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EFFECT OF PREVIOUS CROP NITROGEN APPLICATION ON YIELD OF FOLLOWING MAIZE UNDER DIFFERENT PLANTING PATTERNS

Y. X. Zhao, X. M. Mao and X. B. Zhou*

Agricultural College of Guangxi University, Nanning 530004, China.
*Author for correspondence. E-mail: whyzxb@gmail.com

ABSTRACT

Nitrogen application could affect the crop growth and yield, and then affect the water use efficiency (WUE). This study aimed to determine the effects of previous winter wheat (*Triticum aestivum* L.) nitrogen application and following summer maize (*Zea mays* L.) planting pattern on the yield and WUE of maize in the North China Plain. The experiments consisted of the winter wheat 112.5 (N1) and 225.0 (N2) kg/ha nitrogen application, and summer maize flat planting (FP) and ridge tillage planting (RTP) treatments arranged in a split-plot design (4 m × 4 m) with three replications in 2014 and 2015. Results showed that planting pattern and previous crop nitrogen had significant effect on yield components and WUE. Compared with FP, the RTP increased leaf relative water content, soil water content, soil water storage, WUE, and yield by 1.9%, 2.8%, 2.0%, 3.8%, and 7.1%, respectively. The yield, harvest index, stem diameter, and ear diameter of N2 treatment were 13.0%, 11.9%, 5.5%, and 2.3% higher than those of N1, respectively. Nitrogen of the previous winter wheat and the RTP pattern improved the water status and yield component of summer maize. It may be concluded previous crop nitrogen and RTP pattern can improve population structure, increase the yield and WUE of summer maize and thus is a promising method for farmers in North China.

Key words:

INTRODUCTION

Winter wheat and summer maize are the main rotation crops in the North China Plain, with farmers often ignoring the previous crop residue fertilizer. The nitrogen application influences the growth and yield of maize (Javeed *et al*., 2013); however, the application of excess nitrogen can effect on environment, particularly for soil and groundwater (Shi *et al*., 2016). The previous crop residue nitrogen is becoming more and more important problem. Some studies have shown that planting pattern influences conserving water, fertilizer use efficiency, water use efficiency (WUE), and grain yield (Mao *et al*., 2017). Gheysari *et al*. (2009) provide a effective method to control NO_3 leaching out of the root zone by a proper combination of irrigation and fertilizer management. The level of NO_3-N leaching may be minimized during agricultural practices by combining irrigation and fertilizer management (Jia *et al*., 2014).

The double cropping system may significantly increase nitrogen use efficiency (Hartmann *et al*., 2015). However, soil and ground water are affected by excess application of nitrogen in the North China Plain, with approximately 70% of the applied nitrogen accumulated in 0–500 cm soil layer (Li *et al*., 2016). Cultivation problems were encountered with excessive nitrogen fertilizer application in the summer maize (Jin *et al*., 2012). Appropriate management was substantial to maximize nitrogen efficiency (Zhang *et al*., 2016).

Planting patterns and nitrogen application rate significantly affected the yield component factors (Vos *et al*., 2005; Wang *et al*., 2015). Zhang *et al*. (2007) showed that the yield and the WUE of furrow-irrigated raised bed-planting and mulched ridge and furrow planting were higher than that of conventional flat planting. In the wheat–maize crop rotation system, the irrigation combination with straw mulch or straw-mulched furrows practices increased crop yield and WUE (Ma *et al*., 2017). The objective of this study was to determine the effects of previous crop nitrogen level and later crop planting patterns on WUE and yield of the summer maize.

MATERIALS AND METHODS

The study was conducted at the Agronomy Experimental Station of Shandong Agricultural University, Taian, Shandong Province, China (36°09′ N, 117°09′ E) during 2014 and 2015. The field test conditions were sandy soil and the average nutrients of the experimental field (at a depth of 0 cm to 20 cm) were tested. The soil physical and chemical properties of the experimental field are shown in table 1.

The region has a warm and semi-humid continental monsoon-type climate. At the experimental field, the precipitation averages of the 2014 and 2015 growth seasons were 372.5 and 282.6 mm, respectively, and the annual temperature mean was 25.0°C (1971-2015). Approximately 70% to 80% of the precipitation occurred from July to September (Table 2).

The experiment was a split-plot design with summer maize planting patterns (main plot): flat pattern (FP) and ridge tillage pattern (RTP), previous winter wheat nitrogen levels (split plot): 112.5 kg/ha (N1) and 225.0 kg/ha (N2) (Fig. 1). Each plot was 60-cm row spacing, 4 m × 4 m in size, three replications, and the field plots were superimposed on the same position each year. The planting density of the previous winter wheat (var. Jimai 22) was 200 × 10^4/ha on 9 October 2013 and 8 October 2014, and was harvested on 5 June 2014 and 7 June 2015. Irrigation amount was 200 mm during winter wheat growth season. After harvesting winter wheat, the following summer maize (var. Zhengdan 958) was planted with no tillage with a planting density of 62,500/ha on 15 June 2014 and 15 June 2015, and was harvested on 27 September 2014 and 30 September 2015. The summer maize growing period did not undergo fertilization and irrigation, and used hand weeding in managing weeds.

Leaf relative water content (LRWC) was monitored at V6 (6 leaves fully emerged), R0 (silking), R2 (blister), R3 (milking), and R4 (dough) (Zadoks *et al.*, 1974). Five ear leaves were measured for each treatment.

$$\text{LRWC} = (\text{FW} - \text{DW}) / (\text{SFW} - \text{DW}) \times 100\% \quad (4)$$

where FW is the fresh weight, DW is dry weight, and SFW is the saturated fresh weight (Galmés *et al.*, 2007).

The water potential (Ψw) of the leaves was sampled and measured with Psypro Water Potential System (Wescor, Inc., Logan, UT) at VE (emergence), V6, R0, R2, R3, R4, and R5 (dent). Before the test, the measured leaves were wiped clean and dried. Samples were obtained using a 0.6-cm-diameter round puncher, placed into the sample room, waiting approximately 15 min before reading.

The soil water content (SWC, v/v) was monitored at VE, V6, R0, R2, R3, R4, and R5, determined at 0 cm to 120 cm depths by neutron moisture meter (CNC503B, Super Energy Nuclear Technology, Ltd., Beijing, China). All levels were 10 cm, with a total of 12 levels.

$$S\ (\text{mm}) = \sum(\Delta\theta_i \times Z_i) \quad (1)$$

where S is the soil water storage (SWS) (mm), $\Delta\theta_i$ is the volumetric water content of a certain level of soil, Z_i is the depth of the soil layer (mm).

The evapotranspiration (ETa) was computed using climate data obtained from the Taian Agrometeorological Experimental Station with the following equations:

$$\text{ETa} = \Delta W + I + P \quad (2)$$

where ETa is the total amount of seasonal evapotranspiration (mm), ΔW is the change in the stored soil water (mm, Mao *et al.*, 2017), I is the irrigation amount (mm), P is the rainfall (mm). Basing on the observations for the summer maize growing seasons, the researchers found that the surface run-off was negligible.

$$\text{WUE} = Y/\text{Eta} \quad (3)$$

where Y is the grain yield (kg/ha).

The test data were analyzed with SAS9.2, and SigmaPlot10.0 (SPSS Inc., Chicago, IL) was used for drawing.

RESULTS

Leaf relative water content and water potential: In general, the LRWC decreased gradually from R2 to R4 in the 2-year study. The mean LRWC of RTP and FP were 87.0% and 84.5% (2014) and 84.8% and 83.6% (2015) during the whole growing stages, respectively, and RTP was higher than FP (Fig. 2). At R3–R4, the LRWC of RTP was significantly higher than that of FP ($P < 0.05$), indicating that RTP possibly improved summer maize plant physiological function in the late growth period. The LRWC of N2 increased by 1.1% (2014) and 0.8% (2015) compared with N1 ($P > 0.05$). At R4, the LRWC of N2 was significantly higher than that of N1 ($P < 0.05$). Thus, nitrogen application to winter wheat was beneficial to improve the LRWC of summer maize.

The Ψw decreased rapidly at R2, but at R3 for N2 in 2014. The Ψw averages of N1 and N2 were −1.62 MPa and −1.72 MPa in 2014, and −1.39 MPa and −1.46 MPa in 2015, respectively, with a significant difference of $P < 0.05$. At R0 and R4, the Ψw of RTP was significantly higher than that of FP ($P < 0.05$) from a two-year experimental study, except for N2 in 2015. The Ψw of RTP and FP were −1.64 MPa and −1.70 MPa in 2014, respectively. The Ψw of RTP was 27% higher than that of FP in 2015, and showed that the RTP enhanced Ψw of summer maize. The mean values of V6, R0, R2, R3, and R4 water potentials for 2 years were −1.28, −1.46, −1.79, −1.71, −1.54 MPa, respectively, and Ψw gradually decreased and then increased during the growth period.

Soil water content and soil water storage: The SWC in 0 cm to 40 cm increased with the increase of depth. The SWC of 40 cm to 80 cm soil layer was greater than that of 0 cm to 40 cm, and exhibited a small fluctuation scope. The SWC presented an irregular Z-shaped curve. The average SWC of the RTP and FP were different (Fig. 3). The SWC of RTP in 0 cm to 40 and 0 cm to 120 cm were increased by 3.1% and 0.4% (2014) and 3.9% and 3.2% (2015) compared with FP, respectively, and a significant difference was found between their planting patterns ($P < 0.05$). According to the 2-year results, the SWC of the N1 and N2 treatments was basically the same as in 0 cm to 40 cm and 0 cm to 120 cm, showing that the crop nitrogen had no significant effect on SWC. The average SWC of RTP in 0 cm to 40 cm and 0 cm to 120 cm was 3.6% and 2.0% higher than that of FP, respectively.

During the 2015 growing seasons, the ranking of SWS average was RTP > FP, and the values were 312.8

mm and 302.3 mm, respectively. The SWS of N1 and N2 were 295.5 mm and 286.3 mm in 2014, and 309.9 mm and 305.5 mm in 2015, respectively. For SWS, no significant difference between RTP and FP was found in 2014 ($P > 0.05$), whereas a significant difference was found in 2015 ($P < 0.05$). The SWS of RTP was 2.0% higher than that of FP, and was similar between N1 and N2 treatment in the 2-year study. This indicated that previous wheat nitrogen had no significant effect on SWS of summer maize, and ridge tillage was effective to collect rainfall and reduce evaporation.

Water use efficiency: The previous crop nitrogen amount affected the WUE of summer maize (Table 3), whereas planting pattern and planting pattern × nitrogen amount did not. In the 2-year study, the WUE of N2 treatment was significantly higher than that of N1 treatment ($P < 0.05$). The WUE of RTP was 2.7% (2014) and 4.8% (2015) higher than that of FP ($P > 0.05$). Test results showed that for 2 years, the WUE of N2 and RTP were significantly higher than those of N1 and FP ($P < 0.05$) during the growing season.

Grain yield and yield components: Mean of two years experiment showed that planting pattern and previous crop nitrogen amount had significant effects on kernel number per plant (KNP), yield and harvest index, nitrogen amount had significant effects on stem diameter, ear length, ear diameter, while planting pattern × nitrogen amount interaction only had a significant effect on ear length, row number, and kernel number (Table 4). The yield, harvest index, stem diameter, and ear diameter of N2 were 13%, 11.9%, 5.5%, and 2.3% significant higher than those of N1, respectively ($P < 0.05$). The KNP, yield, and harvest index of RTP were 5.9%, 7.1%, and 5.4% significantly higher than those of FP, respectively ($P < 0.05$). The results showed that yield and harvest index of summer maize were increased with increasing KNP under RTP.

Water status relations with yield: The SWC, LRWC, Ψw, WUE, and yield correlation analysis of summer maize for 2 years are shown in Table 5. A negative correlation between LRWC, WUE, yield, and SWC was found. A positive correlation was found between SWC and Ψw; LRWC showed a positive correlation with WUE and yield. The Ψw had an extremely significant negative correlation with WUE ($P < 0.01$) and a negative correlation with yield ($P < 0.05$). The WUE exhibited a significantly positive correlation with respect to yield ($P < 0.01$).

Table 1. The soil physical and chemical properties of the experimental field.

pH	Total N (mg/kg)	A-P (mg/kg)	A-K (mg/kg)	Soil bulk density (g/cm^3)	Soil organic matter (g/kg)	Field capacity (V%)
6.9	123.2	40.6	124. 5	1.50	18.9	38.6

Table 2. The rainfall and temperature of the experimental field in 1971-2015.

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (mm)	5.4	9.9	15.8	30.0	52.3	85.3	209.3	147.4	69.6	33.7	19.3	8.0
Temperature (°C)	-1.7	1.1	7.2	14.3	19.8	24.7	26.3	25.2	20.5	14.4	6.6	0.1

Table 3. Effects of planting patterns and previous crop nitrogen amount on water use efficiency (WUE) of summer maize.

Treatments	2014	2015	Mean
	WUE (kg/ha/mm)	WUE (kg/ha/mm)	WUE (kg/ha/mm)
Nitrogen (kg/ha)			
N1 (112.5)	25.0b	32.4b	28.7b
N2 (225.0)	28.4a	36.0a	32.2a
LSD(0.05)	1.7	2.0	2.7
Planting pattern			
Ridge tillage planting	27.0a	35.7a	31.3a
Flat planting	26.3a	32.8b	29.5a
LSD(0.05)	2.3	1.3	2.9
Nitrogen	0.0387	0.0001	0.0721
Planting pattern	0.1803	0.0001	0.1371
Nitrogen × Planting pattern	0.8073	0.0842	0.7476

Values followed by different letters in the table are significant difference according to $LSD_{0.05}$.

Table 4. The effects of planting pattern (PP) and nitrogen on the yield components and yield.

Treatments	Plant height (cm)	Stem diameter (cm)	Ear length (cm)	Ear diameter (cm)	Row number (/ear)	Kernel number (/plant)	Kernel weight (mg)	Yield (kg/ha)	Harvest index
Nitrogen (kg/ha)									
N1 (112.5)	217a	15.7b	15.6b	5.0b	14.4a	480b	391a	9238b	0.48b
N2 (225.0)	216a	16.5a	16.7a	5.2a	14.4a	524a	397a	10438a	0.53a
LSD	14	1.0	0.7	0.1	0.6	14	24	908	0.09
PP									
Ridge tillage planting	218a	16.1a	16.2a	5.1a	14.5a	517a	392a	10177a	0.52a
Flat planting	215b	16.0a	16.1a	5.1a	14.3a	488b	396a	9498b	0.49b
LSD	2	1.3	1.3	0.2	0.6	14	26	869	0.18
Nitrogen	0.4458	0.0070	0.0001	0.0212	0.9098	0.0017	0.7819	0.0001	0.0001
PP	0.0005	0.6892	0.5449	0.2550	0.7817	0.0150	0.8330	0.0001	0.0001
Nitrogen × PP	0.0983	0.0717	0.0133	0.6961	0.0033	0.0039	0.7988	0.1296	0.1296

Mean of 2014 and 2015; the different letters in the table are significant difference according to $LSD_{0.05}$.

Table 5. The correlation analysis between yield and soil water content (SWC), leaf relative water content (LRWC), water potential (Ψw) and water use efficiency (WUE).

Variable	SWC	LRWC	Ψw	WUE	Yield
SWC	1.000	-0.293	0.782	-0.604	-0.581
LRWC		1.000	-0.738	0.681	0.742
Ψw			1.000	-0.932^{**}	-0.914^{*}
WUE				1.000	0.946^{**}
Yield					1.000

*, ** Correlation is significant at the 0.05 and 0.01 level, respectively.

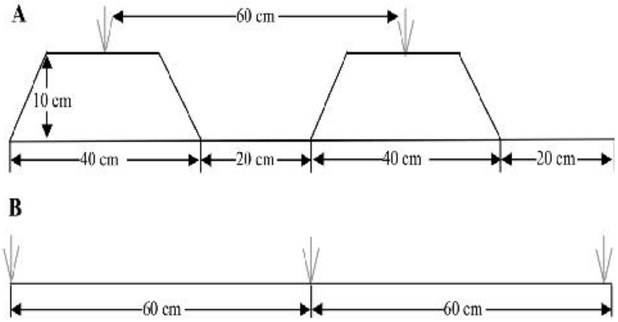

Fig. 1 The summer maize ridge tillage planting (A) and flat planting (B) pattern.

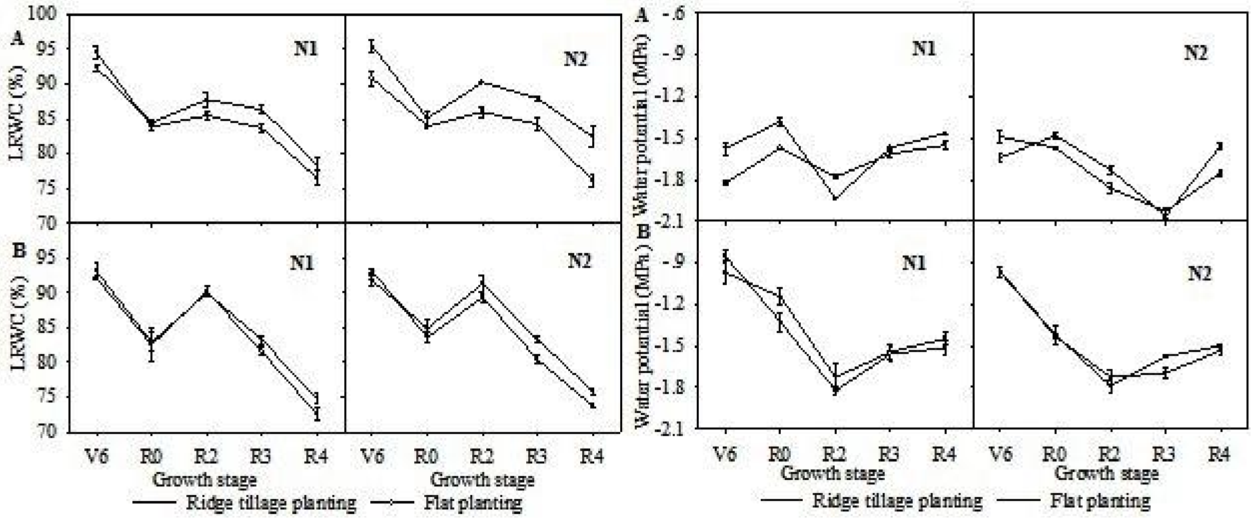

Fig. 2 Effects of planting pattern and previous crop nitrogen on leaf relative water content (LRWC) and water potential in (A) 2014 and (B) 2015. The bars are the SE.

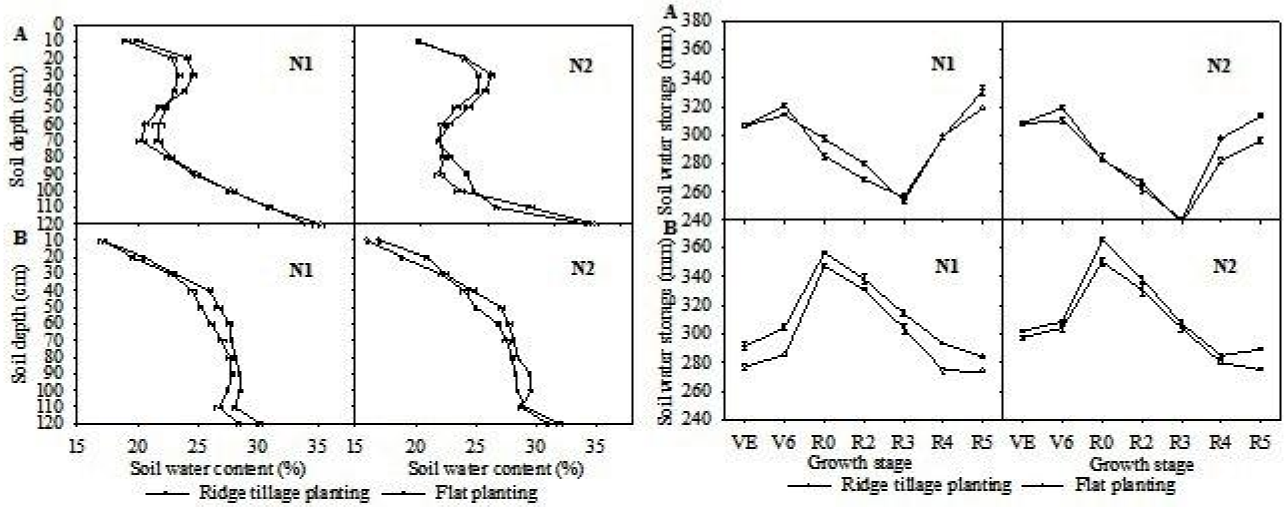

Fig. 3 Effects of planting pattern and previous crop nitrogen on soil water content and soil water storage in (A) 2014 and (B) 2015. The bars are the SE.

DISCUSSION

In this study, the increase of nitrogen amount in winter wheat was beneficial to improve LRWC of summer maize under RTP, which probably be attributed to promoted maize growth because the previous crop residue nitrogen, and had higher LRWC under ridge tillage (Tao *et al*., 2013). During both years, the LRWC mean of RTP was higher than FP; it showed that the RTP could enhance the ability of crop to resist drought stress. The WUE of N2 and RTP were significantly higher than those of N1 and FP. The RTP changed the surface shape, prevented runoff, and increased WUE. The results were similar to the previous finding that planting pattern affects crop yield (Tao *et al*., 2013).

The SWC determined crop water status (Jongdee *et al*., 2002). Previous research reported that ridge tillage can increase root growth and improve soil moisture, thereby enhancing the plant's ability to absorb water, and energetically adjust the osmotic balance (Wang *et al*., 2012). In our study, the SWC average of RTP in 0 cm to 40 cm and 0 cm to 120 cm was higher than that of FP, indicating that RTP improved soil moisture status and was beneficial to root growth of summer maize. These results were consistent with previous studies (Serme *et al*., 2015; Gu *et al*., 2016).

Grain number per plant is the key factor to increase the yield, and N application could improve yield and kernel quality (Ortega *et al*., 2016). The RTP increased maize yield and harvest index, with a yield increase of 30% compared with FP (Hassan *et al*., 2005). Stem diameter, ear height, plant height, panicle length, ear width, rows per ear, and other production-related indicators affected yield formation (Tsimba *et al*., 2013). Tao *et al*. (2013) also found that the filling rate, prolonged metaphase, increased grain number per spike, the 1000-grain weight, and yield of maize were improved by ridge tillage. Two-year results showed that planting pattern and previous crop nitrogen amount had significant effects on KNP, yield, harvest index, stem diameter, ear length, and ear diameter. The increase of the amount of nitrogen could increase KNP, stem diameter, ear diameter, and ear length of summer maize.

The nitrogen of previous crop winter wheat could increase SWC, SWS, LRWC, Ψw, promoting the increase in stem diameter, ear diameter, ear length, and grain number per plant of the succeeding crop summer maize. The RTP pattern was beneficial to the increase of grain yield and WUE by improving water status and yield component of summer maize. For summer maize production, combining the previous crop nitrogen with ridge tillage is a promising method in North China.

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