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Impact of plastic film mulching and fertilizers on the distribution of straw-derived nitrogen in a soil-plant system based on ^{15}N–labeling

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A R T I C L E I N F O

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A B S T R A C T

Crop yield response to nitrogen (N) application has been well documented, but quantitatively tracing the distribution of exogenous straw derived N (straw-N) in a soil-plant system amended by plastic film mulching and fertilizers is poorly understood. Focus on this, we used a ^{15}N tracer, applied as maize straw, into a monoculture maize field experiment in China to quantify the distribution of straw-N in a soil-maize system. The effects of straw-N utilization by maize were also assessed over the course of a six-month field experiment by adding ^{15}N labeled maize straw into four fertilizer treatments (no fertilizer, N chemical fertilizer alone, manure fertilizer alone and manure combined with N chemical fertilizer) both with and without mulching. Mulching promoted straw-N transfer to stems, leaves and grains of maize. Fertilizers increased straw-N transfer to these plant parts both with and without mulching due to the increase of plant biomass, showing greater plant utilization rates of straw-N in the N fertilizer addition treatments, while residual rates of straw-N in soil decreased in these treatments. Nevertheless, fertilizer application relatively decreased the contribution of straw-N to N uptake of plant. The manure combined with N fertilizer treatment both with and without mulching had resulted in the highest straw-N accumulation in plant, but the lowest straw-N accumulation in soil. Meanwhile, mulching significantly increased straw-N distribution in plant but decreased in soil in the manure and manure combined N treatments. These results suggested that there were differences in straw-N turnover and uptake by maize in the soil-maize system due to the influences of plastic film mulching and different N sources of inorganic and organic fertilizers, especially showing that inorganic fertilizer positively primed straw-N distribution to plant compared to organic fertilizer.

1. Introduction

Straw incorporation into soil, as an important agricultural practice, affects carbon (C) and nitrogen (N) cycling, and improves soil quality (Heijboer et al., 2016; Minoshima et al., 2007). It can significantly increase total N in surface soil (Zhang et al., 2015), and provide greater available N for plant (Heijboer et al., 2016). Straw incorporation promotes N utilization efficiency of maize, improves grain quality and decreases the nitrate residues in soil (Zhao and Chen, 2009). The immobilization and transformation of straw derived N (straw-N) by plant and soil depends on the modes of straw returning to soil. Compared with single application of straw to soil, maize straw combined with fertilizer increases the utilization of straw-N by plant while decreases the loss of straw-N (Yang et al., 1993), since the decline of soil C/N ratio and the acceleration of straw decomposition (Bindraban et al., 2015). Similarly, the application of ditch-buried straw also increases N retention in soil, increases crop uptake and minimizes N leaching in a rice-wheat rotation system (Yang et al., 2015). However, the mechanisms of straw-N distribution and contribution in soil-plant system remains unclear when the application of straw is combined with inorganic N fertilizer and manure, especially added with other cultivated patterns (e.g. covered by plastic film mulching).

In the cold and cool conditions of Northeast China, plastic film mulching and fertilizers are important agricultural management practices, which influences N dynamics in soil-plant system (Soto et al., 2015; Liu et al., 2014). Plastic film mulching improves soil temperature and moisture, which leads to the increase of crop yield, but simultaneously accelerates the deterioration of soil fertility. Previous studies suggest that plastic film mulching can increase exogenous N (e.g. straw-N) decomposition and soil organic N mineralization, reducing the contents of soil microbial N, soil available N, soil alkali-hydrolyzable-N, soil amino acid-N and soil NO_3^--N (Li and Li, 2015; Wang et al., 1996;

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Table 1
Basic properties of soil samples in different treatments in 2014.

Film mulching	Fertilizers	TOC ($g\ kg^{-1}$)	TN (gkg^{-1})	C/N ratio	pH (H_2O)	AP ($mg\ kg^{-1}$)	AK ($mg\ kg^{-1}$)	$\delta^{15}N$ (‰)	Soil bulk density ($g\ cm^{-3}$)
Without mulching	CK	9.35^{g}	1.14^{d}	8.20^{e}	5.83^{c}	40.5^{e}	104^{d}	7.51^{e}	1.22^{ab}
	N	10.8^{e}	1.14^{d}	9.39^{d}	5.51^{e}	114^{d}	88.1^{e}	7.73^{e}	1.08^{e}
	M	13.2^{a}	1.28^{a}	10.36^{b}	6.07^{a}	144^{a}	128^{b}	8.58^{d}	1.09^{de}
	MN	11.9^{c}	1.21^{b}	9.87^{c}	5.73^{d}	125^{bc}	139^{a}	6.86^{f}	1.24^{a}
With mulching	CK	9.87^{f}	1.05^{f}	9.39^{d}	5.15^{g}	39.5^{e}	92.1^{e}	12.4^{a}	1.19^{b}
	N	10.9^{d}	1.16^{c}	9.39^{d}	5.29^{f}	130^{b}	85.4^{e}	9.48^{c}	1.06^{e}
	M	12.4^{b}	1.18^{c}	10.49^{ab}	6.04^{b}	141^{a}	115^{c}	10.1^{b}	1.14^{c}
	MN	11.8^{c}	1.11^{e}	10.61^{a}	5.74^{d}	120^{cd}	116^{c}	6.25^{g}	1.12^{cd}

Note: TOC, total organic C; C/N ratio, the ratio of TOC and TN; AP, available P; AK, available K; CK, no fertilizer; N, chemical N fertilizer; M, manure; MN, manure combined with chemical N fertilizer. Different letters in a column indicate significant differences among different treatments ($P < 0.05$).

Gao et al., 2009), and even decreasing N_2O emissions from soil (Liu et al., 2014; Cuello et al., 2015; Nan et al., 2016). It has a great impact on soil N cycling and crop production (Wang et al., 1996), which could promote more added N uptake by plant, increasing plant yield (Ge et al., 2014; Yang et al., 2015). From literatures, tracing the distribution and utilization efficiencies of different N sources (exogenous or soil N) in crop-soil system under mulching condition is an important issue.

Long-term fertilizer application is also an effective way to improve soil fertility, influencing soil N content, N_2O emissions and plant N uptake (Grant et al., 2016; Congreves et al., 2017). Compared to inorganic N (chemical N fertilizer), manure (organic N) application improves the soil N contents in different forms, alkali-hydrolyzable N, NO_3^--N and organic N (Wang et al., 1996). At the same time, it also reduces soil N mineralization, prevents the N leaching from surface soil and increases N content in the plowed layer (Wang et al., 2015; Grant et al., 2016). In addition, organic and inorganic fertilizers have different impacts on soil N, N_2O emissions and plant N uptake, showing that manure application resulted in higher organic N in soils than inorganic fertilizers (Meng et al., 2005). Moreover, soil N use efficiency by plant during the growing season can be further increased after more organic fertilizer is applied (Steiner et al., 2008). Applications of manure and inorganic fertilizer at high rates can lead to large increase in N_2O emissions (Meng et al., 2005). Therefore, different fertilizer N sources affect N distribution and transformation in soil and utilization by crop.

Compared to the fertilizer nitrogen, straw is another important source of soil N, improving soil organic matter and fertilizing soil. However, the distribution and fate of straw-N are complicated, including remain in soil or loss by leaching, gas emission or uptake by plant, which was affected by soil fertility levels or cultivation practices (e.g. mulching) (Xie et al., 2016). Few available information on quantifying the distribution of straw-N in plant-soil system under the conditions of plastic film mulching combined with fertilizers. Base on this issue and the influence factors in N cycling such as soil microbial activity, plant biomass and residue quality (Macarty et al., 1995; Burger and Jackson, 2003), our objectives for this study were to: (1) trace straw-N dynamics during the process of soil N transfer (including soil microbial biomass N immobilization) and plant uptake; (2) quantify the distribution of straw-N to the soil-plant system under the conditions of long-term plastic film mulching and fertilizers addition; and (3) examine the effects of long-term plastic film mulching and fertilizers on added organic N cycling. Our hypothesis is that (1) plastic film mulching will increase straw-N uptake by plant while reduce its distribution to soil, (2) fertilizers' application should decrease straw-N uptake by plant while increase its retention in soil, (3) plastic film mulching and fertilizer application would have an interaction on the distribution of straw-N in soil-plant system. In this study, an approach of ^{15}N–labeled maize straw was applied into a monoculture maize field experiment under different fertilizer treatments with or without mulching in order to quantify the distribution of straw-N in a soil-maize system in Northeast China.

2. Materials and methods

2.1. Experiment site and design

The experiment was conducted in a long-term experimental station (41°49′ N, 123°34′ E) at Shenyang Agricultural University, Liaoning Province, China. A monoculture maize field was established here in 1987, where the mean annual temperature is 7.9 °C and the mean annual precipitation is 705 mm. The soil is classified as Hapli-Udic Cambisol (FAO Classification). Maize (*Zea mays L.*) was sown in early May and harvested in October every year (Wang et al., 2006). Each experimental plot was 69 m^2.

The experiment was arranged in a split-plot design with mulching as main plot and four fertilizer treatments as subplots. The treatments in both with and without mulching conditions included: (1) no fertilizer treatment (control, CK); (2) N chemical fertilizer (135 $kg\ N\ ha^{-1}\ y^{-1}$, N); (3) manure (containing 135 $kg\ N\ ha^{-1}\ y^{-1}$, M); (4) manure (containing 67.5 $kg\ N\ ha^{-1}\ y^{-1}$) combined with N fertilizer (67.5 $kg\ N\ ha^{-1}\ y^{-1}$) (MN). Annual application of total N remains the same in three different fertilizer treatments. Urea was used as the N chemical fertilizer, and pig compost was used as the manure which contained 150 $g\ kg^{-1}$ organic carbon, 10 $g\ kg^{-1}$ N, 4.4 $g\ kg^{-1}$ phosphorus (P), and 3.3 $g\ kg^{-1}$ potassium (K) on a dry weight basis. All fertilizers were applied before sowing. Plastic film was applied in spring (after sowing) and removed in autumn (after harvest) each year. The basic soil properties are provided in Table 1.

2.2. Field experiment and sampling

This experiment was conducted using PVC containers, each with a dimension of lm (L) × lm (W) × 0.6 m (H). These PVC containers were vertically inserted into field plots of corresponding treatments on April 25th, 2014. The soil in PVC container was taken from the surface (0-20 cm) and passed through a 5 mm sieve. The ^{15}N labeled maize straw (ground and passed through a 0.425 mm sieve, 450 g per container, 0.2% of dried soil weight, equal to local amount of straw returning) was uniformly mixed with soil and put it back into the container on April 28th, 2014. The treatment without maize straw addition was as the control. After placing the soil mixed with ^{15}N labeled maize straw in the container, the corresponding N fertilizer and manure were applied in these treatments. Maize seeds were sown in each container on April 29th, 2014, and 6 plants were kept to mature in autumn. All treatments were replicated three times.

Matured maize plants were harvested and soil samples (0–20 cm) were collected on October 18th, 2014. Five soil cores in the same container were randomly collected with a 5 cm diameter auger and then mixed thoroughly inside a plastic valve bag to composite an individual soil sample. After removing visible roots and gravels, soil