

Effects of Different Nitrogen Applications on Soil Physical, Chemical Properties and Yield in Maize (*Zea mays* L.)

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Abstract

Application of nitrogen (N) fertilizer is one of the most important approaches on improving maize grain yield. However, as is known to all, overuse N fertilizer not only leads to decline of N use efficiency and maize yield, but also leads to potential risk to environment pollution. This experiment was conducted to determine the effects of N fertilizer applications with nine different treatments on soil physical-chemical characters and maize grain yield using hybrid variety Zhengdan 958 in 2011 and 2012. Results indicated that the soil bulk densities of T₂ (CK) and T₁ were the lowest compared to other treatments in 2011 and 2012, respectively, whereas the soil bulk density of T₅ in 2011 and T₃ in 2012 were higher than other treatments. The soil porosity and field capacity of T₅ in 2011 and T₃ in 2012 were lower than other treatments, but those of CK in 2011 and T₁ in 2012 were higher than other treatments. The pH values of T₃ to T₇ were lower than other treatments. These results indicated that the soil bulk densities were increased, whereas the soil porosity, field capacity and values pH were decreased by N application at different stages. N application could increase the N contents of leaf and stem, whereas less or excess N application should not significant improve maize yield. Although the soil organic matter and total N contents of T₃ were the highest in both 2011 and 2012, the yield of T₄ is the highest in both 2011 and 2012. The application amount, period and times of N fertilizer were important to maize yield.

Keywords

Maize, N Fertilizer Application, Yield, Soil Physical and Chemical Properties, N Content

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1. Introduction

Soil nutrition absorbed by crops can be divided into mobile and immobile [1]. Nitrogen (N) in form of nitrate and water are highly mobile and required in largest amounts by crops. Phosphorus (P) is the most immobile, and potassium (K) is also relatively immobile, both of which are macronutrients required by crops [2]. The contents of N, P and K in agricultural soil are affected by plant growth and yield [3]. Therefore, crop yield is limited by two important mobile resources, including nitrate and water, as well as two immobile resources, P and K [4]. In recent years, there was about 60% of soil nutrition deficiency as a result of long-term agricultural production of existing cultivated land in China, could not meet with the needs of crop yield improvement [5].

Fertilizer plays an important role in crop yield improvement, which increased crops grain yield by 55% - 57%, and contributed to 30% - 31% of the total grain production [6] [7]. The nitrate N is easily lost through leaching and denitrification in field soil, whereas the ammonium N is usually lost through volatilization [8] [9]. China is a big country in consumption of N fertilizer [10]. The effects of N fertilizer applications on soil organics matter status and soil physical properties are importance to agricultural sustainability and to increase crop yield [11]. Modern agriculture cultivation, on the contrary, concentrates on supper high grain yield and maximum output, compromising input-use efficiency, therefore may not be sustainable in the long run.

Maize (*Zea mays* L.) is one of the most important food crops in the world. N is one of essential nutrient elements for maize growth and development, which use 1 kg of N to produce 49 kg of grain [12]. Although more N fertilizer has been applied, N use efficiency has turned lower. The investigation indicated that utilization rate of N fertilizer was 20% to 50% in china [13] [14]. In addition, more and more application of N fertilizer caused pollution of groundwater and other problems [15] [16]. The extreme of excess application and N pollution were found in intensive agricultural systems of Western Europe, the United States, and, more recently, China [17]. Therefore, reasonable field managements and appropriate application of N fertilizer are necessary for the supper high yield of maize.

Many approaches have been practiced for improving N utilization efficiency in crops, for example, optimal time, rate, and methods of application for matching N supply with crop demand and the use of specially formulated forms of fertilizer. The results showed that N application by stages can significantly increase maize grain yield compared to disposable application as sowing manure [18]. Zhang *et al.* (2014) reported that the regulating N application (240 kg/ha, divide into 3 equal amounts, each about 80 kg, used as base fertilizer, tillering fertilizer, and booting fertilizer) could increase rice yield while substantially reduced N leaching losses and improved N use efficiency in the upper reaches of the Yellow River, China [19]. At present research on application of N fertilizer roughly includes onetime application technique, basal application and side dressing, the amount of N fertilizer application, slow-released fertilizers and so on. However, there are few researches on regulating N application for maize.

In present study, nine N treatments were carried out to evaluate the effect of different nitrogen applications on soil physical, chemical properties and grain yield production. The objectives are to evaluate the effects of different N fertilizer application on soil physical and chemical characters and maize yield, and to identify the approach for optimal N fertilizer application in maize management program.

2. Materials and Methods

The experiment was carried out on an experimental farm located in Daguben town (N 42°28', E 122°22'), Fuxin city, Liaoning province, China. The hybrid maize variety Zhengdan 958, widely cultivated in northeastern of china, was used in this study. Nine N fertilizer treatments were arranged in a randomized complete-block design with three replicates, totally including 27 plots. Planting were cultured on 30th April, 2011 and on 6th May, 2012. And each plot was 5 m wide by 8 m long with 10 rows, row spacing 50 cm.

The nine N treatments received T₁ (N 0 kg/ha), T₂ (CK, compound fertilizer 108.75 kg/ha, N 29%, P 10% and K 11%), T₃ (N 138.0 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T₄ (N 241.5 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T₅ (N 345.0 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T₆ (N 241.5 kg/ha, 20% at sowing, 60% as side-dressing at jointing stage and 20% at big flare period), T₇ (N 241.5 kg/ha, 30% at 7 cm soil layer and 70% at 15 cm soil layer), T₈ (N 205.2 kg/ha, Jin zhengda slow-released urea of N 35% at 15 cm soil layer), T₉ (N 241.5 kg/ha, Jin zhengda slow-released urea of N 35% at 15 cm soil layer), respectively. In seven treatments from T₃ to T₉, phosphorus (P₂O₅ 103.5 kg/ha) and potassium (K₂O 144 kg/ha) fertilizers were ploughed into the soil tillage layer in one time as a basal fertilizer.

Soil samples were collected from a depth of 0 - 20 cm on the ridge after harvest in 2011 and 2012. Soil bulk density, soil porosity and field moisture were measured by Wilcox method. Soil organic matter content was measured by potassium dichromate method. The total N content of soil and plants were calculated by using the Kjeldahl N method, total P content using Mo-Sb colorimetric method, and total K content using flame photometry described by Zhang *et al.*, 2014 [19]. The pH was measured by composite electrode method.

Plant samples were taken at jointing stage and big flare period from the two center rows of each plot. Grain yield were determined by harvesting the two center rows from each plot. One way analysis of variance (ANOVA) at $\alpha = 0.05$ probability was conducted to test the significance in different treatments.

3. Results

3.1. Effects of Different N Applications on Soil Physical Properties

The effects of different N applications on soil physical properties were list in **Table 1**. In 2011, soil bulk density of CK was the lowest, whereas that of T₅ was the highest, 23.23% more than CK. Soil bulk densities under different treatments in 2012 were higher than those in 2011. In 2012, soil bulk density of T₁ was the lowest, significantly less than other treatments and 10.44% less than CK. Soil bulk density of T₃ to T₉ varied from 1.37 to 1.42 g/cm³, which of T₃ was the highest and 5.97% higher than CK.

In 2011, different applications of N fertilizer had no significant on soil moisture. The moisture of T₁ was the highest, 10.51% higher than CK, which of T₃ was the lowest, 17.13% lower than CK. The moisture values in 2012 were higher than those in 2011. The moisture of T₇ was the highest, significantly 9.72% more than CK, while that of T₈ was the lowest, and 7.03% less than CK.

In 2011, field capacity of T₁ was the highest, while that of T₃ was the lowest, 23.33% significantly lower than CK. There were no significant different among treatments. In 2012, field capacity of T₁ was significantly higher than other treatments. Field capacity of T₄ was the lowest, 8.22% lower than CK, whereas that of T₁ was significantly 28.88% higher than CK. There was no much difference on pH of different treatments in both 2011 and 2012.

Soil porosity of CK was the highest, while that of T₅ was the lowest, 10.7% less than CK. soil porosities in 2012 were lower than those in 2011 except T₁. Soil porosity of T₁ was the highest, 8.9% higher than CK, whereas that of T₃ was the lowest, and 5.72% lower than CK. Application of N fertilizer can increase soil bulk

Table 1. Effects of different nitrogen managements on soil physical properties.

Year	Treatment	Bulk density (g/cm ³)	Moisture (%)	Field moisture (%)	Soil porosity (%)	pH
2011	T ₁	1.16a	16.93a	31.48ab	55.55a	7.78a
	T ₂	0.99a	15.32a	37.76a	61.33a	7.54a
	T ₃	1.17a	14.03a	28.81b	55.23a	7.39a
	T ₄	1.12a	15.22a	33.72ab	57.03a	7.68a
	T ₅	1.22a	14.75a	32.35ab	53.83a	7.68a
	T ₆	1.16a	15.53a	31.12ab	55.71a	7.56a
	T ₇	1.15a	14.21a	34.34ab	56.02a	7.73a
	T ₈	1.06a	15.62a	32.24ab	58.95a	7.87a
	T ₉	1.19a	15.31a	33.32ab	54.80a	7.84a
2012	T ₁	1.20b	17.02ab	36.38a	54.23a	7.74a
	T ₂	1.34a	17.49ab	28.23b	49.80b	7.51a
	T ₃	1.42a	16.30b	26.10b	46.95b	7.94a
	T ₄	1.40a	17.16ab	25.91b	47.74b	7.51a
	T ₅	1.38a	17.29ab	28.20b	48.55b	7.67a
	T ₆	1.38a	16.71ab	27.30b	48.56b	7.58a
	T ₇	1.37a	19.19a	29.43b	48.60b	7.73a
	T ₈	1.40a	16.26b	26.78b	47.75b	7.98a
	T ₉	1.40a	17.16ab	28.55b	47.75b	7.84a

Note: Different letter stand for the significant levels at 0.05.

density and decrease soil porosity.

There were not significant different on pH values among nine treatments. The values of T₃ in 2011 and CK, T₄ in 2012 were lower than other treatments, whereas the values of T₈ were higher than other treatments in two years.

3.2. Effects of Different N Applications on Soil Chemical Properties

The effects of different N applications on soil chemical properties were shown in **Table 2**. In 2011, soil organic matter content of T₃ was the highest and 2.93% higher than CK, which were significantly higher than T₆, T₇, T₈ and T₉. Soil organic matter content of T₈ was the lowest, significantly lower than CK. In 2012, soil organic matter content of T₃ was also the highest and 3.01% higher than CK, significantly higher than T₇, T₈ and T₉. Soil organic matter content of T₉ was the lowest and 8.79% lower than CK.

In 2011, soil total N content of T₃ was the highest, 13.87% significantly higher than CK, whereas that of T₁ was the lowest, 27.72% lower than CK. In 2012, soil total N content of T₃ was also the highest, 10.53% higher than CK, whereas that of T₁ was still the lowest, 23.17% lower than CK. Soil alk-hydr. N content of T₉ was the highest, significantly 79.14% higher than CK, while that of T₁ was the lowest, and 7.29% lower than CK.

In 2011, soil available P content of T₆ was the highest, 5.13% higher than CK, whereas that of T₄ was the lowest, 16.28% lower than CK. In 2012, soil available P content of T₅ was the highest, 33.76% higher than CK, whereas that of CK was the lowest.

In 2011, soil available K content of T₈ was the highest, significantly 45.4% higher than CK, while that of T₁ was the lowest, significantly 21.2% lower than CK. In 2012, soil available K content of T₅ was the highest, significantly 45.39% higher than CK, whereas that of T₁ was still the lowest, significantly 21.19% lower than CK.

3.3. Effects of Different N Applications on Dry Matter Accumulation and N, P, K Contents in Plant

At jointing stage, shoot dry weight of T₃ was the highest and significantly 14.77% higher than CK, whereas that of T₆ was the lowest, 17.68% lower than CK (**Table 3**). There was no significant influence on alk-hydr. N contents in leaves. Alk-hydr. N content in leaf of CK was the highest, whereas that of T₉ was the least. Available P content in leaf of T₃ was the highest, 4.9% higher than CK, while available P content in leaf of T₈ was the lowest, 13.64% higher than CK. Available K content of T₃ was the highest, 13.64% higher than CK, whereas that of T₁ was the lowest, 15.61% lower than CK.

At big flare period, shoot dry weight of T₇ was the highest, 12.48% higher than CK, whereas that of T₄ was the lowest, significantly 63.64% lower than CK (**Table 4**). Alk-hydr. N content in leaf of T₁ was significant 51.98% lower than CK. Available P content in leaf of T₅ was the highest, 67.79% higher than CK. Available P content in leaf of T₁ was the lowest, significant 39.07% higher than CK. Available K content of T₅ was the highest, significant 41.29% higher than CK, while that of T₁ was the lowest, 12.48% lower than CK. Alk-hydr. N content in stem of CK was the lowest, whereas that of T₅ was the highest. Available P content in stem of T₆ was the lowest, 13.61% higher than CK, whereas available K content in stem of T₄ was the highest, 97.97% significantly higher than CK, whereas that of T₁ was the lowest, 36.11% lower than CK.

3.4. Effects of Different N Applications on Maize Yield

The effects of different N application on yield were shown on **Figure 1**. In 2011, the yield of T₄ was the largest, 1094.4 kg/ha more than CK, whereas that of T₉ was the least, 948.9 kg/ha less than CK. In 2012, the yield of T₄ was still the highest, 224.4 kg/ha higher than CK, whereas that of T₁ was the least, 1831.2 kg/ha less than CK.

4. Discussion

Soil bulk density is the ratio of the mass of dry solids to the bulk volume of the soil. The bulk volume includes the volume of the solids and of the pore space. The bulk density reflect the compaction soil, and influence the transform and utilization rate of nutrient in soil directly [20]. In the present study, the soil bulk density of T₁ and CK were lower than other treatments in 2011 and 2012, whereas the soil bulk density of T₅ in 2011 and T₃ in 2012 were higher than other treatments. Field capacity is the amount soil moisture held in soil after

Table 2. Effects of different nitrogen applications on soil chemical properties.

Year	Treatment	Organic matter (g/kg)	Total N (g/kg)	Alk-hydr. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)
2011	T ₁	19.2abc	0.41b	44.91c	21.34a	69.09b
	T ₂	19.8ab	0.56ab	55.28bc	23.62a	88.40b
	T ₃	20.3a	0.64a	68.52ab	25.04a	75.59b
	T ₄	19.3abc	0.44ab	48.39c	20.42a	131.66a
	T ₅	18.6abc	0.57b	58.75b	23.80a	129.11a
	T ₆	18.2bc	0.59ab	70.01a	25.57a	66.98b
	T ₇	18.1bc	0.59b	59.49b	25.32a	73.22b
	T ₈	17.9c	0.49b	71.96a	24.08a	133.55a
	T ₉	18.2bc	0.64ab	76.20a	23.75a	117.23b
2012	T ₁	19.1a	0.40a	48.72e	23.26a	88.96e
	T ₂	19.9ab	0.52a	50.97e	20.44a	112.88c
	T ₃	20.5a	0.58a	61.14cd	22.02a	147.85b
	T ₄	19.2ab	0.53a	67.37abc	22.49a	143.92b
	T ₅	19.0ab	0.48a	71.21ab	27.34a	164.12a
	T ₆	18.5ab	0.45a	67.37bcd	22.45a	116.06c
	T ₇	18.3b	0.51a	75.39ab	24.98a	111.39c
	T ₈	17.7b	0.52a	54.9de	26.82a	101.84d
	T ₉	18.2b	0.57a	75.48a	23.35a	93.80de

Table 3. Effects of different N applications on dry matter accumulation and N, P, K contents in plant at joint stage.

Treatment	Shoot dry weight (g)	N (%)	P (%)	K (%)
T ₁	22.89bc	4.280a	0.288abc	1.460b
T ₂	24.64ab	5.282a	0.330ab	1.730ab
T ₃	28.28a	4.580a	0.347a	2.003a
T ₄	23.55bc	4.813a	0.277bc	1.563ab
T ₅	22.06bc	4.726a	0.303abc	1.758ab
T ₆	20.29c	4.319a	0.342a	1.929ab
T ₇	20.56c	4.736a	0.334ab	1.702ab
T ₈	24.85ab	4.733a	0.261c	1.957a
T ₉	22.07bc	4.150a	0.298abc	1.697ab

Table 4. Effects of different N applications on dry matter accumulation and N, P, K contents in plant at big flare period.

Treatment	Shoot dry weight (g)	Leaf			Stem		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
T ₁	172.0b	1.55e	0.12e	0.84c	1.10e	0.069a	0.52d
T ₂	210.9ab	3.22d	0.20cd	0.96bc	1.03e	0.046a	0.70cd
T ₃	225.8a	5.11ab	0.25bc	1.21ab	1.59abc	0.079a	0.98abcd
T ₄	217.1ab	5.29a	0.17de	0.96bc	1.49bc	0.081a	1.39a
T ₅	186.5ab	4.99ab	0.33a	1.35a	1.75ab	0.074a	1.00abcd
T ₆	186.0ab	4.91abc	0.26abc	1.26ab	1.31de	0.040a	1.27ab
T ₇	233.0a	4.52abc	0.29ab	1.30a	1.48bc	0.045a	1.29ab
T ₈	205.4ab	4.04bcd	0.31ab	1.26ab	1.57abc	0.068a	1.05abc
T ₉	220.6ab	3.80cd	0.31ab	1.14abc	1.37cd	0.061a	0.84bcd

excessive water has drained away and the upper limit of water stage [21]. Soil porosity and assignment can be affected by the bulk volume [22]. The soil porosity and field capacity of T₂ in 2011 and T₁ in 2012 were higher than other treatments. On the contrary, those of T₅ in 2011 and T₃ in 2012 were lower than other treatments.

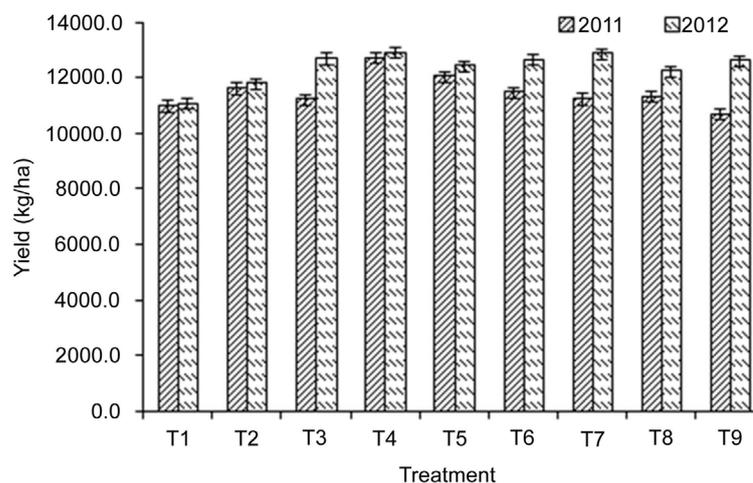


Figure 1. Effects of different N applications on yield.

Zhong and Shangguan (2014) reported that N-applied treatments increased water consumption in different layer of soil and evapotranspiration, which were significantly higher in N-applied than in non-N treatments [23]. The average soil pH has decreased 0.5 units due to the excess utilization of N fertilizer in the past two decades in China [24]. Li *et al.* (2013) reported that the soil pH declined from 8.76 to 8.56 from 1992 to 2008 during long-term field trials in North region, China [25]. The pH values of T3 to T7 were lower than other treatment in this study. These results indicated that N application by stages could increase the soil bulk density and decreased the soil pH, while non-N fertilizer or slow-released urea application should lead to soil harden.

N uptake and efficiency utilization by maize is very important to N economy and yield improvement in agricultural production systems [26]. The dry matter production and nutrient accumulation were usually positively correlated with crop grain yield [27]. Meng *et al.* (2013) reported that the wheat yield increased from 7 - 9 Mg·ha⁻² to > 9 Mg·ha⁻² was mainly attributed to increased dry matter and N accumulation from stem elongation to anthesis period in eleven filed experiments [28]. Ma and Dwyer (1998) indicated that prolonged maintenance of green leaf area for photosynthate and the ability to take up available soil N during grain filling were characteristics of hybrids maize with greater NUE [29]. Zhang *et al.* (2013) reported that the contribution of remobilized N from maize organs to grain showed a trend of blade > stem and sheath > cob > bract according to the maximum value of accumulated N in organs [30]. In present study, N contents of shoot were not significant different among nine treatments at joint stage. However, N contents of leaf in T₃ to T₇ were significant higher than T₁, T₂, T₇ and T₈ at big flare period. Specially, N content of leaf in T₄ and T₅ was the higher than other treatments. Although the N, P, K contents of leaf and stem in T₅ treatment were higher than other treatments, yield of T₅ was not the highest. These results indicated that N application should increase the N content of leaf and stem, but only reasonable level should increase N utilization efficiency and significant improve maize yield. These partially attribute to excessive growth caused by overuse fertilizer and vegetative growth consumed more nutrition during growth period in crops.

Soil organic matter content is a major source of system stability in agro ecosystems. Soil total N and alk-hydr. N contents are important fertility indexes of soil. Zhou *et al.* (2013) reported that the soil organic carbon and total nitrogen concentrations had a significant effect on crop yield in the semi-arid Loess Plateau by long-term experimentation [31]. Gong *et al.*, (2013) also indicated that the contribution of soil productivity was significantly correlated with soil organic carbon, total nitrogen, available nitrogen, available phosphorus and available potassium in wheat with long-term soil fertility experiments [32]. The same results were reviewed from the 1970s to the 2000s in the Loess Plateau in China by Wang *et al.* (2014) [33]. Results showed that changed trends of soil organic matter content under different treatments in two years were similar. Both soil organic matter and total N content of T3 were the highest in both 2011 and 2012. However, the yield of T₄ was higher than other treatments in both two years. Bassoa *et al.* (2010) indicated that yield response was stronger for 120 kg N/ha than 60 kg N/ha and 90 kg N/ha with the long-term wheat experiment response to N under rain-fed Mediterranean environments [34]. So these results indicated that separated N application could significantly increase grain

yield compared to only one application at sowing, but N application times should also be controlled. Not only the amount of N fertilizer application should be taken into account, but also N application periods and times should be controlled. In our study, control release urea didn't significantly increase maize production and didn't take a significant advantage in improvement of N use efficiency. But the results of control release urea application in 2012 were better than that in 2011. The advantage of control release urea should be obvious in some years.

5. Conclusion

In the present study, nine treatments of N fertilizer application were carried out to evaluate the variances of soil physical and chemical, the contents of N, P and K in plant and maize grain yield. Results indicated that the soil bulk densities were increased, whereas the soil porosity, field capacity and pH values were decreased with more N application. Reasonable N fertilizer amount (241.5 kg/ha) and application at two stages (30% at sowing and 70% at jointing stage) could significant increase N utilization efficiency and improve maize yield.

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