

Evaluation of In-season Nitrogen Management for Summer Maize in the North China Plain

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Field experiments tested N fertilizer at different rates and ratios of basal:topdress application. A total N rate of 120 to 180 kg/ha was shown to maximize grain yield and, with split application, reduce N inputs by 25 to 50% compared to typical farm practice within the North China Plain.



The North China Plain (NCP) is one of the most important areas for summer maize production in China. The crop grows from the middle of June to the end of September and high yields in this intensively farmed region have been obtained over the past 2 decades through excessive N fertilization (He et al., 2009; Ju et al., 2009). This results in the accumulation of soil N as leachable NO_3^- , which risks groundwater pollution and low NUE by crops (Cui et al., 2009; Zhao et al., 2010). At present, typical farmer practice is to apply all their N fertilizer at once, either as a basal application before planting or as topdressing during the 7-leaf stage. Neither of these patterns of N application can provide a soil N supply that is in synchrony with crop N demand.

It is essential to develop appropriate N management methods that can overcome any environmental problems or low NUE that results from excessive N application. It is also important to promote the development of sustainable agricultural production within this region. The most logical approach to increasing NUE is to combine applications of basal N and topdressed N at critical growth stages that coincide with crop N demand and seasonal soil N supply. High-yielding maize varieties show increased N uptake after anthesis, and the 8 to 10-leaf stages are critical times for topdressed N (Barbieri et al., 2008). Since current N management practices for summer maize in this region are not tailored to these growth requirements, this study evaluated in-season N management based on grain yield and crop N uptake, and provides a theoretical base for reducing N application and enhancing NUE in the NCP.

Field experiments were conducted simultaneously on farms near the cities of Hengshui and Xinji (37°N , 115°E), in Hebei province, from July to October 2009. The two sites were approximately 25 km apart, and had similar climatic conditions. The previous crop at both sites was winter wheat. In Hengshui, the soil texture was clay loam, and the chemical properties in the 0 to 20 cm soil profile were: pH 8.4; organic matter 13.4 g/kg; Olsen-P 8.9 mg/kg; and $\text{NH}_4\text{OAc-K}$ 103 mg/kg. Before planting, the $\text{NH}_4^+\text{-N}$ content in the 0 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm soil layers were 3.1, 0.9, 2.5, 13.2, and 10.0 mg/kg, respectively, and $\text{NO}_3^-\text{-N}$ content were 12.2, 11.6, 12.7, 7.2, and 6.3 mg/kg, respectively. In Xinji, the soil texture was sandy loam, and the chemical properties in the 0 to 20 cm soil profile were: pH 8.6; organic matter 0.82 g/kg; Olsen-P 6.2 mg/kg; and $\text{NH}_4\text{OAc-K}$ 97 mg/kg. Before plant-

ing, the $\text{NH}_4^+\text{-N}$ content in the 0 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm soil layers was 1.2, 1.2, 1.1, 1.0, and 0.8 mg/kg, respectively, while the $\text{NO}_3^-\text{-N}$ contents were 14.8, 11.9, 10.4, 7.8, and 6.1 mg/kg, respectively.

Besides a zero-N control, seven N treatments varied the amount and/or ratio of basal: top-dressed N (**Table 1**). A 0:240

Table 1. Experimental design for nitrogen applied to summer maize (Hengshui and Xinji, Hebei).

Treatment	Basal ----- kg/ha -----	Topdress ----- kg/ha -----	Topdress date
N0	0	0	-
N120 (0:120) ^a	0	120	June 25
N120 (30:90)	30	90	June 25
N120 (60:60)	60	60	June 25
N180 (0:180)	0	180	June 25
N180 (45:135)	45	135	June 25
N180 (90:90)	90	90	June 25
N240 (0:240) ^b	0	240	July 17

^a Values in the parenthesis indicate basal:topdress N rate.

^b Farmers' practice treatment.

treatment (i.e. 0 kg basal and 240 kg topdressed) was designed to simulate the N application pattern commonly used by farmers. Basal N (urea) was broadcast before planting followed by 600 m^3/ha of irrigation water; while topdressed N was applied at the V10 (10-leaf) stage. Before planting, all plots received 90 kg $\text{P}_2\text{O}_5/\text{ha}$ and 90 kg $\text{K}_2\text{O}/\text{ha}$. All winter wheat residues were left on the field. The maize variety was Zhengdan 958.

Grain Yield, Crop N Uptake and Utilization

In Hengshui, no significant difference in grain yield was found among N supplying treatments, and only the low rate of 120 kg N/ha was required to achieve the maximum grain yield (**Table 2**). Combining basal N with topdressed N promoted crop N uptake, RE_N , and AE_N ; but did not impact HI or HI_N with the exception of the 0:240 treatment, which generated a significantly lower HI than some treatments that received basal N.

The Xinji site was more responsive to N as all treatments receiving basal N out-yielded the control, and the 180 kg N/ha rate achieved the maximum grain yield (**Table 2**). When N was applied solely as a topdressing, no significant differences in grain yield were found among the N0, N120 (0:120), and N180 (0:180) treatments. Crop N uptake, RE_N , and AE_N showed similar trends to those observed in Hengshui. Treatments that

Common abbreviations and notes: N = nitrogen; P = phosphorus; NUE = nitrogen use efficiency; $\text{NH}_4\text{OAc-K}$ = ammonium acetate-extractable K; NH_4^+ = ammonium; NO_3^- = nitrate; RE = recovery efficiency; AE = agronomic efficiency; HI = harvest index.

Table 2. Maize grain yield, crop N uptake, nitrogen use efficiency (RE_N and AE_N), HI, and HI_N of different N treatments (Hengshui and Xinji, Hebei).

Sites	Treatment	Grain yield, kg/ha	Crop N uptake, kg N/ha	RE_N , kg/kg	AE_N , kg/kg	HI, %	HI_N , %
Hengshui	N0	7,384 ^a	178.8 ^c	-	-	54.5 ^a	60.2 ^a
	N120 (0:120)	7,877 ^{ab}	207.1 ^b	23.6 ^d	4.1 ^b	54.2 ^a	59.9 ^a
	N120 (30:90)	8,181 ^a	230.6 ^{ab}	43.2 ^b	6.6 ^a	54.8 ^a	60.7 ^a
	N120 (60:60)	8,231 ^a	246.7 ^a	56.6 ^a	7.1 ^a	54.5 ^a	60.6 ^a
	N180 (0:180)	8,037 ^{ab}	212.3 ^b	18.6 ^d	3.6 ^{bc}	53.3 ^{ab}	60.5 ^a
	N180 (45:135)	8,088 ^{ab}	217.4 ^b	21.5 ^d	3.9 ^b	54.7 ^a	62.9 ^a
	N180 (90:90)	8,181 ^a	239.1 ^a	33.5 ^c	4.4 ^b	52.3 ^{ab}	60.6 ^a
	N240 (0:240)	8,074 ^{ab}	239.5 ^a	25.3 ^d	2.9 ^c	50.1 ^b	57.1 ^a
Xinji	N0	6,158 ^c	103.2 ^d	-	-	57.6 ^a	70.1 ^a
	N120 (0:120)	6,299 ^c	124.1 ^c	17.5 ^e	1.2 ^d	51.7 ^b	63.9 ^{ab}
	N120 (30:90)	6,908 ^b	153.4 ^a	41.9 ^a	6.2 ^{ab}	55.8 ^a	67.3 ^{ab}
	N120 (60:60)	6,769 ^b	146.8 ^{ab}	36.3 ^b	5.1 ^b	55.8 ^a	65.2 ^{ab}
	N180 (0:180)	6,677 ^{bc}	137.3 ^b	19.0 ^e	2.9 ^c	51.3 ^b	64.0 ^b
	N180 (45:135)	7,228 ^{ab}	150.7 ^{ab}	26.2 ^c	5.9 ^b	56.2 ^a	68.8 ^{ab}
	N180 (90:90)	7,435 ^a	154.1 ^a	28.3 ^c	7.2 ^a	56.6 ^a	67.4 ^{ab}
	N240 (0:240)	6,912 ^b	155.4 ^a	21.8 ^d	3.1 ^c	50.2 ^b	62.4 ^b

^a Within each column, mean values followed by different letters are significantly different ($p < 0.05$).

Table 3. Nitrogen balance sheet for treatments applied during maize growing season (Hengshui and Xinji, Hebei).

Site	Treatment	----- N output -----			----- N input -----		
		N rate (1)	Initial N_{min}^a (2)	Apparent N mineralization (3)	Crop N uptake (4)	Residual $N_{min}^{b(5)}$ (5)	Apparent N loss (1)+(2)+(3)-(4)-(5)
Hengshui	N0	0	217.4	107.8	178.8 ^{cd}	146.4 ^d	0
	N120 (0:120)	120	217.4	107.8	207.1 ^b	242.0 ^b	-3.9 ^d
	N120 (30:90)	120	217.4	107.8	230.6 ^{ab}	237.0 ^b	-22.4 ^e
	N120 (60:60)	120	217.4	107.8	246.7 ^a	218.5 ^c	-20 ^e
	N180 (0:180)	180	217.4	107.8	212.3 ^b	257.3 ^{ab}	35.6 ^b
	N180 (45:135)	180	217.4	107.8	217.4 ^b	255.6 ^{ab}	32.4 ^b
	N180 (90:90)	180	217.4	107.8	239.1 ^{ab}	246.8 ^b	19.3 ^c
	N240 (0:240)	240	217.4	107.8	239.5 ^{ab}	271.9 ^a	53.8 ^a
Xinji	N0	0	156.6	60.6	103.2 ^c	114.0 ^d	0
	N120 (0:120)	120	156.6	60.6	124.1 ^b	154.9 ^{ab}	51.2 ^c
	N120 (30:90)	120	156.6	60.6	153.4 ^a	131.1 ^c	45.7 ^c
	N120 (60:60)	120	156.6	60.6	146.8 ^{ab}	138.5 ^c	44.9 ^c
	N180 (0:180)	180	156.6	60.6	137.3 ^b	156.1 ^{ab}	96.8 ^b
	N180 (45:135)	180	156.6	60.6	150.7 ^{ab}	149.0 ^{bc}	95.5 ^b
	N180 (90:90)	180	156.6	60.6	154.1 ^a	142.7 ^{bc}	93.4 ^b
	N240 (0:240)	240	156.6	60.6	155.4 ^a	164.9 ^a	129.9 ^a

^a Initial N_{min} , soil mineral N in 0 to 100 cm soil layer before planting.

^b Residual N_{min} , soil mineral N in 0 to 100 cm soil layer after harvest.

^c Within each column, means followed by different letters are significantly different ($p < 0.05$).

received basal N showed higher HI values than the zero-N control, but there were no significant differences in HI_N except for the low HI_N value of the N240 (0:240) treatment.

At both sites, RE_N and AE_N increased along with basal N rate. Maize grown in Hengshui showed higher grain yield, crop N uptake, and NUE than in maize grown in Xinji; however, the HI and HI_N values were lower for maize grown in Hengshui (**Table 2**).


Nitrogen Balance

The initial N_{min} , apparent N mineralization, and crop N uptake in Hengshui were higher than those values obtained in Xinji (**Table 3**). Thus, indigenous N supply in Hengshui was higher than that in Xinji. Compared with treatments that only received top-dressed N at V10 stage, those that received both basal and top-dressed N showed reduced residual N_{min} after maturity. In Hengshui, soil residual N_{min} was higher in the N240 (0:240) treatment than in the N120 (0:120) treatment. In Xinji, however, no significant difference was found among the three N treatments that did not receive basal N. At both sites, the apparent N losses during the maize growing season increased with total N application rate. For treatments receiving the same amount of total N, the apparent N loss increased with topdress N rate, and these values were significantly higher in Xinji than in Hengshui.

Discussion and Conclusions

In this study, basal application of N did not affect grain yield in Hengshui because of high indigenous N supply. In Xinji, the highest grain yield was achieved via application of N as basal and top-dressed fertilizer. This despite reports that indicate no basal N fertilizer is recommended to improve NUE when soil N indigenous supply is considered adequate (Zhao et al., 2012).

In Hengshui and Xinji, the total N rate of 120 and 180 kg N/ha—half applied basally and half topdressed—could meet the N demands of high yielding maize during the entire growing season. The optimal N application rates determined here for maximum grain yield indicate that N fertilizer could be reduced by more than 50% and 25% in one summer maize season in Hengshui and Xinji, respectively. Therefore the apparent risk to N loss can be reduced if compared with traditional N fertilization practice. The

question of whether N rates of 120 and 180 kg/ha can sustain high grain yields in the next crop season requires further study. However, for optimum N management, fertilizer applications should be tailored to each specific field or region, because N availability and N use vary according to crop growth, soil fertility, and soil texture. 

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