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Integrated agronomic practices management improve yield and nitrogen balance in double cropping of winter wheat-summer maize

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ABSTRACT

Crop production alters nitrogen balance in double cropping of winter wheat-summer maize in grain nitrogen content, soil nitrogen pool and nitrogen loss, ultimately affecting nitrogen use efficiency and environmental health. In comparison to the information on crop responses only limited knowledge exists on the response of nitrogen balance to integrated agronomic practices management (IAPM, defined as a comprehensive management framework consisted of tillage method, plant density, seeding and harvest dates, and fertilizer application) under field. Planting pattern will affect crop production and environmental costs. And how the nitrogen balance change under IAPM? In order to answer this question, four treatments (T1, T2, T3 and T4) were conducted on double cropping of winter wheat-summer maize for 4 years in North China Plain. Annual grain yield of T2, T3, and T4 was 22.0%, 51.2%, and 33.3%, respectively, higher than T1. And single grain yield of winter wheat or summer maize had the same trend as the annual grain yield. Dry matter accumulation of T2, T3, and T4 in summer maize season were 8.3%, 42.0%, and 23.0%, and those in winter wheat season were 3.9%, 25.7%, and 12.1%, respectively, higher than T1 at harvest. The grain yield of T4 was lower than that of T3 but higher than that of T1 and T2, and net profit and nitrogen use efficiency of T4 were higher than that of T3. Meanwhile the highest current and residual nitrogen recovery efficiency (${}^{C}RE_N$ and ${}^{RE}RE_N$) were obtained by T4 treatment during the study period. The soil nitrogen content in 0–90 depth (SN), grain nitrogen content (GN), nitrogen apparent recovery efficiency (ARE_N) and fertilizer nitrogen loss (FNL) were measured for nitrogen balance. T4 treatment promoted nitrogen balance as higher GN, higher ARE_N and lower FNL. The GN kept stable and FNL was increasing slowly in all treatments, which mean the contribution to soil nitrogen pool was decreasing with experimental years. The grain yield for T4 treatment of winter wheat, summer maize and annual increased by 36.4%, 31.3% and 33.3% averagely in the past 4 years, compared with T1 treatment. While maintaining crop production, T4 treatment made an important contribution to promoting nitrogen use efficiency, improving the situation of nitrogen balance, and reducing nitrogen loss about 39.1–54.4%, compared with other treatments.

1. Introduction

During the 21st century, more than half of the increase that has been achieved in crop yields is due to the increased application of chemical fertilizer, especially nitrogen (N) fertilizer (Tilman et al., 2011; Fan et al., 2011). N is a necessary nutritional element in crop production, and also one of the main limiting factors for crop yield (Ferguson et al., 2002; Samonte et al., 2006). In populous areas around the world, such as China with more than 1.3 billion people according to the census in 2015 (National Bureau of Statistics of People's Republic of China), sustainable food production is a great challenge. In the North China Plain (NCP), winter wheat-summer maize rotation is the most popular cropping system. In this system, farmers sow wheat in autumn, and then plant maize after harvesting wheat the following summer, year after year (Huang et al., 2017a,b). The rotation makes full use of rain and heat resources and it is important for food security. As crop yields are comparatively stable, this practice proves that an increase in N fertilizer cannot produce a continuous increase in grain yield (Wang et al., 2003; Wu et al., 2005). The local farmers usually apply superfluous nitrogenous fertilizer for higher crop yield resulting in more N was lost into the environment rather than grain or soil N pool (Zhao et al., 2006; Yan et al., 2016; Omonode et al., 2017), which brings risks to health and environment (Liu et al., 2003; Huang et al., 2012; Liu et al., 2017a). The traditional cultivation practice are difficult to provide higher crop yields while maintaining ecological safety (Jin et al., 2012; Chen et al., 2014). Population increases and societal changes are placing greater demands on agriculture, so we try to build a new cultivation pattern to break the dilemma.

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There has been much argument about the standard to measure N efficiency for a long time, and the efficiency that is based upon different calculation method exist huge differences. It has been suggested that the use efficiency of N fertilizer is lower than 35% in China; however, this estimate is for seasonal and not annual N utilization (Meng et al., 2016; Rowlings et al., 2016; Chen et al., 2017). In double cropping system, a huge number of residual N fertilizers exist in the soil after harvest. Residual soil N can take many forms including NO_3^--N, NH_4^+-N, and organic N that are stored in various soil fractions (Stevenson, 1965). In winter wheat-summer maize rotation, local farmers usually apply over-fertilization to obtain high grain yield, which lead to a higher residual N after harvest. To evaluate N use efficiency and loss precisely, we focused on crop-soil system and studied the N balance from N input and output. According to previous researches, N enters the system in seeds, irrigation, rainfall, wet deposition, biological nitrogen fixation (BNF), and fertilizer (Xu et al., 2006; Guo et al., 2017). There are five outputs for N, namely harvested grain, runoff, leaching into deep parts of the ground, ammonia volatilization, and denitrification. These N outputs are considered as N loss except harvested grain. The function of N fertilizer in an agricultural system is to meet crop requirements and to maintain soil fertility (Kieloaho et al., 2016; Kumari and Singh, 2016; Yousefi et al., 2017).

The integrated agronomic practices management (IAPM) is defined as a comprehensive management framework including tillage methods, plant density, seeding and harvest dates, and fertilizer application (Chen et al., 2011, 2014; Jin et al., 2012). The better performance in terms of crop production and N efficiency have been achieved (Jin et al., 2012; Zhu et al., 2014; Liu et al., 2017b), but the effects on N balance are poorly understood. Many studies have focused on the effect of changes to a single factor or combination of several factors on wheat or maize instead of annual crop productions; however, the effects of IAPM on crop-soil system are more important, as crop production is the result of the combined action by various aspects of agronomic practice. In earlier work, we paid more attention to nitrogen use efficiency of maize than to nitrogen balance in crop-soil system. The above mentioned results make us wonder − how the nitrogen balances change under IAPM. The objective of this study was to determine the effects of IAPM on N balance in a winter wheat-summer maize rotation.

2. Materials and methods

2.1. Experiment design

This study was conducted from 2013 to 2016 at the State Key Laboratory of Crop Science and at Dawenkou research field (36°11′N, 117°06′E, 178 m a.s.l.), Shandong Province, China. The region is characterized by brown loam soils and has a temperate continental monsoon climate. Organic matter, total N, rapidly available phosphorous (P_2O_5), and rapidly available potassium (K_2O) in the upper 30 cm of soil were 12.6 g kg^{-1}, 0.83 g kg^{-1}, 19.6 mg kg^{-1}, and 125.7 mg kg^{-1} (measurement methods refer to Mulvaney and Bremner, 1979; Smith and Bain, 1982; Toth et al., 1948), respectively. Air temperatures and rainfall during the study period came from Tai'an meteorological station, China Meteorological Administration. The annual accumulated temperature was determined by the methods of McMaster and Porter, and the base temperatures for wheat and maize were 0 and 10 °C, respectively (McMaster and Wilhelm, 1997; Porter and Gawith, 1999).

Nitrogen use efficiency and balance in a winter wheat-summer maize rotation was analyzed using a split plot experimental design. The summer maize hybrid 'Zhengdan958' and winter wheat hybrid 'Tainong18', which are the most common hybrids planted in the NCP, were used as the experimental material. Four treatments, T1 (local conventional cultivation practices), T2 (Based on T1, increase planting density of maize and wheat, delay maize harvesting and wheat sowing, decrease annual N application, increase phosphorous and potassium application, and change fertilization time), T3 (Based on T2, further increase planting density, and further increase fertilizer rate) and T4 (Based on T3, increase wheat planting density and decrease maize planting density, and decrease the amount of fertilizer), were carried out in a randomized block design with four replications (Table 1). Each plot was 6 × 40 m^2. A distance of 1 m was left between each block, and the total experimental area was 24 × 163 m^2. Each plot consisted of 10 rows of maize spaced 0.6 m apart or 24 rows of wheat spaced 0.25 m. The combination details of tillage method, plant density, seeding and harvest date, and fertilizer application are shown in Table 1. All

Table 1
Cultivation managements and fertilizer strategies for different treatments.

Treatment		Tillage method	Seeding rate (× 10^4 seeds ha^{-1})	Seeding Date (m/d)	Harvest date (m/d)	The periods and rates of fertilizer application (kg ha^{-1})				
						Fertilizer	Pre seeding	Jointing	VT (maize)	VT + 7d (maize)
T1	Winter wheat	Straw-covering Rotary tillage	225	9/25	6/15	N	157.5	157.5		
						P	120			
						K	30			
	Summer maize	Straw-covering No-tillage Interplanting	6	6/10	9/20	N		225		
						P		45		
						K		75		
T2	Winter wheat	Straw-returning Rotary tillage	300	10/5	6/12	N	96	144		
						P	150			
						K	75			
	Summer maize	Straw-returning Rotary tillage	6.75	6/15	10/1	N	45	115.5		
						P	45			
						K	45	30		
T3	Winter wheat	Straw-returning Rotary tillage	375	10/5	6/12	N	94.5	220.5		
						P	180			
						K	120			
	Summer maize	Straw-returning Rotary tillage	8.7	6/15	10/1	N		135	225	90
						P	60	90		
						K	150	150		
T4	Winter wheat	Straw-returning Rotary tillage	450	10/5	6/12	N	72	168		
						P	150			
						K	72	48		
	Summer maize	Straw-returning Rotary tillage	7.5	6/15	10/1	N	30	90	64.5	
						P	30	25.5		
						K	30	70.5	30	