Fates of ^{15}N-urea in black soil – maize system and their response to straw incorporation in northeast China: a case study

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Abstract
A better understanding of the fates of fertilizer N is critical to design appropriate N management strategies in intensively cultivated croplands. In this study, we evaluated the fates of ^{15}N-urea in a field experiment on a black soil-maize system and their responses to straw incorporation in *Gongzhuling*, Northeast China. In order to get realistic results, we adopted the field management used by local farmers. Results showed that the crop N uptake was the main sink, recovering 52-53 % of the fertilizer N. Total ^{15}N recoveries in plant organs followed the order: grain (27-29%) > leaf (11-12%) > stem (6%) > tassel, silks, leaf sheath, husks, etc. (5%) > root (2%) > cob (1%). Tracer N remaining in soil was the second largest sink (25-33%), and most (18-29%) was located in the ridge 0-20 cm layer (fertilized area). The total loss of fertilizer N was 13-23%. Straw incorporation increased the retention of applied fertilizer N and decreased its losses, although there was no significant difference in plant N uptake. The contribution of fertilizer N to total N uptake was 36-37% at the physiological maturity stage of maize. Fertilizer N was an important N source for maize growth but soil N was still the main N source. Our results indicate that Nitrogen Use Efficiency (NUE) in maize cultivation system in northeast China is not as low as that reported by many previous studies using difference or balance method. Considering the low NUE in China, our next aim is to find out which region, and which kinds of crops lowered the overall NUE in Northeast China.

Key words
Isotopic ^{15}N labelling, fertilizer N, field experiment, transportation, allocation

Introduction

The nitrogen (N) from fertilizers has three main fates: uptake by crops, retention in soil and losses as nitrogenous gas and migration. Industrial agriculture has profoundly altered the earth's biogeochemical nitrogen cycle. Though N is the element most often limiting to crop productivity, excess N in ecosystems has far-reaching consequences for the environment and human health (Galloway, 2008; Ju et al., 2009). Previous studies showed that the Nitrogen Use Efficiency (NUE) in China is only 20-35%, and more than 50% of fertilizer N was lost into the environment (Zhu and Chen, 2002; Zhang et al., 2008).

There are several sinks for the N added or cycling in agrosystems. Crop absorption, the objective of fertilization, is just one of them but not always the most important. Nitrogen recovery from fertilizers depends on the crop, environmental conditions and cropping technology. Labeled fertilizer has been used to quantify the fate of plant nutrients in different soil/plant compartments (Stevens et al. 2005). The ^{15}N isotope gives a direct method to quantify the nutrients coming from the fertilizer that are located in different plant organs (Schindler and Knighton 1999, Rimski-Korsakov et al., 2012). This technique has been widely used to study the fate of fertilizers and there are several studies addressing the issue of the plant recovery of N from fertilizers. However, studies involving the fates of fertilizer nitrogen in all possible compartments and multi-sampling stages in one season are still less common. It is also uncommon to discriminate the N recovery in all aerial organs or roots (Rimski-Korsakov et al., 2012; Liu et al., 2015).

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Maize (*Zea mays L.*) is widely cultivated throughout the world, and it is also the staple crop in northeast China, and plays an important role for food security in China. A better understanding of the fate of fertilizer nitrogen (N) in soil-maize system is critical to design appropriate N management strategies. Several authors have found average recoveries of N in maize ranging from 28 to 57% (Reddy and Reddy, 1993; Schindler and Knighton, 1999; Stevens et al., 2005). Within this figure, grains are usually the main sink of the fertilizer N, since they accumulate an average of 24% of the N applied. The lowest recovery percentages have been found when some stress (like drought or high temperatures) occurs and crops can't reach their productive potential (Macdonald et al. 1997; Stevens et al. 2005). But about its response to straw incorporation, there was still less studies conducted.

In this study, we evaluated the fates of urea N in a black soil-maize system and their responses to straw incorporation using ^{15}N tracer in *Gongzhuling*, northeast China. We adopted the field management used by local farmers (furrow-ridge cultivation and fertilizer placed in the ridge as a basal dressing before sowing), but a bigger plot area (25 m^2) and lower ^{15}N atom abundance (1.2%) than that in previous studies, to facilitate multi-sampling stages in one season and to get more realistic results. We hope that our results provide valuable guidance for field nitrogen management to farmers in this region.

Methods

The experiment was conducted in a field with long-term maize cultivation in Jilin academy of agricultural sciences (43°30'N, 124°48'E). This site located in the biggest black soil region, and also the main corn production base in China. This site belongs to the temperate semi-humid continental monsoon climate. Average annual temperature here is 3-6 ℃, annual precipitation is 450-650 mm, and frost-free period is 120-150 days.

The experiment was arranged in a randomized design as three treatments with four replicates in April 2015 (Fig. 1). Three treatments were set up according to the application of urea N and straw: 1) **Control**, without N application; 2) **N**, applying urea-N, 200 kg N ha^{-1}; 3) **NS**, applying urea-N and straw, 200 kg urea-N ha^{-1} and 2400 kg straw ha^{-1}. Plant biomass, N concentration and related ^{15}N abundance in plant organ samples (root, stem, leaf, cob, grain, other) were determined at twelve leaves (day 68), tasselling (day 94), dough (day 131) stages and at physiological maturity (day 154). Bulk density, N concentration and related ^{15}N abundance were determined at the four stages too, in soil samples (ridge 0-10, 10-20, 20-30, 30-40 cm and furrow 0-10, 10-20 cm).

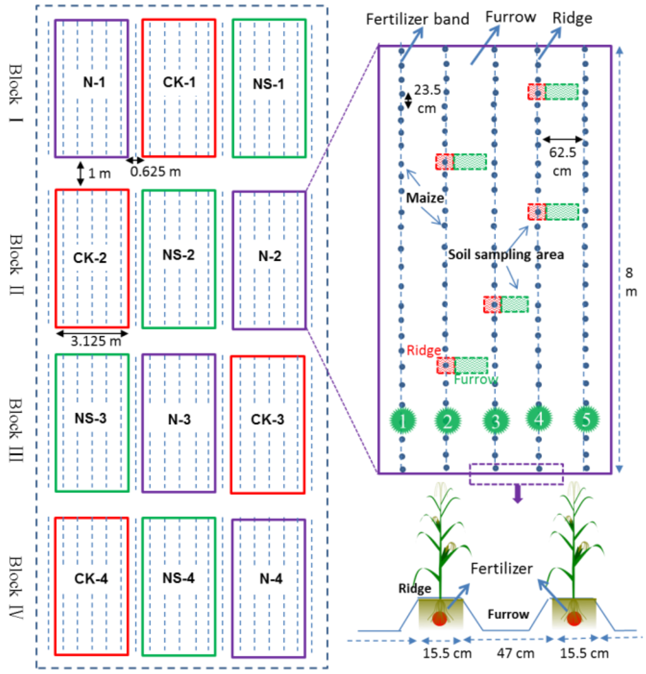

Fig. 1 Field arrangement and diagram showing the ridge-furrow cropping system, as well as the sampling area in the plot.

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Results

Total N uptake increased with time and shifted from vegetative to reproductive growth (Fig. 2). Nitrogen was rapidly assimilated by stem and leaf at the early stage of the cultivation, while the absorbed N was mainly transferred to grain at the late stage. At the harvest, total uptakes of N by maize were 214, 280, 299 kg N ha^{-1} for the control, N and NS treatments, respectively.

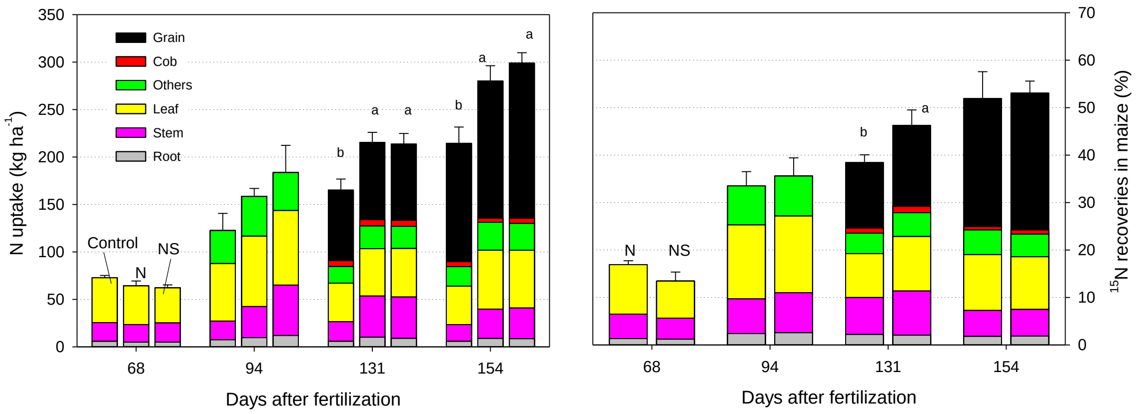

Fig. 2 Dynamics of N uptake and ^{15}N recoveries in different organs of maize at four sampling periods during the cultivation.

Plant uptake was the main sink of ^{15}N at physiological maturity stage and 52-53 % of the fertilizer N was recovered (Fig. 3). Tracer ^{15} remaining in the soil was the second largest sink (25-33%). Total ^{15}N recoveries in plant organs were in the order: grain (27-29%) > leaf (11-12%) > stem (6%) > other (5%) > root (2%) > cob (1%), and the losses was 13-23%. Most of ^{15}N remaining in soil (72-78%) was located in the ridge 0-20 cm layer. Straw incorporation increased the retention of applied fertilizer N and decreased its losses, although there was no significant difference in plant N uptake.

The contribution of fertilizer N to total N uptake was 36-37% at the physiological maturity stage of maize (Fig. 4), suggesting fertilizer N is an important N source for maize. Separating the total growth time to three periods, the proportions of them during day 0-68, day 68-94, day 94-154 were 43-53%, 35-36%, 30-31% (Fig. 5). Soil native N (deep N or newly mineralized N in the soil) was still the main N source, and it became more and more important along with the maize growing, especially at the late stages of crop development.

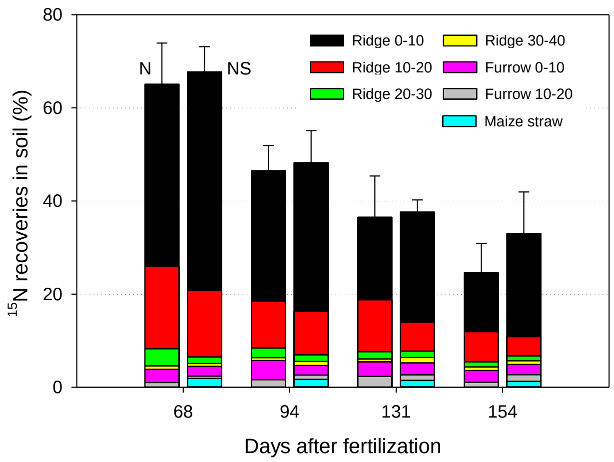

Fig. 3 Dynamics of ^{15}N recoveries in different layer of soil in ridge and furrow at four sampling periods during the cultivation.

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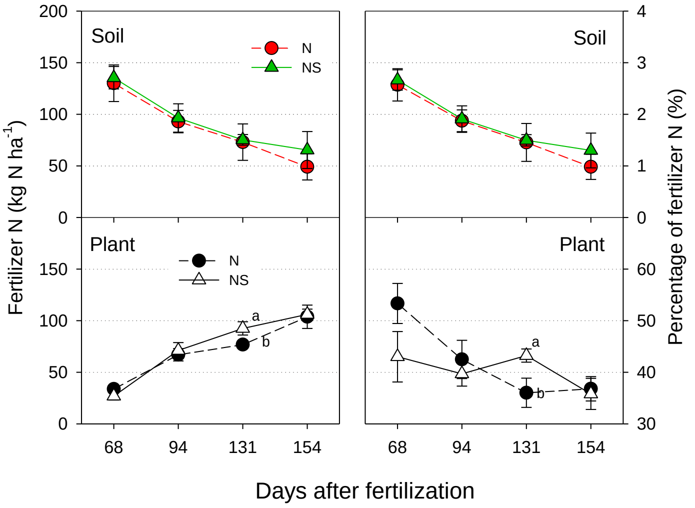

Fig. 4 Amounts of fertilizer-derived N and its proportions in soil and plant pools at four sampling periods during the cultivation.

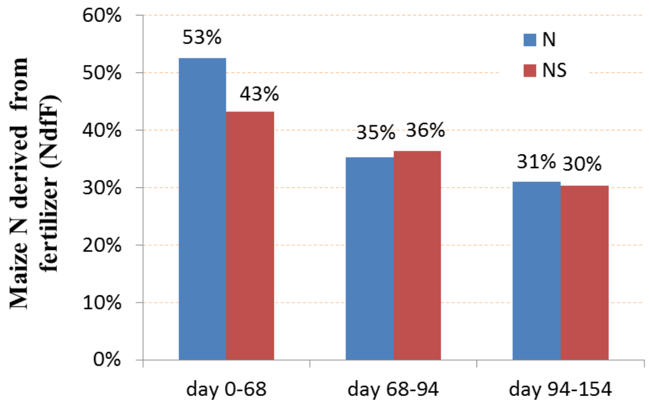

Fig. 5 Proportions of maize absorbed-N derived from fertilizer at three periods of time during the cultivation.

Conclusion

Straw incorporation increased the retention of applied fertilizer N and decreased its losses, although there was no significant effect of straw management on plant N uptake. The contribution of fertilizer N to total N uptake was 36-37% at the physiological maturity stage of maize, which indicated that fertilizer N was an important N source for maize growth but soil N was still the main N source.

Our results also indicate that nitrogen use efficiency in maize cultivation system in northeast China is not as low as that in previous studies (where NUE was generally calculated using difference or balance method). Considering the low NUE in China, our next aim is to find out which region, which kind of crops and which management systems lowered the overall NUE in northeast China.

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