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# Effects of Fertilizer Placement and Nitrogen Forms on Soil Nitrogen Diffusion and Migration of Red-Yellow Soil in China

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## Abstract

A better understanding of nitrogen (N) diffusion and transformation in soils could reveal the capacity of the biological inorganic N and improve the efficiency of N fertilizers. A field micro-plot experiment was carried out to study the effects of fertilization methods (mixed uniformly with 12 cm top soil, placed in holes at a 12-cm depth, or placed in furrows at a 12-cm depth) and forms of N fertilizers (urea and ammonium phosphate) on the dynamics of soil N's vertical diffusion and horizontal migration in red-yellow soil. The soil inorganic N ($NH_4^+$-N and $NO_3^-$-N) content following point deep placement was greater than that from mixed or furrow applications. Under point placement, the migration of soil inorganic N in urea and ammonium phosphate treatments occurred in the 6 - 15 cm layer at a horizontal distance of 0 - 9 cm. However, the nutrient preservation capability of the soil receiving ammonium phosphate was greater than that receiving urea under point deep placement. Thus, point deep placement had a tendency to increase the inorganic N in the soil and reduce inorganic N loss, which probably occurred due to the reduced soil volume with which the N fertilizer was mixed. According to crop growth and fertilizer requirements, the optimized fertilizer placement and N species resulted in a continuously high nutrient supply to crops for 90 d. However, the effects of point deep placement on increasing the N-use efficiency and reducing N loss have to be evaluated under natural field conditions.

## Keywords

Fertilization Method, Nitrogen Fertilizer, Point Deep Placement, Migration, Transformation

## 1. Introduction

Inappropriate applications of nitrogen (N) fertilizer have led to low N-use efficiencies (NUEs) and great N losses [1] [2], and have caused environmental problems, such as groundwater and surface water contamination, greenhouse gas increases, and soil quality degradation [3] [4]. The movement and transformation of N fertilizers in soils significantly affects the N supply, NUE and N loss. Therefore, research has focused on the migration and transformation of N in soils after fertilization [5] [6] [7]. Wang and Hou [8] reported that the migration of urea in soil was closely related to soil properties (especially the clay content) and the amount of urea applied. Additionally, the migration of N from urea occurred in a less than 10-cm zone in calcareous soil. Zhang *et al.* [9] suggested that the migration and transformation of urea and ammonium sulfate mainly occurs in the 0 - 5 cm soil layer in a black soil column. Recently, a soil column experiment also found that the transfer and nitrification of $NH_4^+$-N and $NO_3^-$-N mainly occurs in the 0 - 15 cm and 0 - 50 cm layers, respectively, of black soil [10].

The migration and transformation of N in soil, and the NUE and N loss, were significantly different under different methods of fertilization. An optimum fertilization model can reduce N loss, and increase crop yield and the NUE [11] [12] [13]. Rees *et al.* [11] indicated that $NH_4^+$-N and $NO_3^-$-N concentrations in the point-placement (hole–source fertilization) application were significant greater than in the corresponding surface-application and mixed-incorporation treatments. Wang *et al.* [14] found that point deep placement can reduce the N fertilizer loss and improve the NUE. The $NH_4^+$-N was mainly distributed around fertilizer micro-regions and decreased as the distance increased from the point of fertilization [15]. Point deep fertilization can reduce inorganic N losses compared with mixed and broadcast fertilization [6]. Compared with the surface broadcast, the deep placement of N fertilizers (8 - 10 cm) can enhance the NUE [16], cause roots to grow down [13], and increase crop yields [12].

To improve the NUE and reduce N loss, previous studies have primarily focused on the application of the right source (or product) at the right rate, right time and right place (four rights, 4R). Based on previous studies, Wang and Zhou [17] recently indicated that the optimal fertilizer placement coordinates its migration with plant root' extension, improving the fertilizer-use efficiency and reducing non-point source pollution in the field. Understanding the migratory abilities and scopes of fertilizer nutrients is the foundation for realizing the coordination of fertilizer migration and root extension. Therefore, it is critically important to understand the characteristics of N migration to reduce the amount of N fertilizer used and increase the NUE. In the present study, a field micro-plot experiment was initiated to determine the effects of fertilization methods and forms of N fertilizers on N diffusion and migration in red-yellow soil.

## 2. Materials and Methods

### 2.1. Site Description

The field experiment was conducted at Dongzhi county (30˚17'N, 117˚4'E) of Chizhou city, in southern Anhui province, China (**Figure 1**). The soil at the experimental sites was classified as a red-yellow soil in the Chinese classification system (Chinese Academy of Sciences, 2001). The topsoil (0 - 20 cm) has a pH of 5.7, an organic matter content of 17.03 g/kg, a total N content of 760 mg/kg and an available N content of 76.9 mg/kg.

### 2.2. Experimental Treatment and Implementation

The experiment was designed as a split-plot experiment with fertilizer method as the main plot and N fertilizer form as the split-plot, with three replicates. The fertilizer methods included mixed uniformly with 12 cm top soil (mixed application), point placement in holes at a depth of 12 cm (point deep placement), and placed in furrows at 12-cm depths (furrow application). The fertilizers in both the point deep placement and the furrow application treatments were covered with soil and pressed slightly. The two forms of N fertilizer were urea (46% N) and ammonium phosphate (21.2% N).

The N-fertilizer rate was 180 kg/ha, which is typical of the farmer's practice in this region. Each microplot measured 140 × 120 cm. As usual, the maize was planted with an inter-row spacing of 60 cm and an intra-row spacing of 28 cm (60,000 plant/ha) in this region. Thus, for the mixed application, the amounts of urea and ammonium phosphate in each microplot were 65.2 g and 141.5 g, respectively. For the point deep placement, the microplot was divided into 10 points


**Figure 1.** Location of the experimental site at Dongzhi county of Chizhou city.

sing a 60 × 28 cm spacing, and the amounts of urea and ammonium phosphate in each point were 6.52 g and 14.15 g, respectively. For the furrow application, the fertilizers were equally applied in two 140-cm furrows with a space of 60 cm, and the amounts of urea and ammonium phosphate in each furrow were 32.6 g and 70.75 g, respectively. During the experiment, no crops were planted, there was no irrigation supplied, and the weeds were removed from the plot. The monthly mean rainfall during the experimental period was 365.5, 259.1 and 137.4 mm for June, July and August in 2015, respectively.

### 2.3. Sample Collection and Measurement

The topsoil (0 - 20 cm) samples were collect in each microplot before fertilization. At 30, 60 and 90 d after fertilizer application, the soil cores were taken from the placement using a fertilizer soil sampler with a 3-cm diameter, to a depth of 21 cm and divided into 0 - 3, 3 - 6, 6 - 9, 9 - 12, 12 - 15, 15 - 18 and 18 - 21-cm sections. At the same time, for the point deep placement and furrow-application treatments, the topsoil (0 - 21 cm) samples were also collected to an 18-cm horizontal distance away from the fertilization point, and divided into 0 - 3, 3 - 5, 5 - 7, 7 - 9, 9 - 12, 12 - 15 and 15 - 18-cm sections.

Soil samples were extracted by using 2 M KCl, and the ammonium N ( $NH_4^+$-N ) and nitrate N ( $NO_3^-$-N ) were determined using an automated discrete analyzer (Smart Chem 200, AMS/Westco, Italy) as described by Ling *et al.* [6].

### 2.4. Statistical Analysis

The statistical analysis was carried out using SPSS 19.0 statistical software (SPSS, Inc., Chicago, IL, USA), and data were presented as the mean ± SE. All of the experiments included three replicates.

## 3. Results

### 3.1. Soil $NH_4^+$-N Content for Different Fertilization Methods

The $NH_4^+$-N content in different soil layers for all treatments during the experimental period is shown in **Figure 2**. During the mixed application and furrow application, $NH_4^+$-N levels in soil were lower than 30 mg/kg, and decreased as the soil depth increased. As expected, point deep placement resulted in a greater $NH_4^+$-N content in the soil than that of the mixed and furrow applications, particularly at 30 and 60 d after the treatment. Although the $NH_4^+$-N contents in the point deep placement layers decreased gradually during the treatment, in the 9 - 12-cm layer, the $NH_4^+$-N content in the soil was 472, 142 and 21 mg/kg on 30, 60 and 90 d, respectively. These values were greater than those of the mixed and furrow applications.

For the horizontal migration of N, throughout the experiment, the soil $NH_4^+$-N content of the point deep placement application was greater than that of the furrow application within 9 cm of the fertilizer placement site (**Figure 3**).

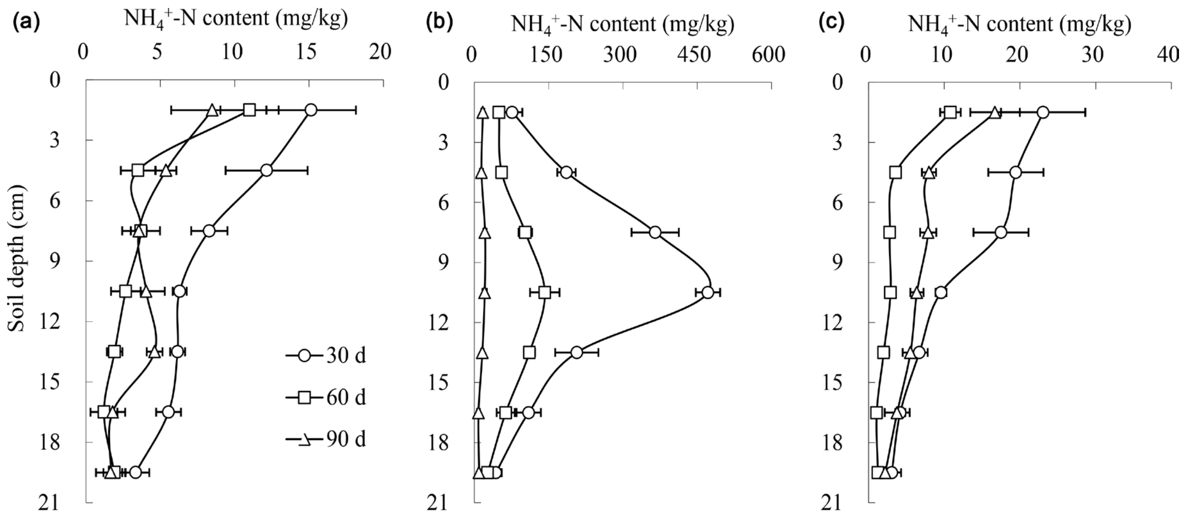


**Figure 2.** Dynamic changes of soil $NH_4^+$-N content under different fertilization methods (vertical direction). (a) mixed uniformly with 12 cm top soil (mixed application), (b) placed in holes at 12-cm depth (point deep placement), (c) placed in furrows at 12-cm depth (furrow application).

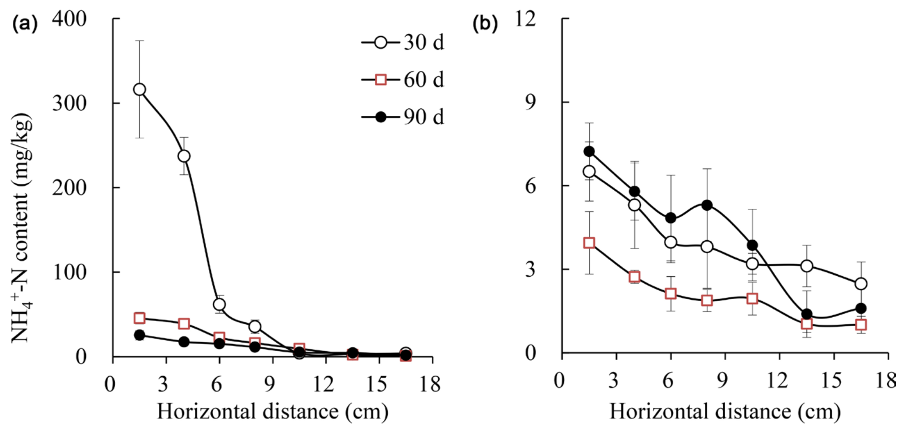


**Figure 3.** Dynamic changes of soil $NH_4^+$-N content under different fertilization methods (horizontal direction). (a) placed in holes at 12-cm depth (point deep placement), (b) placed in furrows at 12-cm depth (furrow application).

The soil $NH_4^+$-N content of point deep placement application at 7 - 9 cm from the fertilizer placement site was 8.3, 7.6 and 1.1 times greater than that of the furrow application on 30, 60 and 90 d, respectively. The differences in the soil $NH_4^+$-N content between the point deep placement and furrow applications increased as the distance from fertilizer placement site decreased. The migration (horizontal distance) of urea in the point deep placement was ~7 - 9 cm, and the soil $NH_4^+$-N content was mainly concentrated in the 3 - 18-cm layer.

## 3.2. Soil $NO_3^-$-N Content for Different Fertilization Methods

Throughout the study period, the soil $NO_3^-$-N contents in different layers were greater in the point deep placement application than in the mixed and furrow applications (**Figure 4**). In all of the treatments, the soil $NO_3^-$-N content was greatest in the 0 - 3 cm layer at 30 d and 60 d, and decreased as the soil depth increased. However, the soil $NO_3^-$-N content was greatest in the 3 - 6-cm layer at 90 d in all of the treatments. For the point deep placement, the soil $NO_3^-$-N content was higher in the 0 - 9-cm layer than at the fertilization point (9 - 12-cm layer). Thus, the soil $NO_3^-$-N content had a tendency to migrate to the soil surface during the treatment.

For the horizontal distance, the soil $NO_3^-$-N content was greater in the point deep placement than in the furrow application within 12 cm from the fertilizer placement site during the 90 d of treatment (Figure 5). The migration (horizontal distance) of urea from the point deep placement was ~10 cm, and the soil $NO_3^-$-N content sharply decreased from 0 cm to 18 cm away from the fertilizer placement site.

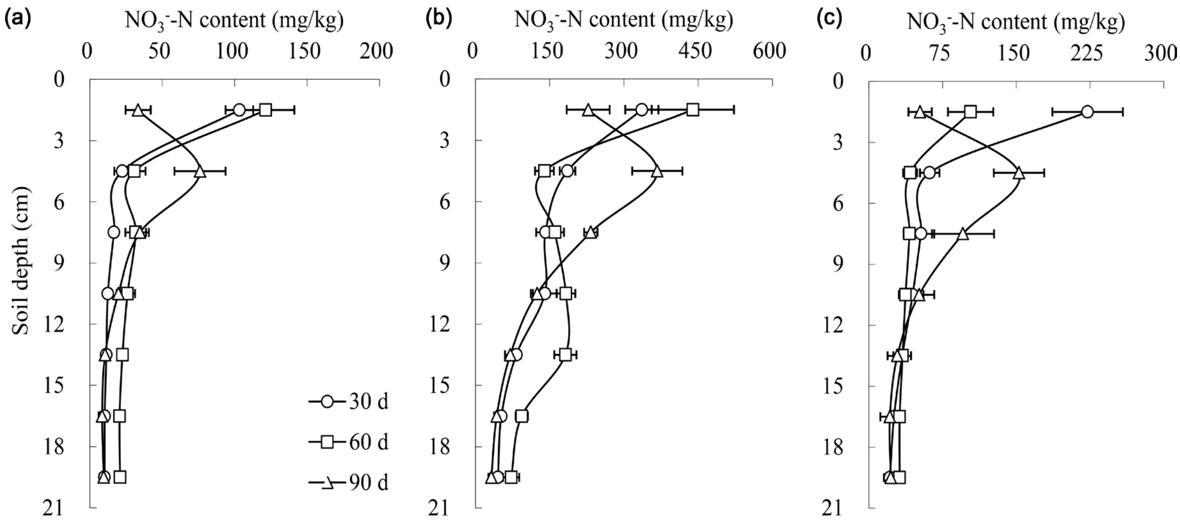


**Figure 4.** Dynamic changes of soil $NO_3^-$-N content under different fertilization methods (vertical direction). (a) mixed uniformly with 12 cm top soil (mixed application), (b) placed in holes at 12-cm depth (point deep placement), (c) placed in furrows at 12-cm depth (furrow application).

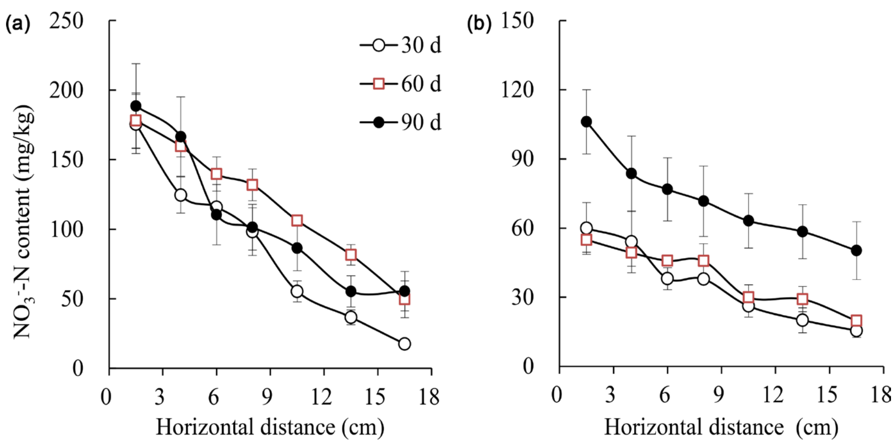


**Figure 5.** Dynamic changes in the soil $NO_3^-$-N content under different fertilization methods (horizontal direction). (a) placed in holes at 12-cm depth (point deep placement), (b) placed in furrows at 12-cm depth (furrow application).

### 3.3. Soil inorganic N Content for Different N Forms in the Point Deep Placement

Under the point deep placement conditions, the soil inorganic N ( $NH_4^+$-N + $NO_3^-$-N ) content near the fertilization point (9 - 18 cm layer) was greater with the ammonium phosphate treatment than with the urea treatment (Figure 6). However, the inorganic N levels were greater in the topsoil (0 - 3 cm) with the urea treatment than with the ammonium phosphate treatment at both 60 d and 90 d. As expected, on 30 d, the greatest inorganic N content was observed at the fertilization point (9 - 12 cm layer) for both the urea and ammonium phosphate treatments (612 and 779 mg/kg, respectively). Conversely, on 90 d, the inorganic N levels were greatest in the 3 - 6 cm layer for both urea and ammonium phosphate treatments (382 and 329 mg/kg, respectively), and decreased as soil profile's depth increased.

For horizontal distance, the inorganic N content was greater with the ammonium phosphate treatment than with the urea treatment within 6 cm of the fertilizer placement site (Figure 7). However, the gap in the inorganic N content between the ammonium phosphate and urea treatments decreased as the horizontal distance increased, and the inorganic N levels at 15 - 18 cm away from the fertilization site were similar in the two treatments (57 and 59 mg/kg urea and ammonium phosphate, respectively).

## 4. Discussion

In the present study, the soil inorganic N content was strongly affected by the N application method. The soil $NH_4^+$-N and $NO_3^-$-N contents with the point deep placement application were greater than those of the mixed and furrow applications, and the difference in the soil inorganic N content between the point deep placement and the mixed or the application was more apparent in the 6 - 15

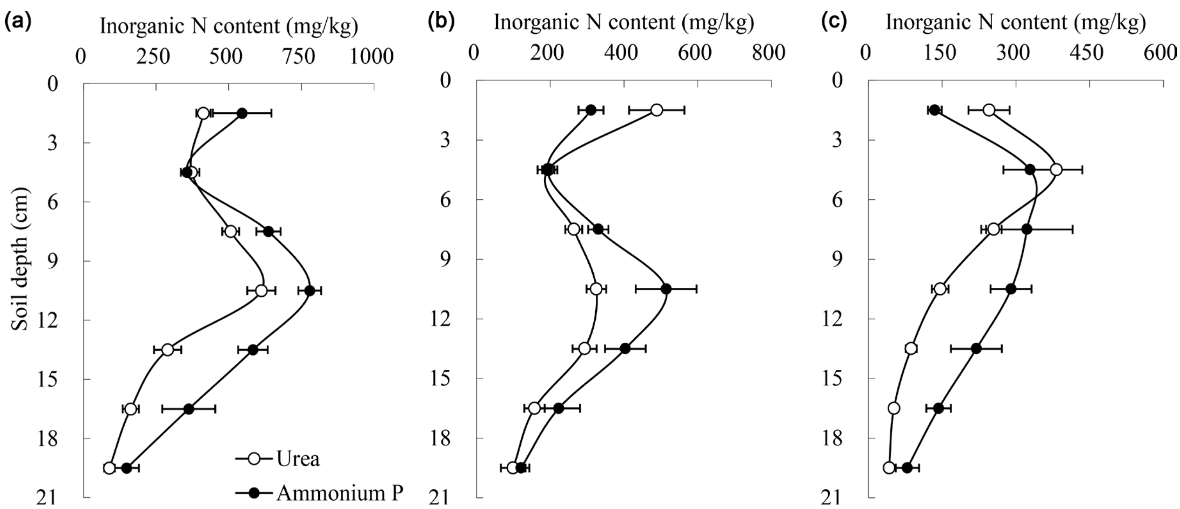


Figure 6. Effects of different nitrogen (N) fertilizers on inorganic N ( $NH_4^+$-N + $NO_3^-$-N ) contents in soils after a point deep placement (vertical direction) treatment. (a) 30 d, (b) 60 d and (c) 90 d.

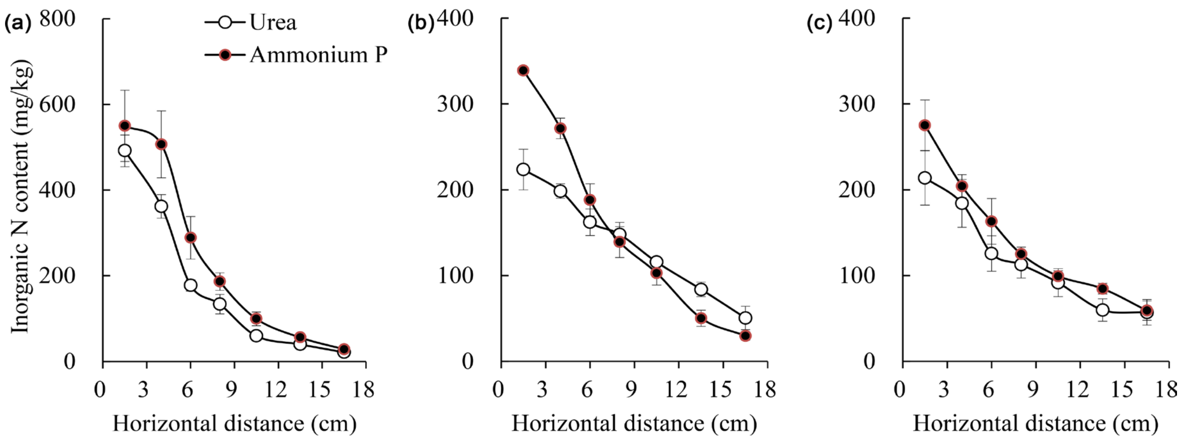


**Figure 7.** Effects of different nitrogen (N) fertilizers on the inorganic N ( $NH_4^+$-N + $NO_3^-$-N ) contents in soils after a point deep placement (horizontal direction) treatment. (a) 30 d, (b) 60 d and (c) 90 d.

layers and the horizontal distance of 0 - 9 cm. Similarly, Ling *et al.* [6] found that the inorganic N concentration in the 6 - 16 cm layers of paddy soil showed the following sequence: point deep fertilization > mixed fertilization with 3% soil > mixed fertilization with 10-cm top soil > broadcast. Rees *et al.* [11] showed that the mineral nitrogen ( $NH_4^+$-N + $NO_3^-$-N ) contents in soil of point deep placement applications were much greater than those of surface applications. Cheng *et al.* [15] found that $NH_4^+$-N was mainly distributed around the film hole and decreased as the distance from film hole increased after film hole irrigation with urea solution. The greater concentration of soil inorganic N in the point deep placement was probably due to the decrease in the initial soil volume with which the N fertilizers were mixed [6]. This is shown by the greater yields and NUEs after large particles of urea were applied compared with small particles of urea in rice field experiments [18]. Moreover, under the point deep placement application, the urea was buried beneath the soil and the ammonia volatilization occurred at a much slower rate than that in the mixed or furrow application [19] [20]. Recently, our research group found that N fertilizer applied in bands increased grain yields by 15% compared with a broadcast application, and the banded placement of N fertilizer decreased the N loss in the wheat-soil system [21]. Thus, the smaller the initial soil volume with which the N fertilizers were mixed, the greater the inorganic N content achieved in the soil and the less inorganic N was lost.

The migration and transformation of N fertilizer were significantly affected by fertilization methods, which resulted in different levels of N nutrients in the soil profile. In this study, the topsoil (0 - 6 cm) had more $NO_3^-$-N than the deeper (9 - 21 cm) soil layer, and the soil $NO_3^-$-N content decreased as the soil depth increased within 21 cm during the 60 days after fertilization. Even at 90 days after treatment, the $NO_3^-$-N contents in the 0 - 6 cm layers were still at high levels. The $NO_3^-$-N levels were greater in topsoil than in the deeper soil layer possibly because the N fertilizer had a tendency to migrate to the soil surface.

During the dry season, the soil water evaporation was greater than the rainfall (data not shown), and the soil water in the deep layer moved to the surface easier. Therefore, the N fertilizer was likely to be carried to the soil surface by the soil water. In addition, the migratory ability of $NH_4^+$-N in soil following a point deep placement was weaker than that of $NO_3^-$-N, whereas there was a sharper reduction in $NH_4^+$-N than in $NO_3^-$-N. Jarvis *et al.* [22] showed that the water potential in the soil may reduce mineralization and $NH_4^+$-N levels because of the limitations of biological activities. Here, the low soil water content may limit solute diffusion and the transportation of N fertilizer, particularly for $NH_4^+$-N. Similar observations have been found in previous studies [23]. Higher levels of $NH_4^+$-N and $NO_3^-$-N 90 days after the point deep placement application can provide the N nutrients needed during the growth periods of most crops. Thus, a continuously high concentration of nutrients for crops could be supplied by optimizing fertilizer placement.

N migration and transformation vary with fertilizer type, which will result in different impacts on the soil inorganic N content. Under point deep placement, the migration of soil inorganic N in urea and ammonium phosphate treatments occurred in the 6 - 15-cm layers and the horizontal distance of 0 - 9 cm. The soil inorganic N had a tendency to migrate to the soil surface during the treatment. For example, the highest soil inorganic N content was observed in the 3 - 6-cm layer for both urea (382 mg/kg) and ammonium phosphate (329 mg/kg) treatments at 90 d. Thus, the migratory distances of both urea and ammonium phosphate were ~6 cm and 9 cm in the vertical and horizontal directions, respectively, within 90 d. According to Zhang *et al.* [9], the migration and transformation of N mainly occur in the 0 - 5-cm soil layer, and the N transformation rate of urea is greater than that of ammonium sulfate. However, Wang and Hou [8] observed that the migration of urea in Fluvo-aquic soils was ~10 cm from the fertilizer placement site, and the migratory distance of urea was strongly related to the soil properties (especially the clay content) and fertilizer rates. Similarly, the migratory distances of urea and ammonium phosphate with a point deep placement were mainly within 10 cm, and the horizontal movement distance from the fertilizer site was ~5 - 7 cm after 90 d.

In addition, the soil inorganic N content was greater with the ammonium phosphate treatment than with the urea treatment, except for the topsoil (0 - 6 cm layer), especially in 9 - 15 cm layer. The soil inorganic N content of the ammonium phosphate treatment was significant greater than that of the urea treatment at 30, 60 and 90 d. Thus, ammonium phosphate had a greater capacity than urea to maintain a high inorganic N content in soil under point deep placement. A possible explanation for the lower inorganic N content following urea applications is that urea may be quickly converted to ammonium N after being applied to the soil, leading to an increase in $NH_3$ volatilization [8]. However, Ling *et al.* [6] observed no significant difference in the nutrient-retaining property between urea and ammonium phosphate treatments in paddy soil. This may be related to a high soil water content because in flooded paddy soil not only can the $NH_4^+$-N penetrate deeply into the soil by mass flow [24], but $NH_4^+$-N may also be lost by $NH_3$ volatilization [25]. Xiao *et al.* [25] found that in paddy fields the total amount of $NH_3$ volatilization ranged from 31.67 to 69.70 kg/ha in the whole growth period, accounting for 17.95% - 28.64% of applied N. In contrast, in the present study, ammonium phosphate was buried in the dry land, most of the ammonia-based N was trapped in the soil, and less ammonia escaped to the atmosphere than in the flooded paddy soil. Thus, the higher soil inorganic N content was maintained. With the point deep placement application method, the urea and ammonium phosphate were buried beneath the soil, and ammonia volatilization occurred at a much slower rate than in the mixed and furrow applications [20]. Thus, fertilizer placement is an important way to improve the nutrient preserving capability of soil.

## 5. Conclusion

Under point deep placement (placed in holes at a 12-cm depth), the migration of soil inorganic N in urea and ammonium phosphate treatments occurred in the 6 - 15 cm layer at a horizontal distance of 0 - 9 cm. The nutrient preservation capability of soil treated with ammonium phosphate was greater than that treated with urea. The point deep placement of N fertilizer helped to increase the $NH_4^+$-N and $NO_3^-$-N contents in red-yellow soil, suggesting that point deep placement had a tendency to increase inorganic N in soil and reduce inorganic N loss probably due to the reduced initial volume of the soil with which the fertilizer N was mixed. Based on crop growth and fertilizer requirements, a single basal application could supply a continuously high concentration of nutrients to the crop for 90 days through the optimization of the fertilizer placement and N species.

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