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Effects of types and application rates of nitrogen fertilizer on the development and nitrogen utilization of summer maize

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Abstract To reduce nitrogen fertilizer (NF) loss and improve nitrogen use efficiency (NUE) in summer maize, the effects of the different application rates of three types of NF (urea, coated urea and compound fertilizer) on the growth and development and NUE of summer maize (cultivars: Zhengdan958 and Nongda108) were studied in 2004. The main findings of this study were: (1) The yields of the two cultivars increased significantly with each increment of N application rate from 0–180 kg N·hm⁻². The increase in the yield of summer maize treated with compound fertilizer was greater than the yield of those treated with either of the other two fertilizers at the same application rate, while the differences among the three types of NF were not significant. (2) Grain number per ear of the two cultivars rose in relation to the increase in N application rate, while its relationship with the type of NF was very weak. The type of NF had a greater impact on 1000-grain weight, and a difference between cultivars was observed. (3) Leaf area index (LAI), dry matter weight and leaf chlorophyll content grew in relation to the increase in N application rate, and were improved more sharply by compound fertilizer or coated urea than by urea alone. (4) Compared to the results achieved with urea, the NUEs of summer maize treated with coated urea and compound fertilizer were higher but the nitrogen harvest index was not improved. In addition, the NUEs of three types of NF exhibited a genotype difference from summer maize.

Keywords summer maize, type of nitrogen fertilizer, N application rate, growth and development, nitrogen use efficiency (NUE)

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1 Introduction

Maize is one of the most important food crops in China. Maize yield is highly sensitive to nitrogen in soil and increases significantly with N application. Hence, N application is an important means to achieve a high and stable yield in maize production. Maize can also withstand high concentrations of N in its tissues without suffering adverse effects. As a result, nitrogen over-fertilization is a common feature of the summer maize-winter wheat rotation system in North China Plain. An investigation showed that the average N application rate to summer maize was 256 kg·hm⁻² in the outskirts of Beijing (Zhao et al., 1997), while the nitrogen use efficiency (NUE) was only 16%–22% (Li, 1999).

Nitrogen over-fertilization may result in a significant decrease in NUE and potential pollution of the environment, which impacts not only the economic benefit of agricultural production but also the environment and human health. In this paper, we were thus compelled to study the effects of different application rates of three types of NF (urea, coated urea and compound fertilizer) on the growth and development and nitrogen utilization of summer maize in order to improve summer maize production fertilization techniques in the North China Plain.

2 Materials and methods

2.1 Experimental field

This experiment was conducted in Wuqiao Experimental Station (37°29′–37°47′N, 116°19′–116°42′E) of China Agricultural University in 2004. The previous crop was winter wheat, which had been cultivated with the water-saving cultivation technique called Wuqiao model (Li et al., 2000). The basal soil fertility is shown in Table 1.

Table 1 The total N, Olsen-P, extractable-K and organism content in 0–20 cm, and 20–40 cm soil depth before the summer maize growing season in the experimental field

soil layer/cm	total N/mg·g ⁻¹	Olsen-P/mg P ₂ O ₅ ·kg ⁻¹	NH ₄ AC extractable-K/mg K ₂ O·kg ⁻¹	organism content/mg·g ⁻¹
0–20	0.76	14.05	79.11	8.5
20–40	0.44	5.22	75.26	4.7

2.2 Experimental design and field management

There were a total of 14 treatments with 3 replications, and a completely randomized distribution in the field. The size of each plot was 33.6 m² (4.8 m × 7 m). The abbreviation of each treatment is shown in Table 2. Coated urea (N content = 42%) was provided by the College of Resource and Environment, China Agricultural University. Compound fertilizer (Brand: Wuliang, Sichuan Fangying Fertilizer Company, with N, P₂O₅ and K₂O of compound fertilizer at 15%, respectively) and urea (N content = 46%) were commercially available. One third of the urea was applied as the basal fertilizer on June 18 and the remainder was used as top-dressing on July 22 (10-leaf stage). Coated urea and compound fertilizer were applied as the basal fertilizer on June 18. A basal dressing of 90 kg·hm⁻² P₂O₅ and 90 kg·hm⁻² K₂O was applied during the urea and coated urea treatments. Band sowing of summer maize was applied with a 80 cm row space on June 14 under non-tillage conditions. Planting densities for Zhengdan958 and Nongda108 were 75000 and 60000 plants per hectare, set at a 5-leaf stage, respectively. The silking and harvesting dates of Zhengdan958 were on August 9 and September 28, respectively, with a growing period of 106 days. The Nongda108 silked on August 12 and was harvested on October 3 with a growing period of 111 days.

2.4 Calculations

$$\text{Nitrogen use efficiency (NUE, \%)} = \frac{\text{N uptake in fertilized plants} - \text{N uptake in no N fertilization plants}}{\text{N application rate}} \times 100.$$

Nitrogen harvest index (NHI, %) = N accumulated in grains/N accumulated in shoot × 100.

Data was analyzed by Excel 2003 and significance of difference was tested by SAS (9.0).

Table 2 Treatments and their codes

cultivar	fertilizer	N rate/kg N·hm ⁻²	code	cultivar	fertilizer	N rate/kg N·hm ⁻²	code
Zhengdan958	no fertilizer	0	Z 0	Nongda108	no fertilizer	0	N0
	urea	90	ZU90		urea	90	NU90
		180	ZU180		urea	180	NU180
	coated urea	90	ZCU90		coated urea	90	NCU90
		180	ZCU180		coated urea	180	NCU180
	compound fertilizer	90	ZCF90		compound fertilizer	90	NCF90
		180	ZCF180		compound fertilizer	180	NCF180

2.3 Sampling and measurements

Sampling was conducted at key growing stages, including 9-leaf, 12-leaf, silking, dough (21 days after silking, or 21DAS) and maturity. Leaf area (LA) was determined through the length-width-coefficient method (Yi et al., 2006). The leaf area index (LAI) was calculated as LA per unit land area. The leaves, stems and ears of the plants were separated. These were segregated and placed in sacks and dried in an oven at 105°C for 30 minutes and then at 80°C until a constant weight for dry matter was reached. The N content of different parts of the maize shoots was measured with the Kjeldahl method (Hunan Agricultural College, 1988).

Leaf chlorophyll content was reflected by Soil Plant Analysis Development (SPAD) value, which was determined by a chlorophyll meter (SPAD-502, MINOLTA, Japan). Leaf above ear, ear-leaf and lead under ear of five plants per plot were measured continuously, and the average of 10 measurements on each leaf was recorded as one data point.

Yields were measured by harvesting 5 m × 2 line in each plot. Grain yield was calculated by factoring in 14% of humidity. Yield components were measured using 10 ears randomly collected in the field.

3 Results

3.1 Yields and yield components

There was a significant increase in yield by N application for both cultivars. Different types of NF had different effects on yield. At a 180 kg N·hm⁻² (high N) level, the yield of Zhengdan958 showed a trend of compound fertilizer (CF) > urea (U) > coated urea (CU), while the yield of Nongda108 showed a trend of CF > CU > U without significant differences among the three treatments. At a 90 kg N·hm⁻² (low N) level, Zhengdan958 showed a trend of CF > CU > U and the yield of CF treatment was significantly higher than that of U treatment, while Nongda108 showed a trend of U > CF > CU, without significant differences among the three treatments. Yields in high N treatments were generally significantly higher than those in low N treatments. CF treatment had the greatest effect on improving yield, but the yield increase of CU and U showed a difference between cultivars (Table 3).

The grain number per ear of both cultivars could be increased by N application. The grain number per ear at a high N level was higher than that at a low N level in the three types of NF. The trend for Nongda108 was clearer than that of Zhengdan958 and the increasing extent of

the former was greater. 1000-grain weight of Zhengdan958 was increased with each increment of N rate, and the three types of NF showed the same trend. As for Nongda108, 1000-grain weight showed a trend of low N > high N > N0 in U and CU treatments, but it was heightened slightly only in high N treatment of CF. The results showed that the grain number per ear of two cultivars could be increased in the three types of NF, but the effect of N application rate on 1000-grain weight varied between cultivars and among types of NF (Table 3).

3.2 Leaf area and dry matter accumulation

Leaf area index (LAI) at all stages could be increased by N application, with the LAI at a high N level being greater than that at a low N level. A similar trend for two cultivars was observed with the three types of NF. When LAI at silking was measured, Zhengdan958 showed a trend of CF slightly higher than that of CU while Nongda108 showed an opposite trend, with the least LAI of the two cultivars undergoing U treatment (Table 4). The results showed that the LAI of two cultivars could be increased by the N rate and the growth observed in CF and CU treatments was greater than that seen in U treatments.

Table 3 Yields and yield components of different treatments of Zhengdan958 and Nongda108

treatment	effective ears	grain number per ear	1000-grain weight/g	theoretical yield/kg·hm ⁻²	actual yield/kg·hm ⁻²	harvest index
Z 0	73754	443 b	304 b	9902 dC	9509 d C	0.54 a
ZU90	72087	464 a	300 b	10042 cdBC	9875 cd BC	0.55 a
ZU180	78754	456 ab	308 ab	11021 aA	10621 a A	0.56 a
ZCU90	76254	438 b	310 a	10319 bcAB	10103 bc AB	0.55 a
ZCU180	72920	473 a	315 a	10808 aA	10573 a A	0.55 a
ZCF90	76671	455 ab	309 a	10761 abA	10492 ab A	0.55 a
ZCF180	75837	469 a	312 a	11101 aA	10756 a A	0.55 a
N 0	62503	446 c	294 b	8171 dC	7914 d C	0.50 a
NU90	63753	477 b	306 a	9314 bcAB	9086 bc AB	0.50 a
NU180	63337	498 a	304 a	9580 abA	9310 ab A	0.50 a
NCU90	64170	470 b	304 a	9155 cAB	8978 c AB	0.49 a
NCU180	62503	505 a	304 a	9582 abA	9327 ab A	0.49 a
NCF90	63337	496 a	293 b	9201 bcAB	9083 bc AB	0.50 a
NCF180	63753	511 a	296 b	9641 aA	9496 a A	0.50 a

Note: Figures within each cultivar and each column followed by the same lowercase letter are not significantly different at $P < 0.05$ level; Figures within each cultivar and each column followed by capital letter are not significantly different at $P < 0.01$ level. The same below.

Table 4 Trend of leaf area index (LAI) in different treatments

treatment	9-leaf	12-leaf	silking	21DAS	maturity	treatment	9-leaf	12-leaf	silking	21DAS	maturity
Z0	1.46	3.30	4.75 d	4.24	2.43	N0	1.48	4.11	4.42 c	3.64	2.41
ZU90	1.76	3.68	4.96 c	4.60	2.68	NU90	1.78	4.39	4.58 c	3.94	2.62
ZU180	1.81	3.78	5.30 b	4.66	2.71	NU180	1.73	4.51	4.87 b	4.09	3.04
ZCU90	1.86	3.61	5.17 bc	4.81	2.47	NCU90	1.82	4.56	4.88 b	4.15	2.85
ZCU180	1.92	3.75	5.57 a	5.10	3.26	NCU180	1.84	4.57	5.06 a	4.64	3.20
ZCF90	1.83	3.61	5.16 bc	4.60	2.90	NCF90	1.69	4.54	4.86 b	3.97	2.61
ZCF180	1.88	3.74	5.64 a	5.16	3.38	NCF180	1.78	4.65	4.91 b	4.56	3.11

Dry weight (DW) of summer maize was significantly improved by N application at all stages. The DW of Zhengdan958 at maturity showed a trend of ZCF180 > ZCF90 > ZCU180 > ZU180 > ZCU90 > ZU90 > Z0, while the DW of Nongda108 showed a trend of NCU180 > NCF180 > NU180 > NU90 > NCU90 > NCF90 > N0 (Fig. 1 and Fig. 2). The DWs of the two cultivars showed a trend of high N > low N > N0 commonly. At a high N level, the effect of improved DW in CU or CF treatment was more pronounced, whereas at a low N level, the CF treatment had the best effect on improving DW for Zhengdan958, while U and CU treatments worked better for Nongda108. These results showed that CF and CU were more advantageous to dry matter accumulation than U. Furthermore, the difference in DW between the high N and low N level of Zhengdan958 was greater than that of Nongda108 after the 12-leaf stage. It is clear that dry matter accumulation of Zhengdan958 is more affected by the types of NF than that of Nongda108.

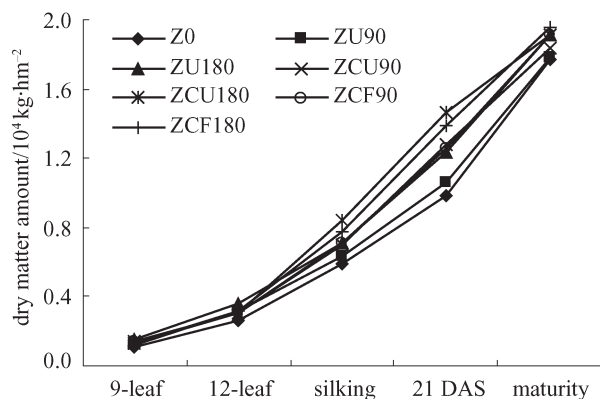


Fig. 1 Trends of dry matter accumulation of Zhengdan958 in different treatments

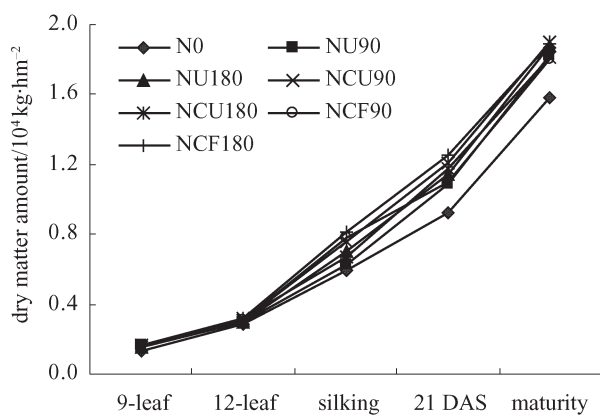


Fig. 2 Trends of dry matter accumulation of Nongda108 in different treatments

3.3 SPAD value of leaves

Leaf SPAD values of two cultivars clearly increased after N application. Leaf SPAD values at a high N level were greater than those at a low N level, with the same trend observed among three positional leaves and between August 25 and September 6. The SPAD value of the leaf above ear was highest and minimal differences between ear-leaf and leaf under ear were found at the two stages for Zhengdan958. The SPAD values of the ear-leaf (August 25) and the leaf above ear (September 6) were higher, and that of the leaf under ear was lower for Nongda108. The differences in the leaf SPAD value among different positional leaves of Zhengdan958 were clearer than those in Nongda108. Based on the distribution of “#” in three types of NF (Table 5), it was determined that the leaf SPAD values in CF and CU treatments are higher, indicating that the leaf SPAD values of the two cultivars were increased by the N rate, and the effects of CF and CU on improving chlorophyll content were greater than that of U.

3.4 Nitrogen accumulation and nitrogen utilization

Shoot nitrogen accumulation (NAA) of two cultivars was improved by the N application, while nitrogen use efficiency (NUE) was decreased with each increment of N rate. NUE was 40%–50% at the low N level (besides ZU90), and was 24%–37% at the high N level (Table 6). A clear difference in NAA at maturity between cultivars was observed, which shows that a clear genotype difference in the NAA of maize exists (Xiang et al., 2003). The NAA in CU and CF treatments was larger than that in the U treatment at the same N level, which resulted in the heightening of NUE, but the extent of the increase was different among the two cultivars. Compared to U, CU and CF were more effective for Zhengdan958 and Nongda108 in improving the NUE at a low N level and at a high N level, respectively. The effect of CU was greater than that of CF simultaneously. If used to improve NUE, CF is appropriate for Zhengdan958 at a low N level, while CU can be used at a high N level. Meanwhile, CU can improve NUE for Nongda108 at any N level.

The difference in the NAA between the two cultivars treated with the low N and the high N was less before 12-leaf stage. The three types of NF showed the same trend, whereas a more obvious difference appeared after silking. The appearance of the greatest level of difference in the NAA was related to both cultivars and types of NF. Zhengdan958 should be treated with U at maturity, CU at 21 days after silking and CF at silking. Nongda108 should be treated with U at silking, CU at 21 days after silking and CF at maturity. The results indicated that the changes in maize shoot nitrogen accumulation induced by the N application rate were influenced by the types of NF and cultivars.

Table 5 Leaf SPAD values in filling stage of different treatments

treatment	August 25				September 6			
	leaf above ear	ear-leaf	leaf under ear	average	leaf above ear	ear-leaf	leaf under ear	average
Z0	55.1	52.3	52.0	53.1	56.7	51.5	53.2	53.8
ZU90	56.3	54.8	53.5	54.9	56.9 [#]	55.2 [#]	54.3	55.5 [#]
ZU180	55.8	56.0 [#]	53.2	55.0	56.8	55.1 [#]	54.2	55.4
ZCU90	57.0	53.3	53.7	54.7	55.4	51.1	54.8 [#]	53.8
ZCU180	60.8 [#]	55.4	56.6 [#]	57.6 [#]	56.7	54.2	57.2 [#]	56.0 [#]
ZCF90	57.1 [#]	55.1 [#]	53.9 [#]	55.4 [#]	56.8	52.5	51.6	53.6
ZCF180	58.9	55.6	55.8	56.8	57.6 [#]	54.0	55.5	55.7
N0	53.8	54.4	52.5	53.6	55.9	55.5	54.8	55.4
NU90	58.6	57.4	56.9	57.6	59.9	58.1	56.8	58.3
NU180	60.3	60.5	59.2	60.0	59.3	61.7 [#]	57.0	59.3
NCU90	56.6	59.0 [#]	57.1	57.6	59.1	58.9 [#]	57.3	58.4
NCU180	61.1	60.1	59.8 [#]	60.3 [#]	61.7 [#]	59.3	59.2	60.1
NCF90	58.7 [#]	59.0 [#]	59.3 [#]	59.0 [#]	60.3 [#]	57.2	60.5 [#]	59.3 [#]
NCF180	61.2 [#]	61.4 [#]	58.1	60.2	61.5	59.4	59.4 [#]	60.1 [#]

Note: # means the data was the maximum under the same N application rate.

Table 6 Nitrogen use efficiency (NUE, %), nitrogen harvest index (NHI, %) and trend of plant shoot nitrogen accumulation (kg N·hm⁻²) in different treatments

treatment	9-leaf	12-leaf	silking	21 DAS	maturity			NUE/%
					total N	grain N	NHI/%	
Z 0	25.1	44.9	73.5	116.8	166.3	110.5	66.45	–
ZU90	28.8	63.5	109.6	134.1	192.5	128.7	66.84	29.06
ZU180	38.8	61.3	127.5	163.4	209.6	135.2	64.49	24.06
ZCU90	40.6	68.7	113.5	169.6	204.2	127.3	62.34	42.10
ZCU180	41.6	70.4	140.9	210.8	214.4	137.7	64.19	26.73
ZCF90	34.8	62.1	116.0	169.3	207.0	132.9	64.22	45.19
ZCF180	36.4	67.1	142.1	178.2	209.9	133.0	63.36	24.19
N 0	22.8	36.4	86.5	107.7	152.5	89.0	58.40	–
NU90	28.5	54.7	108.6	144.7	195.1	117.4	60.16	47.43
NU180	35.6	53.0	136.2	160.1	200.9	120.0	59.71	26.93
NCU90	39.6	59.1	124.9	145.1	196.2	114.3	58.24	48.63
NCU180	40.5	62.7	148.9	174.9	219.3	122.1	55.66	37.15
NCF90	34.5	56.2	131.0	170.7	195.5	118.9	60.84	47.86
NCF180	39.6	65.9	146.5	177.6	211.4	121.9	57.66	32.74

The NAA in plant shoots and grains of two cultivars were increased by the N rate, and the three types of NF showed the same trend, but the nitrogen harvest index (NHI) was improved in only a few treatments (ZU90, NU90, NU180 and NCF90). At the same time, the NHIs in the CU and CF treatments were smaller than those in the U treatments (Table 6). So, the NAA in plant shoots could be improved by both CU and CF, but the NHI could not be improved accordingly.

time, yields in high N treatments were generally significantly higher than yields in low N treatments. At the same N level, the CF treatment had the greatest effect on improving yield, but yield increase with CU and U differed between cultivars. Yield component was affected by N application and the grain number per ear was increased by the N rate of the three types of NF, but the effect of N application rate on 1000-grain weight differed according to type of cultivar and NF.

4 Discussion and conclusion

4.1 Effects of types of NF and N rates on yield and its component

In this study, a significant increase in yield with N application for both cultivars was observed. At the same

4.2 Effects of types of NF and N rates on development characteristics

LAI, DW and leaf SPAD value can be improved by N rate, with the effect of CU or CF being greater than that of U, but variances between two cultivars were also observed. At the same N level, the differences in DW of Zhengdan958 treated with the three types of NF were

more obvious than that of Nongda108, so Zhengdan958 is considered more sensitive to the type of NF. To improve DW, the results about the choice of types of NF, namely CF and CU are superior at the high N level, while at the low N level, choosing CF for Zhengdan958 and U and CU for Nonda108 produces more satisfactory results. More research needs to be done to resolve this question.

4.3 Effects of types of NF and N rates on utilization and loss of nitrogen fertilizer

There are three fates of nitrogen fertilizers applied to crops in the field. The first can be absorbed by crops, the second can be left as residue in soil, and the third may be lost in different forms. The soil residual N can still be taken up by crops, but its accumulative use efficiency may be lower than 10%, so there is a possibility of leaching. N leaching into groundwater is viewed as one of the most important reasons for N loss, especially in the North China Plain, where more than 70% of precipitation occurs in the summer maize season. In order to protect groundwater, the N application rate must be reduced and the NUE must be improved. In this study, the results revealed that the NUE was decreased with the increase of N rate. The NUE was between 40%–50% at a N 90 kg·hm⁻² level but it was reduced to 24%–37% at a N 180 kg·hm⁻² level. At the same N level, the NUE of CF and CU was higher than that of U, but the increasing extents were different between the two cultivars. The application of CU and CF can therefore result in higher economic and environmental benefits. In addition, the genotype difference in the effects of CU and CF indicates that CF and CU are more beneficial to Zhengdan958 at low N and high N levels, respectively, whereas CU is more beneficial to Nongda108 regardless of N levels.

NHI can be used to reflect the distribution of nitrogen in plant shoots. In order to maximize the use of soil

nitrogen and NF, a higher NHI of a cultivar is needed in crop production (Zhang and Zhang, 1996). This study shows that in twelve N application treatments, NHI was improved only after four N treatments, three of which were urea treatments. Therefore, compared to urea, CU and CF can improve shoot N accumulation but not NHI.

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