soils are affected by the presence of two distinct soil layers, a thin surface aerobic layer underlain by a thicker, anaerobic layer. Applied NH₄⁺-N fertilizer in a flooded soil undergoes nitrification in the aerobic soil layer and denitrification in the anaerobic soil layer (Pearsall 1950; Mitsui 1954; Patnaik 1965). The total amount of NH₄⁺-N lost from the soil, however, is greater than the amount of NH₄⁺-N present in the surface aerobic layer at any one time (Tusneem and Patrick, 1973; Broadbent and Tusneem, 1971; Yoshida and Padre, 1974; Patrick and DeLaune, 1972). The extra NH₄⁺-N lost from flooded soil is transported through ionic diffusion from the aerobic soil layer to the aerobic layer, where it undergoes nitrification and subsequent denitrification (Patrick and Reddy 1976; Reddy et al. 1976a). The movement of NH₄⁺-N, and consequently its loss, depends on such factors as the depth of placement and the magnitude of the NH₄⁺-N concentration gradient established across the aerobic and anaerobic soil layers. In addition to the concentration gradient of NH₄⁺-N across the aerobic-anaerobic layer, which governs the rate of movement of NH₄⁺-N to the aerobic layer, the loss of applied NH₄⁺-N depends on the thickness of the aerobic soil layer (Patrick and Gotch 1974; Patrick and Reddy 1976), the organic matter content (Tusneem and Patrick 1971), and the rates of nitrification and denitrification. Because of the absence of data, the present laboratory experiments were designed to study the effect of placement and concentration of NH₄⁺-N on loss from flooded soil. Another objective was to determine the effect of NH₄⁺-N on the thickness of the aerobic soil layer as measured by its redox potential profile.

MATERIALS AND METHODS

The soil used in this study was a Crowley silt loam sampled from the Rice Experiment Station, Crowley, Louisiana. The soil had a total carbon content of 0.70 percent and a total N content of 0.08 percent (NH₄⁺-N = 10 µg/g and NO₃⁻-N + NO₂⁻-N = 18 µg/g). The pH of the soil was 5.5. Air-dried samples were mixed thoroughly, ground to pass a 40-mesh sieve, and stored in tightly sealed glass containers. Labeled (NH₄)₂SO₄ (10.146 atom % ¹⁵Ν) was used as the N source and applied as described below in Experiment I. Labeled N was not used in Experiment II.
Experiment I: This experiment was designed to measure the loss of N from a flooded soil as influenced by placement of NH$_4^+$-N. The following treatments were used:

(A) NH$_4^+$-N applied uniformly throughout a 4-cm soil column
(B) NH$_4^+$-N applied to upper 1 cm of the soil column
(C) NH$_4^+$-N applied to lower 1 cm of the soil column
(D) NH$_4^+$-N applied to the overlying floodwater

To follow the fate of applied NH$_4^+$-N, labeled N was used at a rate of 100 μg/g of soil. To measure the effect of organic matter on N loss, this experiment was carried out with and without added rice straw. One-hundred grams of soil (oven-dry basis) was used for each treatment which gave a 4-cm column. An overlying floodwater depth of 2.0 cm was maintained throughout the incubation period. In treatment A, NH$_4^+$-N was uniformly mixed with the soil. In treatments B and C, NH$_4^+$-N was applied to only one-quarter of the soil column at a rate of 400 μg N/g of soil (which was equivalent to 100 μg N/g of soil on whole soil column basis). Finely ground rice straw at 0.2 percent concentration was uniformly mixed with the soil. Duplicate samples were incubated for periods of 0, 7, 15, 30, 60, 90, and 120 days at 30°C and analyzed for total and labeled N (in both organic and inorganic fractions). The thickness of the aerobic soil layer was measured for treatment A by slowly driving a platinum electrode through the soil column and recording redox potential (Patrick and DeLaune 1972).

Experiment II: This study was carried out to find the extent of NH$_4^+$-N loss at varying rates of NH$_4^+$-N application on a flooded soil and the effect of NH$_4^+$-N concentration on the development of the aerobic soil layer. Duplicate 100-g samples of soil containing 0, 100, 200, and 400 μg N/g of soil as (NH$_4$)$_2$SO$_4$ were weighed into wide-mouth bottles and incubated at 30°C under flooding for periods of 0, 7, 15, 30, 60, 90, and 120 days. Another set was incubated in polyvinyl chloride (PVC) cylinders after adding NH$_4^+$-N uniformly throughout the soil column for a period of 90 days to study the vertical distribution of applied NH$_4^+$-N. At the end of the incubation period the soil columns were sliced horizontally into 2-mm sections and analyzed for both NH$_4^+$-N and NO$_3^-$-N content.

The redox profile of the soil column was also measured.

Analytical methods

Inorganic N (NH$_4^+$ + NO$_3^-$) was extracted with 10 percent KCl (pH 2.5) and distilled over after adding MgO and Devarda alloy, using macro Kjeldahl distillation system. Organic N in the residue was determined by the Kjeldahl method (Bremner 1965a). The titrated samples were concentrated to approximately 1 mg N/ml and analyzed for labeled N using a Dupont Model 21-614 mass spectrometer with an isotope ratio attachment (Bremner 1965c). Where labeled N was not used, the samples were analyzed for extractable NH$_4^+$-N + NO$_3^-$-N only. Ammonium N in sectioned samples was analyzed by direct steam distillation (Bremner 1965b) and NO$_3^-$-N by the phenoldisulfonic acid method.

Results and Discussion

The recovery of applied N in Experiment I with no added rice straw is shown in Fig. 1. The labeled N fraction was determined in both organic and inorganic fractions, and the N unaccounted for was assumed to be lost from the system. A small portion of the added inorganic N was immobilized into the organic fraction and remained at a relatively constant value for all treatments during the entire incubation period. The disappearance of inorganic-N was very rapid for all the treatments. For the soil column in which NH$_4^+$-N was mixed throughout, the initial rate of loss was low, but rapid disappearance occurred during the latter part of incubation. The NH$_4^+$-N disappearance was probably due to two mechanisms: 1) NH$_4^+$-N already present in the aerobic soil layer was lost through nitrification and subsequent denitrification, and 2) the NH$_4^+$-N present in the anaerobic soil layer was lost as the result of several processes occurring in sequence, namely, NH$_4^+$-N diffusion from the anaerobic soil layer to the aerobic surface layer, NH$_4^+$-N oxidation (nitrification) in the aerobic soil layer, diffusion of NO$_3^-$-N from the aerobic soil layer down into the anaerobic soil layer, and denitrification of NO$_3^-$-N into gaseous end products such as N$_2$ and N$_2$O in the anaerobic soil layer (Patrick and Reddy 1976). No evidence of NH$_3$ volatilization was found.
Fig. 1. The distribution of labeled-N in various N fractions of a flooded soil, with no added rice straw as influenced by the placement of NH$_4^+$-N.

In treatment B where NH$_4^+$-N was applied to the upper 1-cm soil layer (which became the aerobic layer), initial N loss was greater than for other treatments. The NH$_4^+$-N probably underwent nitrification without having to diffuse from the underlying anaerobic layer to the aerobic layer and then underwent denitrification as the NO$_3^-$-N diffused downward into the anaerobic soil layer. Ammonium-N disappearance was rapid for treatment B during the first 90-day incubation period. When NH$_4^+$-N was applied to the lower 1 cm of the soil core (treatment C), the disappearance of NH$_4^+$-N showed a lag during the first 2 weeks of incubation, but later showed rapid disappearance like other treatments. The loss of N in this treatment was dependent on diffusion of NH$_4^+$-N to the aerobic layer because nitrification does not occur in the anaerobic soil layer (Alexander 1965). Flooded soil incubated under an anaerobic atmosphere showed no N loss from NH$_4^+$-N (Patrick and Tusneem 1972; Patrick and Reddy 1976). Even though the soil column used was only 4 cm long, the aerobic soil layer was not more than 1.5 cm thick at the end of the 120-day incubation period. For treatment D, where NH$_4^+$-N was applied to the overlying floodwater, there was a rapid loss of N due to direct nitrification of NH$_4^+$-N both in the aerobic floodwater and in the aerobic soil layer, followed by denitrification of NO$_3^-$-N in the anaerobic soil layer.

The effect of added rice straw on N loss was also studied using the same four methods of application of N to flooded soil. Addition of organic matter has been shown to immobilize part of the applied N in soils. Apparently because of this immobilization, the addition of rice straw decreased the magnitude of N loss (Fig. 2). The decrease in N loss was approximately the same as the increase in N immobilization. The amount of N lost was also dependent on the placement of NH$_4^+$-N in the soil column. The thickness of the surface aerobic soil layer was decreased considerably by the added rice straw because of greater demand for O$_2$ in the surface soil layers. Nitrogen loss was lowest in treatment C where N was applied to the lower 1 cm of soil. The low N loss in this treatment was due to the fact that NH$_4^+$-N was an appreciable distance away from the aerobic surface layer. Nitrogen loss was high when NH$_4^+$-N was applied to the overlying floodwater as was also the case where the rice straw was not used. When NH$_4^+$-N was mixed uniformly throughout the soil (with added rice straw), a considerable loss of 52 percent of ap-
applied N occurred as compared to 75 percent of applied N loss for the same treatment with no added rice straw. Net labeled N loss as a function of time is expressed as a quadratic equation in Table 1. The N disappearance was correlated with time elapsed during incubation and the Y values show highly significant relationships in all four treatments. Similar losses of applied fertilizer N can occur under flooded field conditions. Although subsurface placement results in less N loss than surface application, band placement and deep placement of NH₄⁺-N fertilizer create a concentration gradient that enhances the movement of NH₄⁺-N to the surface, resulting ultimately in the loss of N.

When nonlabeled N was applied at different rates uniformly throughout the soil column (Experiment II), similar trends in inorganic N disappearance were shown (Fig. 3). The total

![Figure 2](image)

**Fig. 2.** The distribution of labeled-N in various N fractions of a flooded soil with added rice straw, as influenced by the placement of NH₄⁺-N.

| TABLE 1 |
|-----------------|-----------------|-----------------|
| **Treatment** | **Without added rice straw** | **With added rice straw** |
| A. NH₄⁺-N applied uniformly through the soil | Y = -0.004t² + 1.92t + 5.44 | Y = -0.0014t² + 0.63t + 0.36 |
| | r = 0.982 | r = 0.964 |
| B. NH₄⁺-N applied to upper 1 cm soil layer | Y = -0.005t² + 1.22t + 3.48 | Y = -0.0015t² + 0.69t - 5.44 |
| | r = 0.999 | r = 0.996 |
| C. NH₄⁺-N applied to lower 1 cm soil layer | Y = -0.004t² + 1.15t - 9.86 | Y = -0.004t² + 0.48t - 1.04 |
| | r = 0.997 | r = 0.978 |
| D. NH₄⁺-N applied to overlying floodwater | Y = -0.009t² + 1.43t - 7.49 | Y = -0.0073t² + 1.51t - 10.01 |
| | r = 0.999 | r = 0.986 |

Where Y = net loss of labeled N in µg/g and t = elapsed time in days and is expressed by the equation Y = at² + bt + c. r = correlation coefficient.
inorganic N not recovered was directly proportional to the rate of N application (Fig. 4).

The vertical distribution of applied NH$_4^+$-N in the soil column at different rates of N is shown in Fig. 5 for the 90-day incubation period. Very little difference with depth was observed in the distribution of NH$_4^+$-N where no N was applied, but increased rates of NH$_4^+$-N application showed a depletion of NH$_4^+$-N in the surface layer. The NO$_3^-$-N concentration in the surface layer was maximum (25 µg NO$_3^-$-N/g), where 400 µg NH$_4^+$-N/g of soil was applied. As pointed out above, NH$_4^+$-N depletion and NO$_3^-$-N buildup in the surface layer are indicators of the processes that ultimately result in N loss by denitrification.

Increased rate of NH$_4^+$-N application also increased the thickness of the aerobic soil layer as

---

**Fig. 3.** The recovery of inorganic N, as influenced by the rate of NH$_4^+$-N application and incubation period in a flooded soil.

**Fig. 4.** The recovery of inorganic N, as influenced by rate of NH$_4^+$-N application at 90- and 120-day incubation period.

**Fig. 5.** The distribution of NH$_4^+$-N and NO$_3^-$-N in aerobic and anaerobic soil layers at 90-day incubation period, as influenced by rate of NH$_4^+$-N application to a flooded soil.
Fig. 6. The effect of N application on the thickness of aerobic soil layer after 90-day incubation period.

shown by the redox potential profile (Fig. 6). A redox potential of +300 is indicated as the transition point between aerobic and anaerobic conditions since several studies suggest that nitrate becomes unstable at about this potential (Pearsall 1938; Aomine 1962; Patrick 1960). Although the reason for high concentrations of NH$_4^+$-N increasing the thickness of the surface aerobic layer is not known with certainty, it is very likely due to the greater production of NO$_3^-$-N resulting from this NH$_4^+$-N and the effect of this NO$_3^-$-N diffusing downward into the flooded soil on redox potential. It was shown elsewhere (Reddy et al. 1975b) that NO$_3^-$-N is present in the aerobic zone, but cannot be detected in the underlying anaerobic zone. This same effect can be observed in Fig. 5 where NO$_3^-$-N was detected at a greater depth in the high NH$_4^+$-N treatments. The presence of NO$_3^-$-N in the surface soil layer oxidized Fe$^{+2}$ to Fe$^{+3}$ and increased the thickness of the reddish-brown aerobic layer. A greater depletion in available carbon in the surface layers probably increased the thickness of the aerobic layer.

CONCLUSIONS

Nitrogen loss from flooded soil was lower where NH$_4^+$-N was applied in the anaerobic soil layer, as compared to application in the surface aerobic layer. Addition of rice straw decreased N loss when NH$_4^+$-N was applied to the soil, but did not show any difference when NH$_4^+$-N was applied to the overlying floodwater. Increasing the concentration of NH$_4^+$-N in the soil increased the N loss and also increased the thickness of the aerobic soil layer. The thicker aerobic layer was apparently due to the NO$_3^-$-N produced from the NH$_4^+$-N.

REFERENCES