Journal of Food and Nutrition Research, 2023, Vol. 11, No. 3, 176-184
Available online at http://pubs.sciepub.com/jfnr/11/3/2
Published by Science and Education Publishing
DOI:10.12691/jfnr-11-3-2

Effect of Nitrogen Application Rate on Grain Yield, Dry Matter and Nitrogen Accumulation and Remobilization in a Winter Wheat-Fresh Maize Cropping System

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Received January 18, 2023; Revised February 20, 2023; Accepted March 02, 2023

Abstract Three-harvest in two years is a traditional farming system in the Jinzhong Basin of Shanxi Province of the eastern Loess Plateau in China. Recently, an innovative farming system of winter wheat-fresh maize with two-harvest per year, making full use of temperature and light resources, is proposed. However, there is little known of the optimal nitrogen application rate for the innovative farming system to increase crop yield and improve ecological environment. In current study, six nitrogen application rates were carried out, consisting of winter wheat/fresh maize season 0/0 kg·ha^{-1} (N_0, Control), 75/75 kg·ha^{-1} (N_{75}), 150/150 kg·ha^{-1} (N_{150}), 225/225 kg·ha^{-1} (N_{225}), 300/300 kg·ha^{-1} (N_{300}) and 375/375 kg·ha^{-1} (N_{375}). The grain yield, dry matter and nitrogen accumulation and remobilization were analyzed to determine the optimal nitrogen application rate in the winter wheat-fresh maize cropping system in the Jinzhong Basin. The results showed that in the winter wheat and fresh maize season, compared with the N_0, N_{75} and N_{375} treatments, total dry matter accumulation at winter wheat maturity and fresh maize harvesting increased significantly by 82.9%-94.5% and 26.1%-197.1%, respectively, and dry matter remobilization in leaves and stem+sheath (+tassel) increased significantly under the N_{150} treatment. Total nitrogen accumulations under the N_{150}, N_{225} and N_{300} treatments increased significantly by 58.2%-162.9% and 55.7%-301.7% compared with those under the N_0 and N_{75} treatments, respectively. Nitrogen remobilization in the kernel and stem+sheath (+tassel) under the N_{150} treatment increased significantly compared with the N_0 and N_{75} treatments. In addition, nitrogen partial factor productivity of winter wheat and fresh maize under the N_{75} and N_{150} treatments increased significantly by 36.7%-534.1% and 45.2%-390.4% compared with the other nitrogen treatments, respectively, and nitrogen uptake efficiency also increased significantly by 79.1%-321.4% and 58.3%-239.5%, respectively. The yield of winter wheat and fresh maize under the N_{225} treatment was the highest, which significantly increased by 54.1% and 71.6% compared with that under the N_0 treatment, respectively. In summary, nitrogen application rates of 150-225/150-225 kg·ha^{-1} can be potential recommended use amounts with higher crop yield and nitrogen use efficiency in winter wheat-fresh maize cropping system in the Jinzhong Basin.

Keywords: *nitrogen application rate, fresh maize, winter wheat, dry matter accumulation, nitrogen use efficiency*

Cite This Article: ChangBin Liu, ZiMeng Tian, ZeWei Qi, JingJing Han, XingHua Zhao, and JianFu Xue, "Effect of Nitrogen Application Rate on Grain Yield, Dry Matter and Nitrogen Accumulation and Remobilization in a Winter Wheat-Fresh Maize Cropping System." *Journal of Food and Nutrition Research*, vol. 11, no. 3 (2023): 176-184. doi: 10.12691/jfnr-11-3-2.

1. Introduction

Nitrogen is one of the essential nutrient elements for crop growth, and which can directly affect photosynthesis, dry matter accumulation, crop growth and development [1]. To meet the food demand in China, large amounts of nitrogen fertilizer have been applied in agricultural production for many decades. However, most of the nitrogen that cannot be absorbed by crops loss to the surrounding environment in various forms of reactive nitrogen due to low nitrogen use efficiency [2]. Soil nitrogen loss caused a series of serious environmental problems such as greenhouse effects, water eutrophication, acid rain, groundwater nitrate pollution and ozone layer destruction [3,4]. At the same time, excessive nitrogen application also leads to the reduction of crop yield and quality, as well as, other problems [5,6,7]. Rational nitrogen application can not only relieve on the environment pressure, but also improve crop yield and quality [8-12].

Numerous studies have shown that rational nitrogen application can promote crop dry matter accumulation [13,14,15], improve nitrogen translocation and remobilization [16,17,18], and increase crop yield [19,20,21]. An et al. [22] reported that the nitrogen accumulation in roots, stems, leaves and spikes of winter wheat showed an increasing trend with increasing nitrogen application rates (0-300 kg·ha^{-1}) in Henan Province, while the recovery rate of nitrogen fertilizer showed a significantly decreasing trend. Nitrogen partial factor productivity of winter wheat and summer corn decreased gradually with increasing nitrogen application rate under the drip irrigation winter wheat-summer corn cropping system in the Jiaozhou region of Shandong Province, adoption of 210 kg·ha^{-1} in the winter wheat season and 225 kg·ha^{-1} in the summer maize season improved annual crop yield and nitrogen use efficiency [23]. Belete et al. [24] found that with the increase in nitrogen application (0-360 kg·ha^{-1}), the yield, grain nitrogen uptake, plant nitrogen uptake of bread wheat increased in Ethiopia, however, nitrogen agronomic efficiency, agro-physiological efficiency and apparent recovery efficiency showed a significantly decreasing trend. Due to differences in climatic conditions, soil types, cropping systems and crop varieties, the optimal nitrogen application rate, nitrogen accumulation and remobilization, nitrogen use efficiency and crop yield are different in different studies.

Three-harvest in two years is a traditional farming system in the Jinzhong Basin of Shanxi Province of the eastern Loess Plateau in China. Due to insufficient accumulated temperature and heat, it is generally difficult for common grain maize to mature after winter wheat harvest in current region. In recent years, fresh maize is becoming more popular for the public due to its sticky, fragrant and tender taste and abundant bioactive substances such as multiple vitamins, amino acids and minerals. Therefore, the planting area of fresh maize is increasing recently [25]. Now, the planting area of fresh maize in China exceeds 1.34 million hectares (ha). and China is the largest producer and consumer of fresh maize in the world [26]. Because economic benefit is lager for fresh maize than common grain maize, the planting area of fresh maize increase continuously in the Jinzhong Basin [27]. At the same time, planting fresh maize after winter wheat harvest in the Jinzhong Basin become a possibility, because due to shorter growth period of fresh maize and the increasing accumulated temperature under climate change. Therefore, an innovative farming system of winter wheat-fresh maize with two-harvest per year is gradually developing, which is favor of improve food production and further planting benefit. At present, there is little known about the effect of nitrogen application rate of crop yield, dry matter, nitrogen accumulation and remobilization under the innovative farming system in the Jinzhong Basin. Therefore, the objectives of this study were to (i) analyze the effects of nitrogen application rate on dry matter accumulation and remobilization, (ii) evaluate nitrogen accumulation and remobilization, nitrogen use efficiency, (iii) identity crops yield and its composition, (iv) to determine the optimal nitrogen application rate for the innovative farming system of winter wheat-fresh maize with two-harvest per year in the Jinzhong Basin of Shanxi Province of the eastern Loess Plateau in China.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted at the Agricultural Valley Experimental Station (37° 25′ N, 112° 33′ E) of Shanxi Agricultural University, Mengjiazhuang Village, Taigu District, Jinzhong City, Shanxi Province (Figure 1). The region has a monsoon climate at medium latitudes, with a mean annual temperature of 10.6°C, a mean annual precipitation of 450-490 mm, and a frost-free season of 160-165 days. The basic soil properties in the 0-20 cm layer was 28.89 g·kg^{-1} of soil organic matter, 42.26 mg·kg^{-1} of alkali-hydrolysable nitrogen, 15.04 mg·kg^{-1} of available phosphorus, 205.69 mg·kg^{-1} of available potassium, and pH 7.80. During the experiment, the precipitation was 363.6 mm and the average daily temperature was 11.5°C in the region (Figure 2).

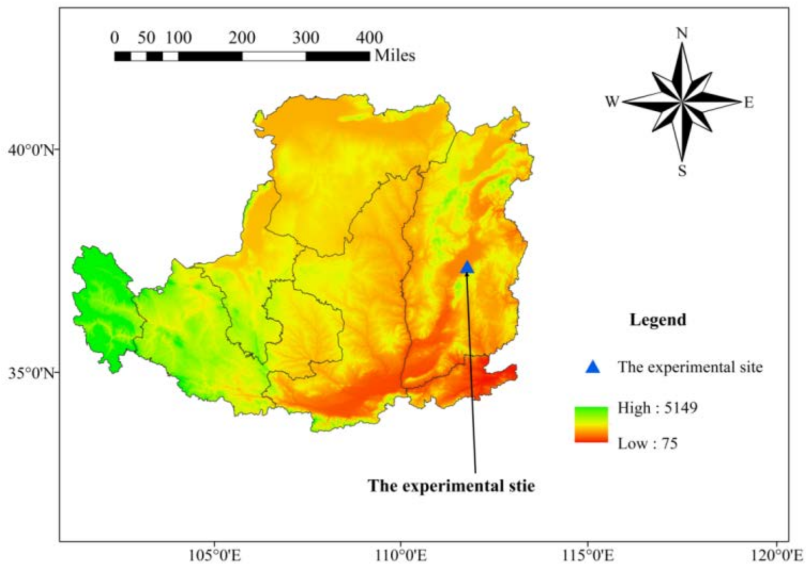

Figure 1. The location of the experiment station

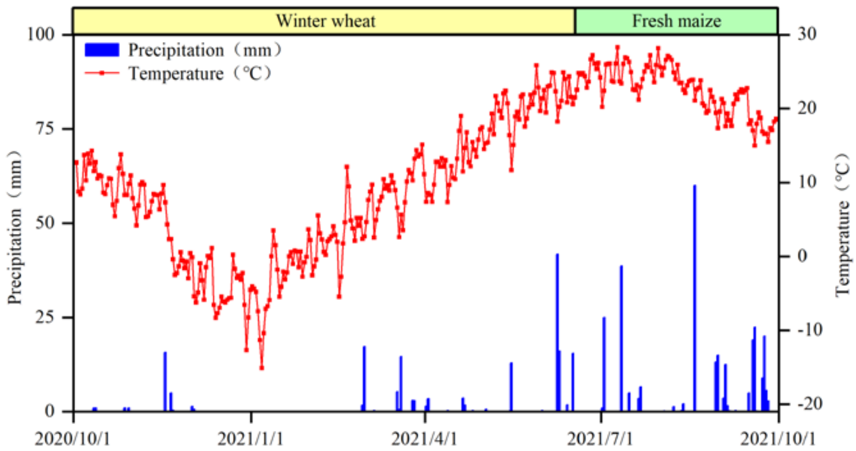

Figure 2. Precipitation and temperature during the experiment**.** Dateset sourced from China Weather (http://www.weather.com.cn/)

2.2. Experimental Design

The experiment was carried out with a random block design. Six nitrogen application rates were set up, including 0/0 kg·ha^{-1} (N_0), 75/75 kg·ha^{-1} (N_{75}), 150/150 kg·ha^{-1} (N_{150}), 225/225 kg·ha^{-1} (N_{225}), 300/300 kg·ha^{-1} (N_{300}) and 375/375 kg·ha^{-1} (N_{375}) for winter wheat/fresh maize season, The N_0 treatment was used as the control. Each treatment was replicated three times, and the plot size was 2 m×6 m (12 m^2). Some panels with polyvinyl chloride, with the burying depth of approximately 20 cm underground and extending approximately 20 cm above ground, were used to isolate adjacent plots to prevent nitrogen and water runoff. Urea was applied to set up different nitrogen treatments in the study. All plots received 150 kg·ha^{-1} phosphorus fertilizer (P_2O_5) and 90 kg·ha^{-1} potassium fertilizer (K_2O) before winter wheat and fresh maize were sown.

The variety for winter wheat was Jintai 182, which was sown with a seeding amount of 300 kg·ha^{-1} on October 3, 2020. Nitrogen fertilizers were used as the basal dose before sowing and topdressing at the jointing stage with a ratio of 1:1. All plots were irrigated with the volume of 160 m^3·ha^{-1} on November 26, 2020, 90 m^3·ha^{-1} on April 10, 2021 and 89.2 m^3·ha^{-1} on April 24, 2021, respectively. Winter wheat was harvested for all plots on June 18, 2021.

The variety of fresh maize was Jinnuo 20. After the wheat straw was returned to the field. Urea was used as basal dose. Fresh maize was sown at a density of 52,500 plants·ha^{-1} with 30 cm of narrow rows and 70 cm of wide rows on June 20, 2021. All plots were irrigated with the volume of 1916.7 m^3·ha^{-1} on August 14, 2021. Fresh maize was harvested for all plots on September 15, 2021.

2.3. Dry Matter Accumulation and Remobilization

In this study, uniform and representative plants (12 to 30 plants of winter wheat, 3 plants of fresh maize) were sampled and analyzed at the overwintering, anthesis and maturity stages for winter wheat and at the jointing, silking and harvesting stages for fresh maize. Different plant organs were divided at the anthesis and maturity stages for winter wheat, and at the silking and harvesting stages for fresh maize. Then, the dry matter of each organ was weighed. Thereinto, those organs for winter wheat comprised of leaves, stem + sheath and cob + glume at the anthesis stage, and leaves, stem + sheath, cob + glume and kernel at the maturity stage. In addition, those organs for fresh maize comprised of leaves, stem + sheath + tassel, and cob + husk at the silking stage, and leaves, stem + sheath + tassel, cob + husk and kernel at the harvest. The plants or separated organs were put into a kraft paper bag, after dried at 105°C for 30 min, dried to constant weight at 75°C and weighed. Dry matter remobilization of each organ was calculated according to equation (1). The sum of dry matter remobilization of different organs was dry matter accumulation.

$$DMR = DMW \times DP \tag{1}$$

where *DMR* is the dry matter remobilization of each organ at the winter wheat maturity stage/fresh maize harvesting (kg·ha^{-1}), *DMW* is the dry matter weight of each organ at the winter wheat maturity stage/fresh maize harvesting (kg·plant^{-1}), and *DP* is the population quantity of winter wheat at the maturity stage/fresh maize at the harvest (plant·ha^{-1}).

2.4. Plant Nitrogen Accumulation, Remobilization and Nitrogen Efficiency

The Tissuelyser-II High Throughput Tissue Grinder (QIAGEN, Germany) was used to crush all sample of plant organs. The nitrogen content of plant sample was determined by the Kjeldahl method using the Kjeldahl nitrogen analyzer (OLB9870) [28]. According to equation (2), the nitrogen remobilization of each organ was calculated. The sum of the nitrogen remobilization of different organs was the nitrogen accumulation. In addition, nitrogen partial factor productivity (*NPFP*), nitrogen uptake efficiency (*NUpE*), nitrogen use efficiency (*NUE*), and nitrogen harvest index (*NHI*) were calculated according to equation (3-6) [30,31].

$$NR = NC \times DMR \tag{2}$$

$$NPFP = Y / N \tag{3}$$

$$NUpE = NA_f / N \tag{4}$$

$$NUE = (NA_f - NA_c) / Nr \tag{5}$$

$$NHI = NK / NA \tag{6}$$

where, *NR* is the nitrogen remobilization of each organ at the winter wheat maturity stage/fresh maize harvesting stage (kg·ha^{-1}), *NC* is the nitrogen content of each organ at the winter wheat maturity stage/fresh maize harvesting stage (%), and *DMR* is the same as equation (1). *NPFP* is nitrogen partial factor productivity (kg·kg^{-1}), *Y* is crop yield (kg·ha^{-1}), *Nr* is nitrogen application rate (kg·ha^{-1}), *NUpE* is nitrogen uptake efficiency (%), NA_f is plant nitrogen accumulation at winter wheat maturity stage/fresh maize harvesting stage in nitrogen application area (kg·ha^{-1}), *NUE* is nitrogen use efficiency (%), NA_c is nitrogen accumulation of all plant at winter wheat maturity stage/fresh maize harvesting stage under N_0 treatment (kg·ha^{-1}), *NHI* is nitrogen harvest index (%), *NK* is the nitrogen remobilization amount of grain kernel at winter wheat maturity stage/fresh maize harvesting stage (kg·ha^{-1}), *NA* is the nitrogen accumulation amount of all plant at winter wheat maturity stage/fresh maize harvesting stage (kg·ha^{-1}).

2.5. Yield and Its Components

At the maturity stage, winter wheat with uniform growth and unsampled was harvested in an area of 0.667 m^2. Meanwhile, total spike numbers of winter wheat were recorded. Twenty spikes were taken to determine the kernel number per spike. Then, 1000 kernels were weighed, which was replicated three times. In addition, the grain kernel weight of all sampled spikes per plot was reported to obtain the actual yield after converting to that with 14% of grain water content. At the harvesting stage for fresh maize, all ears were harvested in each plot. The effective ear number was counted and weighed, which was the actual yield. Ten uniform ears of fresh maize were selected to determine the number of kernels per ear and 1000-kernel weight [31].

2.6. Data Analysis

Analysis of variance was used to test for treatment effect by SPSS 17.0 software. The mean differences between different treatments were separated by the new multiple range test (Duncan) at $p<0.05$. The map was drawn using ArcGIS 10.7, and other figures were plotted using Origin 2021.

3. Results

Dry matter accumulations of winter wheat and fresh maize at key growth stages under different treatments were analyzed in Figure 3. In the winter wheat growth season, dry matter accumulation under all nitrogen application treatments at the overwintering stage increased significantly by 114.7%-227.1% compared with that under the N_0 treatment. Dry matter accumulation under the N_{375} treatment was the highest, and which increased significantly by 35.5%-52.4% compared with those udner the N_{75}, N_{150} and N_{300} treatments. Dry matter accumulations under the N_{150} treatment were the highest at both the anthesis and maturity stages, and which increased significantly by 41.6%-94.5% compared with those under the N_0, N_{75} and N_{375} treatments (Figure 3 I). The N_{225} and N_{300} treatments were significantly larger dry matter accumulation by 37.2%-62.6% compared with N_0, N_{75} and N_{375} treatments at the maturity stage. In the growth season of fresh maize (Figure 3 II), dry matter accumulation under the N_{150} treatment increased significantly by 37.8%-112.0% compared with those under the other treatments. At the silking stage, dry matter accumulation of fresh maize under N_{150}, N_{225}, N_{300} and N_{375} treatments increased significantly by 45.0%-72.6% compared with that under the N_0 treatment, and which under the N_{300} treatment was significantly higher 38.2% compared that with N_{75} treatment. At the harvesting stage, dry matter accumulations of fresh maize under all nitrogen application treatments increased significantly by 123.7%-197.1% compared with that under the N_0 treatment. The N_{150} treatment was the highest dry matter accumulation, which was significantly lager 32.8% and 26.1% compared with the N_{75} and N_{375} treatments, respectively.

At the maturity stage of winter wheat (Figure 4 I), dry matter remobilization in the kernel, leaf and stem + sheath under the N_{150} treatment significantly increased by 32.7%-104.8%, 44.2%-169.9% and 17.6%-93.5% compared with those under the other treatments, respectively. Compared with the N_0, N_{75} and N_{375} treatments, the N_{225} and N_{300} treatments increased significantly dry matter remobilizations in the kernels and stems + sheaths by 36.7%-54.3% and 23.2%-64.5%, respectively. When fresh maize was harvested (Figure 4 II), dry matter remobilization in kernel under all nitrogen application treatments increased significantly by 121.9%-234.0% compared with that under the N_0 treatment. Dry matter remobilization in the cob + husk under the N_{150} treatment was significantly higher 222.1% and 34.8% compared with those under the N_0 and N_{75} treatments, which in the leaf significantly increased by 140.0%, 17.7% and 17.9% compared with those under the N_0, N_{75} and N_{375} treatments, respectively. Dry matter remobilization in stem + sheath + tassel under the N_{150} treatment increased significantly by 17.1%~195.3% compared with other treatments.

At the maturity stage of winter wheat (Figure 5 I), except for the N_{300} treatment, nitrogen remobilization in kernel followed the order of $N_{150} > N_{225} > N_{375} > N_{75} > N_0$ ($p<0.05$), and the nitrogen application treatment significantly increased by 48.4%-224.5% compared with the N_0 treatment. The nitrogen remobilization in cob + glume under the N_{300} treatment increased significantly by 85.1% and 153.1% compared with that under the N_{75} and N_{375} treatments, and which under the N_{150} and N_{225} treatments increased significantly by 129.1% and 97.1% compared with that under the N_{375} treatment. Nitrogen remobilization in leaf under the N_{150} treatment increased significantly by 61.8%-206.6% compared with those under the others treatments. Nitrogen remobilization in the stem + sheath under the N_{150}, N_{225} and N_{300} treatments significantly increased by 41.5%-91.7% compared with those under the other treatments. When fresh maize was harvested (Figure 5 II), nitrogen remobilizations in kernel under nitrogen application treatments increased significantly by 130.0%-286.7% compared with that under the N_0 treatment, and by 67.7% and 61.9% for N_{150} and N_{225}, respectively, compared with N_{75}. Nitrogen remobilization in the cob + husk under the N_{150}, N_{225} and N_{300} treatments increased significantly by 35.1%-261.7% compared with those under the N_0 and N_{75} treatments, which under the N_{375} treatment was significantly higher by 210.3%

compared with that under the N_0 treatment. Nitrogen remobilizations in leaf under the N_{150}, N_{225}, N_{300} and N_{375} treatments were higher by 281.7% and 55.1%-73.6% than those under the N_0 and N_{75} treatments, respectively, and there was also a significant difference between the latter two treatments. Nitrogen remobilizations in stem + sheathing + tassel under the N_{150}, N_{300} and N_{375} treatments increased significantly by 15.8%-405.7% compared with those under the N_0, N_{75} and N_{225} treatments, following the order of N_{225}>N_{75}>N_0 (p<0.05).

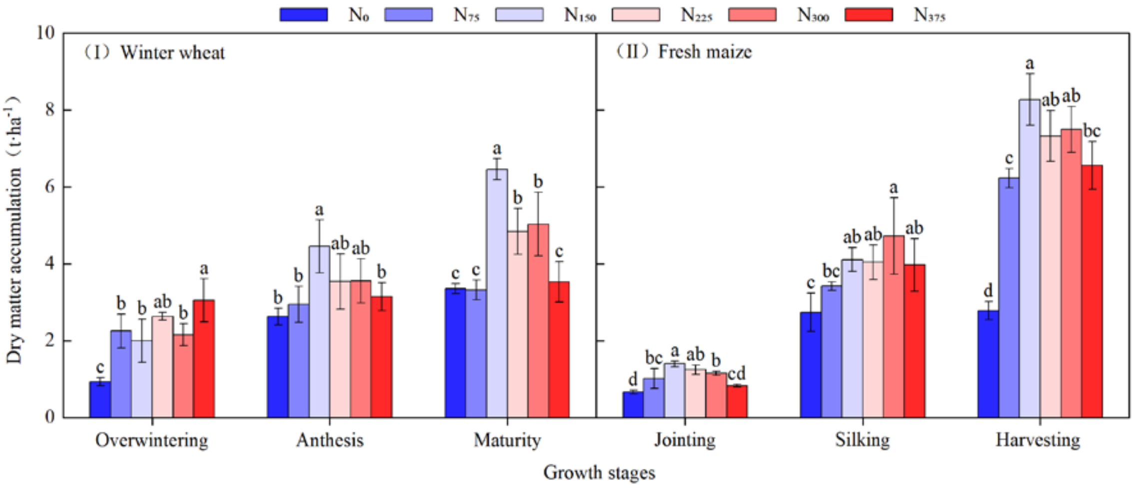

Figure 3. Effect of nitrogen application rate on dry matter accumulation at key growth stages of winter wheat and fresh maize. Different lowercase letters indicate statistical differences at the 0.05 level among different nitrogen treatments

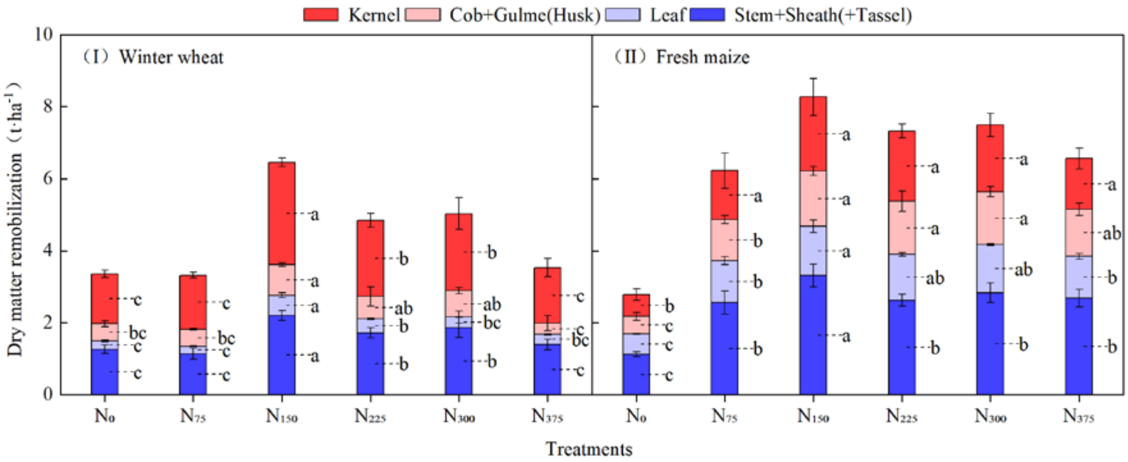

Figure 4. Effect of nitrogen application rate on dry matter remobilization of winter wheat at maturity stage and fresh maize at harvesting. Different lowercase letters indicate significant differences at the 0.05 level among different nitrogen treatments

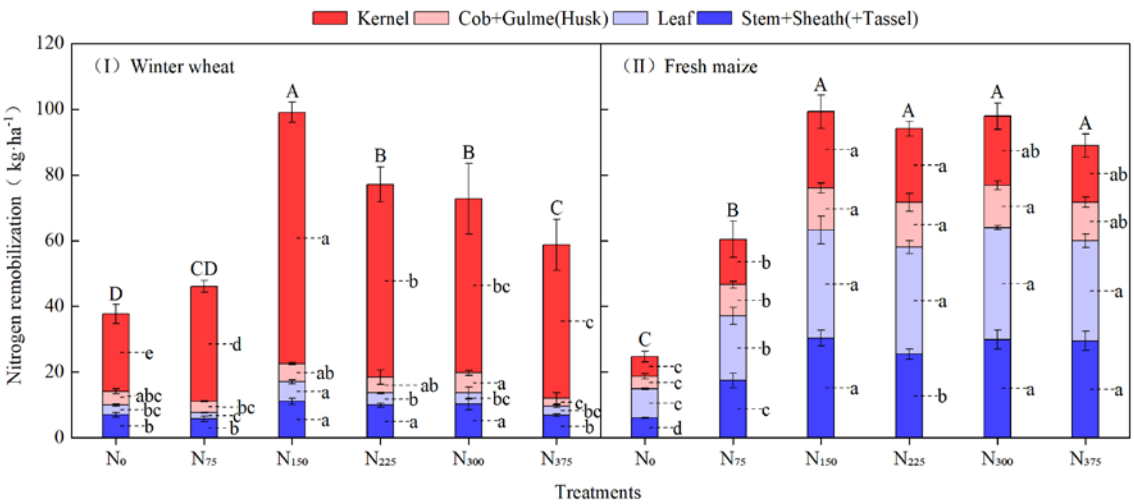

Figure 5. Effect of nitrogen application rate on nitrogen remobilization of winter wheat at maturity stage and fresh maize at harvesting. Different lowercase letters indicate the statistical difference at the 0.05 level of organ remobilization among different treatments, and different uppercase letters indicate the statistical difference at the 0.05 level of total nitrogen accumulation for the whole plant, sum of all organs, among different treatments

With the increase in nitrogen application rate, the *NPFP* of winter wheat showed a gradually decreasing trend (Table 1) as $N_{75}>N_{150}>N_{225}>N_{375}$ ($p<0.05$), while *NUpE* and *NUE* showed a trend of first increasing and then decreasing. The highest *NUpE* and *NUE* under the N_{150} treatment were observed among all treatments. The N_{150} treatment increased significantly by 92.9%~321.4% *NUpE* compared with the N_{225}, N_{300} and N_{375} treatments, and by 133.9%-627.8% *NUE* compared with other nitrogen application treatments. Compared with that under the N_0 treatment, the *NHI* under all nitrogen application treatments increased significantly by 16.5%-27.6%. The *NHI* under the N_{375} treatment increased significantly by 9.5% compared with that under the N_{300} treatment. Both the *NPFP* and *NUpE* for fresh maize were the order of $N_{75}>N_{150}>N_{225}>N_{300}>N_{375}$ ($p<0.05$), except that there was no significant difference in *NPFP* between N_{300} and N_{375} treatments. With the increase in nitrogen application rate, *NUE* showed a trend of first increasing and then decreasing. The *NUE* under the N_{75} and N_{150} treatments were greater significantly by 54.4%-190.1% compared with those in the other treatments.

Table 1. Effect of nitrogen application rate on nitrogen efficiency of winter wheat and fresh maize

Crops	Treatments	*NPFP* (kg·kg^{-1})	*NUpE* (%)	*NUE* (%)	*NHI* (%)
Winter wheat	N_0	-	-	-	62.4±4.8 c
	N_{75}	79.6±11.8 a	61.3±3.8 a	11.1±2.6 bc	76.1±1.0 ab
	N_{150}	39.5±2.5 b	66.0±2.6 a	40.9±2.8 a	77.2±1.2 ab
	N_{225}	28.9±0.4 c	34.2±3.1 b	17.5±2.2 b	76.1±0.6 ab
	N_{300}	20.0±1.1 cd	24.3±4.5 c	11.7±5.2 bc	72.7±3.8 b
	N_{375}	12.6±1.6 d	15.7±2.6 d	5.6±3.1 c	79.7±1.3 a
Fresh maize	N_0	-	-	-	24.1±5.4 a
	N_{75}	94.8±13.4 a	80.5±7.4 a	47.6±5.9 a	22.5±6.7 a
	N_{150}	56.3±4.3 b	66.2±6.0 b	49.7±6.9 a	23.2±3.9 a
	N_{225}	38.8±2.8 c	41.8±3.2 c	30.8±3.6 b	23.8±1.0 a
	N_{300}	26.4±1.3 d	32.6±2.3 d	24.4±2.8 bc	21.4±2.8 a
	N_{375}	19.3±3.3 d	23.7±1.9 e	17.1±2.4 c	19.4±3.5 a

Different lowercase letters indicate significant differences at the 0.05 level under different treatments.

The actual yield of winter wheat under the N_{75}, N_{150}, N_{225} and N_{300} treatments increased by 25.7%-54.1% compared with those of the N_0 and N_{375} treatments (Table 2). The theoretical yield of winter wheat under the N_{225} treatment increased by 34.4%-44.3% compared with those under the N_0, N_{150} and N_{300} treatments. Spike number, kernel number per spike, the theoretical yield and the actual yield of fresh maize under all nitrogen application treatments significantly increased by 15.4%-25.0%, 34.8%-50.4%, 35.5%-70.9% and 39.9%-71.6% compared with those under the N_0 treatment, respectively. However, the 1000-kernel weight of fresh maize under all nitrogen application treatments were lower significantly by 9.1%-13.3% compared with these under the N_0 treatment (except the N_{225} treatment). In addition, kernel number per spike under the N_{300} treatment increased significantly by 8.2% and 11.6% compared with these under the N_{150} and N_{375} treatments. The 1000-kernel weight under the N_{225} treatment increased significantly by 9.6% compared with that under the N_{375} treatment.

Table 2. Effect of nitrogen application rate on yield and its composition of winter wheat and fresh maize

Crops	Treatments	Spike number per unit area (10^4·ha^{-1})	Kernel number per spike	1000-kernel Weight (g)	Theoretical yield (t·ha^{-1})	Actual yield (t·ha^{-1})
Winter wheat	N_0	561.2±33.8 a	24.3±2.9 a	35.5±1.3 a	4.82±0.5 b	4.2±0.5 b
	N_{75}	502.7±71.1 a	29.8±5.9 a	35.2±1.6 a	5.22±1.0 ab	6.0±0.9 a
	N_{150}	538.7±13.9 a	24.7±6.0 a	33.7±1.6 a	4.52±1.3b	5.9±0.4 a
	N_{225}	586.2±46.8 a	31.7±4.0 a	34.9±0.7 a	6.48±0.8 a	6.5±0.1 a
	N_{300}	532.7±37.2 a	25.0±1.2 a	33.8±1.4 a	4.49±0.3 b	6.0±0.3 a
	N_{375}	527.2±78.8 a	30.3±0.8 a	33.6±1.2 a	5.36±0.8 ab	4.7±0.6 b
Fresh maize	N_0	4.3±0.3 b	358.0±34.9 c	264.9±12.1 a	4.09±0.3 c	5.1±0.8 b
	N_{75}	5.3±0.1 a	506.2±17.9 ab	233.9±15.4 bc	6.22±0.5 ab	7.1±1.0 a
	N_{150}	5.4±0.3 a	497.4±14.0 b	240.8±3.6 bc	6.42±0.4 a	8.4±0.6 a
	N_{225}	5.4±0.2 a	512.2±17.6 ab	251.8±7.3 ab	6.99±0.4 a	8.7±0.6 a
	N_{300}	5.0±0.1 a	538.3±7.5 a	236.8±6.3 bc	6.37±0.3 ab	7.9±0.4 a
	N_{375}	5.0±0.5 a	482.5±21.6 b	229.7±6.4 c	5.54±0.7 b	7.3±1.2 a

Different lowercase letters indicate significant differences at the 0.05 level under different treatments.

4. Discussion

In the current study, dry matter accumulation, nitrogen accumulation and remobilization in grain kernel for winter wheat and fresh maize at harvest showed the tread of first increasing and then decreasing with the increase in nitrogen application rate, which was the highest under the N_{150} treatment. In addition, nitrogen application significantly increased dry matter accumulation, nitrogen accumulation and remobilization in grain kernel than the N_0 treatment, except for the accumulation of dry matter in winter wheat. This is because nitrogen application promotes the growth and development of crops, increases the leaf area and root biomass, promotes dry matter and nitrogen accumulation and remobilization [32]. Similar changes in dry matter accumulation, nitrogen accumulation and remobilization with the increase in nitrogen application rate were observed in winter wheat and summer corn cropping system in Jiaozhou, Shandong Province, however, which were the highest at nitrogen application rate of 270 kg·ha^{-1} for winter wheat and 300 kg·ha^{-1} for summer maize [23]. The optimal nitrogen application rate was higher than that in our study. This may be due to the difference in climatic conditions, soil characteristics, crop varieties, other farmland management measures.

The yield of winter wheat and fresh maize under the N_{225} treatment in this study was the highest compared with other treatments, which was consistent with those previous results [33,34]. This may mainly be related to the increase in spike number and kernel number per spike. For winter wheat, insufficient nitrogen application rate could lead to a decrease in plant population and spike number, thus limiting the increase in the yield [35]. Although excessive nitrogen application rate could increase plant population of winter wheat, larger plant population would limit the development of wheat spikes. This could result in the decrease in kernel number and kernel weight per spike, ultimately leading to the yield reduction [5]. For fresh maize, nitrogen application can promote spikelet differentiation and prevent kernel abortion [36], therefore, spike number and kernel number per spike under all nitrogen application treatments were significantly higher than those under the N_0 treatment. In addition, reasonable nitrogen application can prolong the filling duration of kernel, and increase the 1000-kernel weight and the yield [38]. However, the 1000-kernel weights of fresh maize under all nitrogen application treatments were lower than that under the N_0 treatment in this study. It may be because the growth stage of fresh maize under the N_0 treatment was shortened, which lead to higher kernel maturity and relatively more dry matter accumulation [38]. However, the growth processes of fresh maize under nitrogen application treatments were prolonged with lower kernel maturity and relatively less dry matter accumulation, resulting in a lower 1000-kernel weight.

Generally, the *NPFP*, *NUpE* and *NUE* of winter wheat gradually decreased with the increase in nitrogen application rate [39,40], which was basically consistent with the results of the study. In the study, the *NPFP*, *NUpE* and *NUE* of winter wheat and fresh maize under the N_{75} and N_{150} treatments were higher than those under others nitrogen application treatments. However, the *NUEs* under most of treatments were generally lower than 40% and even than 25% in the study, which were lower than those of mean *NUE* for three major food crops in China [41]. Lower *NUE* may be related to the fertilization method and fertilization depth [42]. In the study, nitrogen fertilizer in the winter wheat season was applied as the basal dose before sowing and topdressing at the jointing stage with a ratio of 1:1, and artificial application was adopted. Although rotary tillage was carried out after fertilization, the depth was shallower and more wasteful than strip application. In addition, urea was applied only within narrow rows, and rotated to the depth of approximately 5 cm by micro-rotovator before fresh maize was sown. In addition, no fertilizer was applied within wide rows in the fresh maize season. This may lead to low nitrogen uptake and use of fresh maize. Lower crop yield in the current study may also be responsible for lower *NUE*. In the study, there were less precipitation and insufficient irrigation during winter wheat and fresh maize growth seasons, which resulted in less nitrogen uptake and lower *NUE*. In addition, lower *NUE* of fresh maize may be related to its incomplete maturity. At the harvesting, the plant of fresh maize absorbs and translocates less nitrogen to the kernel under incomplete maturity than full maturity.

In this study, it was difficult to meet the water demand of crops due to the low precipitation during the experiment. Although low irrigation was implemented during the growth for winter wheat and fresh maize, inadequate irrigation resulted finally in lower crop yields and nitrogen use. Water deficit can affect nitrogen uptake and use. In future research, we will assess the effect of nitrogen application rate on dry matter and nitrogen accumulation and remobilization under the condition of sufficient water irrigation, to provide a reliable basis for rational nitrogen application rate in winter wheat-fresh maize cropping systems in the Jinzhong Basin. In addition, the experiment was only carried out for one year, and the implement duration was shorter. The representativeness of the results could be limited at a certain extent. It is necessary to prolong the experimental duration in the further research.

5. Conclusions

Compared with the N_0 and N_{75} treatments, adoption of the N_{150} and N_{225} treatments increased dry matter and nitrogen accumulation, dry matter remobilization in the cob + glume (husk) and stem + sheath (tassel) organs, and nitrogen remobilization in the kernel and stem + sheath (tassel) organs for winter wheat at the maturity stage and fresh maize at the harvesting. There was *NPFP*, *NUpE*, *NUE*, *NHI*, the yield and its components for winter wheat and fresh maize under the N_{150} and N_{225} treatments. In conclusion, 150-225 kg·ha^{-1} for winter wheat and 150-225 kg·ha^{-1} of fresh maize will be potential optimal nitrogen application rates for the innovative farming system of winter wheat-fresh maize with two-harvest per year in the Jinzhong Basin of Shanxi Province of.the eastern Loess Plateau in China.

Acknowledgements

This research was supported by Special project of Biological Breeding for Shanxi Agricultural University (YZGC089).

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