

SHI Yu, YU Zhenwen, WANG Dong, LI Yanqi, WANG Xue

Effects of nitrogen rate and ratio of base fertilizer and topdressing on uptake, translocation of nitrogen and yield in wheat

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Abstract Application of nitrogen (N) fertilizer is one of the most important measures to increase grain yield and protein content in winter wheat (*Triticum aestivum* L.) production. However, misuse of N fertilizer will not only affect grain yield and quality, but also cause the decline of economic benefits and related negative environmental effects. It is essential to study reasonable N application regimes for profitable yields, efficient N utilization and reduction in possible environmental pollution. The objective of this study was to determine the N uptake and translocation in wheat plants by using ^{15}N isotope tracers in PVC cylinders (2.05 m long, Φ 0.2 m, without bottom) in seven treatments: without N fertilizer application (N0); N application rate of 168 kg/hm² (0.527 g/pot), with ratios of base fertilizer to topdressing of 1:1 (N1), 1:2 (N2) and 0:1 (N3); N application rate of 240 kg/hm² (0.753 g/pot), with ratios of base fertilizer to topdressing of 1:1 (N4), 1:2 (N5) and 0:1 (N6). The ^{15}N tracer experiment showed that the main basal N absorbed by plant from sowing to jointing stage accounted for 78.04%–89.67%; fertilizer N use efficiency (FNUE, N fertilizer accumulation in plant/N supplied) of topdressing was significantly higher than that of basal N; reducing basal N amount and increasing topdressing N amount could appropriately promote the plant's absorption of more N fertilizer and enhance FNUE, of which treatment N2 had the highest values. Under the high-yield condition, when N fertilizer rate was increased from 168 to 240 kg/hm², there were no significant differences in the amount of N accumulation in plants and in grains between

treatments with the same ratio of base fertilizer to topdressing; by reducing basal N amount and increasing topdressing N amount accordingly, the translocation efficiency (TE, accumulation amount from vegetative organs to grain/N accumulation in vegetative organs during anthesis) increased, and the amount of N assimilation to grains after anthesis and its contribution proportion (the amount of N assimilation to grains after anthesis/N accumulation in grain) also increased. In other words, grain N accumulation amount increased with increasing amount of topdressing N at the same N fertilizer rate. There were no significant differences among treatments N2, N3, N5 and N6 in grain N accumulation. Appropriate N fertilizer rate with a reduction in basal N amount and an increase in topdressing N amount such as in N2, N5 and N6 increased grain yield and protein content. In conclusion, under conditions used in this experiment, as far as grain yield, protein content and FNUE are concerned, the recommended appropriate N fertilizer application regime is treatment N2, with a N fertilizer rate of 168 kg/hm² and a ratio of base fertilizer to topdressing of 1:2.

Keywords nitrogen fertilizer rate, ratio of base and topdressing, ^{15}N , nitrogen uptake, translocation, yield

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SHI Yu, YU Zhenwen (✉), WANG Dong
Key Laboratory of Wheat Physiology and Genetics Improvement,
Ministry of Agriculture, Shandong Agricultural University, Tai'an
271018, China
E-mail: yuzw@sdau.edu.cn

LI Yanqi, WANG Xue
Center of Agricultural Technique Extension of Longkou City, Longkou
265701, China

1 Introduction

Nitrogen (N) uptake, assimilation and translocation in the wheat plant directly affect kernel yield and protein content. In order to achieve higher grain yield and quality, N fertilizer has been used excessively in China and has led to the decline of fertilizer N use efficiency (FNUE) and environmental pollution (Arvind et al., 2004; Jaime et al., 2001). So applying reasonable amounts of N is an important measure to increase yield and quality of wheat, and at the same time contribute to the control of environmental pollution. Some researchers believe that increasing the N application rate would make the wheat plant absorb more N and increase wheat kernel yield and protein content (Wang et al., 2003c; Du et al., 2001; Lin

et al., 2004; Hou et al., 2001), and increasing the ratio of topdressing N could enhance protein content (Zhao et al., 2004). But other researchers have shown that the correlation between kernel protein content and N accumulation in the wheat plant was not significant. Grain N in wheat mainly represents the N accumulated in the vegetative parts until anthesis and transferred to kernel during the reproductive phase (Zhang et al., 1997). Higher kernel yield was due to higher FNUE and translocation efficiency (Wang et al., 2003a). Although many studies have been conducted concerning N translocation, distribution during grain filling and N use efficiency as affected by the amount of fertilizer N application, little attention has been paid to the ratio of base and topdressing in wheat fields with high yield. Hence, the present study was conducted to examine the effects of N fertilizer rate and ratio of base and topdressing on N efficiency and translocation and distribution to determine optimum N application regimes in wheat fields with high yield.

2 Materials and methods

The field experiment was conducted from the fall of 2003 to the summer of 2004 in Zhongcun village, Longkou City, China. The soil used was brown soil that contained organic matter at 13.1 g/kg and available N, phosphorus (P) and potassium (K) at 87.5, 10.49 and 84 mg/kg respectively. Typical strong gluten winter wheat cultivar (Jimai 20) currently used in local production was chosen as the material in this study. The experiments included a ^{15}N isotope tracing experiment and a field experiment.

An ^{15}N isotope tracing experiment was conducted using polyvinylchloride (PVC) open-ended cylinders (205 cm in depth and 20 cm in internal diameter). The procedure for making the ^{15}N isotope tracing experiment was as follows: first, a micro-plot ($4\text{ m} \times 2\text{ m} = 8\text{ m}^2$) was appointed within the field, and the surface soil (0–0.3 m in depth) was taken out and laid aside; second, soils of 0.3–1 m and 1–2 m in depth were taken out and laid aside and a pit (4 m in length, 2 m in width and 2 m in depth) was dug. All PVC cylinders were put into the pit vertically, and then filled successively with the 1–2 m and 0.3–1 m soils that were previously removed. Water was poured into the cylinder to sink the soil each time the depth reached 0.5 m. Finally, 0.2 m of the surface soil was poured and fertilizers (basal N, total P and K) were applied, then the remaining 0.1 m of surface soil was added. About 0.05 m of the cylinder was left above the soil surface to prevent ^{15}N leakage during irrigation.

There were seven treatments: without N fertilizer application (N0); N application rate of 168 kg/hm^2 (0.527 g/pot), with ratios for base and topdressing N fertilizer of 1:1, 1:2 and 0:1, denoted as N1, N2 and N3 respectively; N application rate of 240 kg/hm^2 (0.753 g/pot), with ratios for base and topdressing N fertilizer of 1:1, 1:2 and 0:1, denoted as N4, N5 and N6 respectively. Treatment N4 was a traditional application regime in this area. Each treatment included two N

application methods. In order to discriminate the effects of either base or topdressing applications, two cylinders were established: basal ^{15}N application and topdressing ^{15}N application. In the basal ^{15}N application, the wheat plants received ^{15}N -labeled and unlabeled urea for base and topdressing applications respectively. In the topdressing ^{15}N application, the wheat plants received unlabeled and ^{15}N -labeled urea for base and topdressing applications respectively. The data from the above two cylinders were combined to determine the total contribution of the applied basal and topdressing N fertilizer to plant N in this experiment. The atomic percentage of ^{15}N used in urea was 10.28%. Basal N fertilizer, total P_2O_5 (135 kg/hm^2) and K_2O (105 kg/hm^2) were applied before sowing; topdressing N fertilizer was applied at jointing stage (just at the start of stem elongation). At the three-leaf stage, plots (cylinders) were thinned to a density of 5 plants/pot. The sowing date was on October 4, 2003 and the harvesting date was on June 11, 2004.

At the same time, a field experiment was conducted in the same field. The experimental treatment was the same as that of the ^{15}N isotope tracing experiment arranged in a two-factor random design. Each plot size was $3\text{ m} \times 8\text{ m}$. At the three-leaf stage, plots were thinned to a density of 150 plants/ m^2 . The sowing date was on October 4, 2003 and harvesting date was on June 14, 2004.

3 Measurements

At jointing, anthesis and maturity, plants in the six cylinders from every treatment in the ^{15}N isotope tracing experiment and 30 culms from every plot of the main field experiment that were randomly chosen were cut at the ground level. All the plant samples were oven-dried at 70°C to a constant weight, weighed, ground in a Wiley Mill, and passed through a 1-mm sieve. Subsamples were taken for N analysis. The N concentration in the plant tissues and grains was determined by the standard macro-Kjeldahl procedure (Nitrogen Analysis System, Büchi, Switzerland). Atomic percent of ^{15}N in plant tissues and grains was determined with a ZHT-03 mass spectrograph (Beijing Analysis Instrument Factory, Beijing, China) equipped with an ionization source of 1 200 V and a single inlet.

$\text{FNUE}_{^{15}\text{N}} (\%) = \text{fertilizer N uptake (mg/plot)} / (\text{fertilizer N applied}) \times 100\%$ (Stevens et al., 2005);

N translocation amount of vegetative organ = N content of a vegetative organ at anthesis – N content of the organ at maturity (Huo et al., 2004);

N translocation efficiency = N translocation amount of vegetative organ/N amount of the organ at anthesis $\times 100$ (Huo et al., 2004);

N translocation contribution = N translocation amount of vegetative organ/N amount of the grain at maturity $\times 100$ (Huo et al., 2004);

Nitrogen assimilation amount = N accumulation amount in grain at maturity – N translocation amount of vegetative organ.

4 Data statistical analysis

Treatment mean differences were separated by the least significant difference ($LSD_{0.05}$) test when the F -tests were significant ($P \leq 0.05$).

5 Results

5.1 Effect of N rate and ratio of base fertilizer to topdressing on N uptake from different sources by wheat plants

As shown in Table 1, compared with the treatment without N fertilizer application (N0), N fertilizer application (N1, N2, N4 and N5) could remarkably increase N accumulation in wheat plants from sowing to jointing, but there was no significant difference among the latter treatments. This indicates that decreasing base N fertilizer appropriately could meet the N needs of wheat plants before jointing in the field with high yield and enhance base FNUE. The relationship, $N4 < N1 < N5 < N2$, shows that decreasing base N fertilizer appropriately could enhance base FNUE and decrease N fertilizer loss. From Table 1, we calculated that the main basal N absorbed by plants from sowing to jointing stage accounted for 78.04%–89.67%.

From jointing to anthesis and from anthesis to maturity, when N fertilizer rate was increased from 168 to 240 kg/hm², there was no significant difference in the amount of N accumulation in plants between treatments with the same

ratio of base fertilizer to topdressing, indicating that increasing the N fertilizer amount could not promote N accumulation in plants at the two growth periods. When basal N amount was reduced and topdressing N amount was increased appropriately, with the same N amount applied, the amount of N accumulation in plants increased as follows: $N3 > N2 > N1$, $N6 > N5 > N4$. This indicates that adjusting the ratio of base fertilizer to topdressing could change N accumulation amount in plants. When the N fertilizer amount was increased at the same ratio of base fertilizer to topdressing, the N that accumulated in plants contained more fertilizer N and less soil N, indicating that increasing the N amount applied could make wheat plants absorb less soil N. Increasing topdressing fertilizer N with the same fertilizer N amount could encourage plants to absorb more N from both fertilizer and soil. Increasing N fertilizer amount at the same ratio of base fertilizer to topdressing decreased FNUE from jointing to anthesis and from anthesis to maturity as follows: $N4 < N1$, $N5 < N2$, $N6 < N3$. But increasing topdressing N amount appropriately with the same N application amount enhanced FNUE as follows: $N3 > N2 > N1$, $N6 > N5 > N4$.

There was no significant difference between treatments in the amount of N accumulation in plants during the whole growth stage (Table 2). From Table 2, we calculated that N from soil accounted for 73.03%–79.98% and 20.02%–27.97% came from fertilizer N. The amount of topdressing fertilizer N accumulation in plant was more than the base fertilizer N. Increasing the N fertilizer amount at the same ratio of base fertilizer to topdressing decreased FNUE; but increasing topdressing N amount appropriately with the same N amount application enhanced FNUE. The result from treatment N2

Table 1 Nitrogen uptake from different sources by wheat plants at different growth periods

Growth stage	Treatment	TNAA/mg·pot ⁻¹	NDFBF		NDFTF		NDF		NDFS
			NAA/mg·pot ⁻¹	FNUE/%	NAA/mg·pot ⁻¹	FNUE/%	NAA/mg·pot ⁻¹	FNUE/%	
Sowing to jointing	N1	646.03a	73.71	27.95	–	–	73.71	13.97	572.32
	N2	621.19a	65.95	37.51	–	–	65.95	12.50	555.24
	N3	468.05b	–	–	–	–	–	–	468.05
	N4	658.16a	83.81	22.24	–	–	83.81	11.12	574.35
	N5	633.44a	74.6	29.70	–	–	74.60	9.90	558.84
	N6	468.05b	–	–	–	–	–	–	468.05
Jointing to anthesis	N1	275.62b	11.06	4.19	103.09	39.08	114.15	21.64	161.47
	N2	284.89b	5.30	3.02	124.16	35.30	129.47	24.54	155.42
	N3	373.46a	–	–	170.85	32.39	170.85	32.39	202.60
	N4	266.56b	16.63	4.41	118.80	31.53	135.43	17.97	131.13
	N5	286.45b	5.39	2.15	139.08	27.68	144.47	19.17	141.98
	N6	387.48a	–	–	190.37	25.26	190.37	25.26	197.10
Anthesis to maturity	N1	203.65c	4.94	1.87	32.47	12.31	37.41	7.09	166.24
	N2	245.78b	3.07	1.74	51.11	14.53	54.17	10.27	191.60
	N3	317.14a	–	–	69.87	13.24	69.87	13.24	247.28
	N4	214.49c	6.95	1.84	50.66	13.44	57.61	7.64	156.88
	N5	240.84b	3.20	1.27	90.82	18.08	94.02	12.48	146.82
	N6	314.02a	–	–	108.62	14.41	108.62	14.41	205.40

Note: Values followed by different letters within the same column are significantly different at 0.05 probability level at different growth stages. TNAA: amount of total N accumulation in plant; NAA: amount of N accumulation; NDFBF: N derived from basal fertilizer; NDFTF: N derived from topdressing fertilizer; NDF: N derived from fertilizer; FNUE: N fertilizer accumulation in plant/N supplied; NDFS: N derived from soil.

Table 2 Nitrogen uptake from different sources by wheat plants during the whole growth stage

Treatment	TNAA/mg·pot ⁻¹	NDFBF		NDFTF		NDFF		NDFS
		NAA/mg·pot ⁻¹	FNUE/%	NAA/mg·pot ⁻¹	FNUE/%	NAA/mg·pot ⁻¹	FNUE/%	NAA/mg·pot ⁻¹
N1	1125.30a	89.71b	34.02b	135.56d	51.39a	225.27d	42.70c	900.03a
N2	1151.86a	74.32c	42.27a	175.27c	49.83a	249.59c	47.31a	902.27a
N3	1158.65a	–	–	240.72b	45.63b	240.72c	45.63b	917.93a
N4	1139.21a	107.39a	28.50c	169.46c	44.97b	276.85b	36.74e	862.36b
N5	1160.72a	83.19b	33.12b	229.9b	47.75b	313.09a	41.55c	847.63b
N6	1169.55a	–	–	298.99a	39.67c	298.99a	39.67cd	870.56b

was the highest, indicating that reducing basal N amount and increasing topdressing N amount appropriately could encourage wheat plants to absorb more fertilizer N and increase FNUE.

5.2 Effect of N rate and ratio of base fertilizer to topdressing on N translocation at different sources from vegetative organs to grains after anthesis

Table 3 shows that 67.19%–77.78% of N accumulation in the wheat grain originated from the translocation from vegetative tissues after anthesis, and a surplus of 22.22%–32.81% of N from N assimilated during grain filling. For each treatment, the translocation amount and the proportion of its contribution to grains from the soil were higher than those from fertilizer, with topdressing fertilizer contributing more than base fertilizer. Additionally, the translocation efficiency of fertilizer N was higher than that of soil N, and translocation efficiency of topdressing fertilizer N was the highest.

There were no significant differences between treatments with the same ratio of base fertilizer to topdressing and different fertilizer N rate in terms of translocation efficiency, translocation amount and its contribution proportion. This shows that increasing fertilizer N application rate could not encourage the plant to transfer more N from vegetative tissues to grains after anthesis. But at the same N application rate, the ratio of topdressing fertilizer could regulate translocation amount and translocation efficiency, while treatments N2 and N5, with a 1:2 ratio of base and topdressing, gained

the highest translocation amount and translocation efficiency. Increasing the topdressing fertilizer amount enhanced the contribution proportion of N from vegetative tissues after anthesis and decreased assimilation during grain filling. Treatments N2 and N5, whose ratio of base and topdressing was 1:2, had the highest N translocation efficiency, translocation amount and higher contribution proportion of assimilation during grain filling. Thus the ratio of base to topdressing may correspond to pre-anthesis N and post-anthesis N effectivity in order to gain higher grain N yield.

5.3 Effect of N rate and ratio of base fertilizer to topdressing on N uptake from different sources by wheat grains

As shown in Table 4, 73.46%–79.46% of N accumulated in the wheat grain originated from soil N, with the 20.54%–26.54% surplus of N from fertilizer N. When N fertilizer rate was increased from 168 to 240 kg/hm², there was no significant difference between treatments with the same ratio of base fertilizer to topdressing in the amount of N accumulation in the wheat grain. The amount of soil N accumulation in the grain decreased, indicating that increasing fertilizer amount did not increase the amount of N accumulation in the wheat grain, instead it weakened the providing ability of soil N. At the same N application rate, increasing the topdressing N amount consequently encouraged grains to absorb more fertilizer N, indicating that increasing the topdressing N amount appropriately could increase fertilizer N

Table 3 Translocation and contribution of different N sources in vegetative organs to grains after anthesis

Treatment	NDFBF			NDFTF			NDFF			NDFS			Total		
	NTA ^a /mg·pot ⁻¹	TE ^b /%	CP ^c /%	NTA/mg·pot ⁻¹	TE/%	CP/%	NTA/mg·pot ⁻¹	TE/%	CP/%	NTA/mg·pot ⁻¹	TE/%	CP/%	NTA/mg·pot ⁻¹	TE/%	CP/%
N1	63.6	75.9	6.9	92.9	85.9	10.1	156.5	81.6	17.1	556.5	76.3	60.7	713.0ab	77.4b	77.8a
N2	56.3	80.2	5.8	110.8	86.5	11.4	167.1	84.2	17.2	558.6	78.9	57.5	725.7a	80.1a	74.7a
N3				156.7	87.1	16.2	156.7	87.1	16.2	492.8	74.5	51	649.5c	77.2b	67.2b
N4	71.7	70	7.7	110.5	86.4	11.9	182.2	79.1	19.7	529.2	76.2	57.2	711.3ab	76.9b	76.8a
N5	62.2	75.9	6.4	124.9	85.7	12.8	187.1	81.3	19.2	545.2	79	56	732.3a	79.6a	75.3a
N6				163.1	85.7	16.7	163.1	85.7	16.7	497.5	74.8	51.1	660.6c	77.2b	67.8b

Note: ^aNTA: N translocation amount, N accumulation in vegetative organs on anthesis N accumulation in vegetative organs on maturity;

^bTE: translocation efficiency, NTA/N accumulation in vegetative organs on anthesis;

^cCP: contribution proportion, NTA/N accumulation in grain.

Table 4 Nitrogen uptake from different sources in wheat grain

Treatment	TNAA/mg·pot ⁻¹	NDFD						NDFS	
		NDFBF		NDFTF		Total		/mg·pot ⁻¹	/%
		/mg·pot ⁻¹	/%	/mg·pot ⁻¹	/%	/mg·pot ⁻¹	/%		
N1	916.61b	67.96b	7.41	120.36e	13.13	188.31c	20.54	728.29ab	79.46
N2	971.51a	58.39c	6.01	157.92d	16.25	216.31b	22.27	755.20a	77.73
N3	966.68a	–	–	213.59b	22.10	213.59b	22.10	753.09a	77.90
N4	925.83b	74.24a	6.74	152.13d	16.43	214.56b	23.17	711.27b	76.83
N5	973.11a	62.43b	6.42	195.87c	20.13	258.30a	26.54	714.81b	73.46
N6	974.61a	–	–	254.69a	26.13	254.69a	26.13	719.92b	73.87

accumulation amount in grains and increase the amount of N accumulation.

5.4 Effect of N rate and ratio of base fertilizer and topdressing on grain yield and protein content

As shown in Table 5, in the ¹⁵N tracer experiment, applying N fertilizer greatly increased grain yield, grain N concentration and grain N yield compared with that of treatment N0. When N fertilizer rate was increased from 168 to 240 kg/hm², there was no significant difference in grain yield, grain N concentration and grain N yield between treatments with the same ratio of base fertilizer to topdressing. At the same N application rate, increasing the ratio of topdressing fertilizer appropriately enhanced grain yield, and treatments N2 and N5, with a 1/3:2/3 ratio of base fertilizer and topdressing, had the highest grain yield. Grain N concentration increased with increasing ratio of topdressing N with treatments N3 and N6 having the highest concentrations, followed by treatments N2 and N5, then treatments N1 and N4. From Table 5, we can see that grain yield and grain N concentration in different treatments in the field experiment had the same trend in the changes as that in the ¹⁵N tracer experiment. So in the high yield, the changes in the ratio of base fertilizer to topdressing N could regulate grain yield and N concentration, and a high yield of both carbon and N could be simultaneously obtained. Treatment N2 was viewed as the optimum N application regime when considering the economic benefits.

Table 5 Effects of N rate and ratio of base fertilizer and topdressing on grain yield and protein content

Treatment	¹⁵ N tracer experiment			Field experiment		
	Grain yield/ g·pot ⁻¹	Protein content/%	Protein yield/g· pot ⁻¹	Grain yield/ kg·hm ⁻²	Protein content/%	Protein yield/kg· hm ⁻²
N0	36.49c	10.83d	3.95c	7325.57d	13.45d	985.29d
N1	43.28b	12.07c	5.22b	8057.21c	14.37c	1157.82c
N2	44.62a	12.41ab	5.54a	8151.71ab	15.44ab	1258.62ab
N3	43.37b	12.67a	5.51a	8042.85c	15.56a	1251.47ab
N4	42.95b	12.28c	5.28b	7909.80c	14.69c	1161.95c
N5	44.45a	12.47ab	5.55a	8177.21a	15.36ab	1259.09ab
N6	44.36a	12.52a	5.56a	8162.54ab	15.61a	1274.17a

6 Discussion

6.1 Effect of N rate and ratio of base fertilizer and topdressing on FNUE

Fertilizer N use efficiency is an important target in wheat management systems, which varies with different N rate and ratio of base fertilizer and topdressing. Many experiments (Huo et al., 2004; Jiang et al., 2004) have shown that the increases in N application decreases FNUE, similar to the results in this study. Zhao et al. (2000) reported that reasonable applications of N fertilizer increased the N accumulation amount in plants and enhanced FNUE. The better application regime was one half of N fertilizer applied in the fall and the other half applied at the jointing and anthesis stages. According to Bian et al. (1997), 37.8%–48.3% of N fertilizer can be utilized in a meadow-chestnut soil and topdressing fertilizer has no significant difference with base fertilizer. Our study showed that the main basal N absorbed by plants from sowing to jointing stages accounted for 78.04%–89.67%. Topdressing FNUE was remarkably higher than that of base fertilizer N. At the same N application rate, the ratio of base fertilizer to topdressing could regulate FNUE during different growth periods, and the FNUE of treatment N2 was the highest. Its N fertilizer rate was 168 kg/hm² and ratio of base fertilizer to topdressing is 1:2.

6.2 Effect of N rate and ratio of base fertilizer and topdressing on N uptake and translocation

The growth period from anthesis to maturity is an important stage for N uptake, translocation and distribution. Some studies (Pan et al., 1999) have reported that the wheat variety with the better ability for N uptake at the post-anthesis period could increase grain yield and improve grain quality. Our previous research (Wang et al., 2003b) showed that increasing N fertilizer application to within 240 kg/hm² could promote N absorption during late grain filling, corresponding to the performance of pre-anthesis N and post-anthesis N effectivity in order to gain higher grain N yield. Researchers (Elvira et al., 2004; Yu et al., 2002) reported that applying topdressing N could increase the N accumulation amount in plants and promote fertilizer N to be transferred to grains

thereby increasing grain yield and protein content. Under high-yield conditions, and with the same ratio of base fertilizer to topdressing, increasing N fertilizer rate could not regulate N uptake and translocation, but the change in ratio may regulate the mobilization and utilization of N assimilated prior to anthesis (pre-anthesis N) and the utilization of N assimilated during grain filling (post-anthesis N). Treatments N2 and N5, whose ratio of base fertilizer and topdressing was 1/3:2/3, could attain the highest N translocation efficiency, translocation amount and higher contribution proportion of N assimilated during grain filling. Thus, the ratio of base fertilizer and topdressing should correspond to pre-anthesis N and post-anthesis N effectivity in order to get a higher grain yield and protein content.

6.3 Effect of N rate and ratio of base fertilizer and topdressing on grain yield and protein content

Many recent studies (Ayoub et al., 1994; Zhu et al., 2003; Yue et al., 1998) have shown that increasing fertilizer N rate in the correct range and applying topdressing N could increase both grain yield and protein content, but the optimum N fertilizer application regimes were different in the different researches. Ayoub (Yu et al. 2002) suggested that the optimum ratio of base fertilizer and topdressing was 3:2, but Yue et al. (1998) reported that the optimum N fertilizer application regime was 160 kg/hm² and the optimum ratio of base fertilizer and topdressing was 1:1. Under high-yield conditions, at the same N application rate, increasing the ratio of topdressing fertilizer appropriately can enhance grain yield, protein content and protein yield. Based on the results from treatment N2 in this study, as far as grain yield, protein content and FNUE are concerned, the most appropriate N fertilizer application regime is 168 kg/hm² and the optimum ratio of base fertilizer to topdressing is 1:2.

The field experiment was conducted in the wheat field with high yield, and available N was 87.5 mg/kg. Typical strong gluten winter wheat cultivar (Jimai 20) currently used in local production was chosen for this study. But there is a great area of farmland in the Huang (Yellow River)-Huai (Huai River) Plain and the North China Plain where the available N content is lower than 80 mg/kg. So further studies about how plants and yield performance respond to N fertilizer rate and ratio of base and topdressing, and the determination of optimum N application regimes in wheat fields with different fertility are badly needed.

7 Conclusion

Under field conditions, applying N fertilizer can remarkably increase grain yield, grain N concentration and grain N yield compared with that of no application (treatment N0). When N fertilizer rate is increased from 168 to 240 kg/hm², there are no significant differences among treatments with the same

ratio of base fertilizer to topdressing in terms of grain yield, grain N concentration and grain N yield.

The ratio of base fertilizer to topdressing can regulate N uptake and translocation in wheat plants and grains. The main basal N absorbed by plants from sowing to jointing stage accounts for 78.04%–89.67%. Reducing the amount of base N and increasing the amount of topdressing N can reduce the loss of base N, make plants absorb more N, and enhance FNUE, which was the highest in treatment N2. Increasing the ratio of topdressing appropriately can also result in the highest N translocation efficiency, assimilation amount and higher contribution proportion of N assimilated during grain filling, increase N harvest index, grain yield and protein content. As far as grain yield, protein content and FNUE are concerned, the most appropriate N fertilizer application regime is the one used in treatment N2, where the N fertilizer rate was 168 kg/hm² and the ratio of base fertilizer to topdressing was 1:2.

References

- Arvind K S, Jagdish K L, Singh V K, Dwivedi B S (2004). Calibrating the leaf color chart for nitrogen management in different genotypes of rice and wheat in a system perspective. *Agron J*, 96: 1606–1621
- Ayoub M, Guertin S, Fregeau R J, Smith D L (1994). Nitrogen fertilizer effect on breading quality of hard red spring wheat in eastern. *Can Crop Sci Soc Am*, 34(5): 1346–1352
- Bian X J, Wang W J, Yang F C, Li R G, Cai G X, Li X H, Yang Z, Zhu Z L (1997). Fate of fertilizer nitrogen applied to spring wheat growing on a meadow chestnut soil in plateau of north Hebei Province. *Acta Pedol Sin*, 34(4): 60–66 (in Chinese)
- Du J Z, Li W X, Hu S L, Liu J J (2001). Nitrogen assimilation, transfer and utilization in relation to grain protein content and yield of spring wheat genotypes differing in quality. *Acta Agron Sin*, 27(2): 253–260 (in Chinese)
- Elvira G L, Rafael J L B, Luis L B (2004). Effect of N rate, timing and splitting and N type on bread-making quality in hard red spring wheat under rainfed Mediterranean conditions. *Field Crops Res*, 85: 213–236
- He Z F (1985). *Analysis Technique for Grain Quality of Cereals and Oils*. Beijing: Agriculture Press, 31–41, 57–59 (in Chinese)
- Hou Y L, Brien L O, Zhong G R (2001). Study on the dynamic changes of the distribution and accumulation of nitrogen in different plant parts of wheat. *Acta Agron Sin*, 27(4): 493–499
- Huo Z Y, Ge X, Zhang H C, Dai Q G, Xu K, Gong Z K (2004). Effect of different nitrogen application types on N-absorption and N-utilization rate of specific use cultivars of wheat. *Acta Agron Sin*, 30(5): 449–454 (in Chinese)
- Jaime L, Antonio L, Javier F, Sergi E, Joan S (2001). Bread-making wheat and soil nitrate as affected by nitrogen fertilization in irrigated Mediterranean condition. *Agron J*, 93: 1183–1190
- Jiang L G, Dai T B, Jiang D, Cao W X, Gan X Q, Wei S Q (2004). Characterizing physiological N-use efficiency as influenced by nitrogen management in three rice cultivars. *Field Crops Res*, 88: 239–250
- Lin Q, Hou L B, Han W (2004). Effects of nitrogen rates on grain yield and quality of wheat in different soil fertility. *Plant Nut Fert Sci*, 10(6): 561–567 (in Chinese)
- Pan Q M, Yu Z W, Wang Y F, Tian Q Z (1999). Studies on uptake and distribution of nitrogen in wheat at the level of 9 000 kg per hectare. *Acta Agron Sin*, 25(5): 540–547 (in Chinese)

- Stevens W B, Hoelt R G, Mulvaney R L (2005). Fate of nitrogen-15 in a long-term nitrogen rate study: II. Nitrogen uptake efficiency. *Agron J*, 97: 1046–1053
- Wang H, McCaig T N, DePauw R M, Clarke F R, Clarke J M (2003a). Physiological characteristics of recent Canada western red spring wheat cultivars: components of grain nitrogen yield. *Can J Plant Sci*, 83(4): 699–707
- Wang Y F, Jiang D, Yu Z W, Cao W X (2003b). Effects of nitrogen rates on grain yield and protein content of wheat and its physiological basis. *Sci Agric Sin*, 36(5): 513–520 (in Chinese)
- Wang Y F, Yu Z W, Li S X, Yu S L (2003c). Effects of soil fertility and nitrogen application rate and nitrogen absorption and translation, grain yield, and grain protein content of wheat. *Chin J Appl Ecol*, 14(11): 1868–1872 (in Chinese)
- Yu Z W, Tian Q Z, Pan Q M, Yue S S, Wang D, Duan C L, Duan L L, Wang Z J, Niu Y S (2002). Theory and practice on cultivation of super high yield of winter wheat in the wheat fields of Yellow River and Huaihe River districts. *Acta Agron Sin*, 28(5): 577–585 (in Chinese)
- Yue S S, Yu Z W, Yu S L (1998). Effect of nitrogen application at different growth stages on nitrogen distribution and leaves metabolism in winter wheat. *Acta Agron Sin*, 24(5): 1–4 (in Chinese)
- Zhang Q J, Zhang L Y, Bi H W (1997). The absorption, accumulation and translation of nitrogen and their relationships to grain protein content in spring wheat variety. *Acta Agron Sin*, 23(6): 712–718 (in Chinese)
- Zhao G C, He Z H, Tian Q Z, Li K M, Liu L H, Li Z H, Zhang W B (2004). Effect of application rate of nitrogen on its utilization in wheat by using ¹⁵N tracer technique. *Acta Agron Sin*, 30(2): 159–162 (in Chinese)
- Zhao G C, Li C X, Zhang B M, Wang C Y (2000). Effect of different proportion and stage of nitrogen application on nitrogen utilization in winter wheat. *Acta Agric Boreal-Sin*, 15(3): 99–102 (in Chinese)
- Zhu X K, Guo W S, Zhou J L, Hu H, Zhang Y, Li C Y, Feng C N, Peng Y X (2003). Effects of nitrogen on grain yield, nutritional quality and processing quality of wheat for different end uses. *Sci Agric Sin*, 36(6): 640–645 (in Chinese)