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

Heng Zhong[1*], Qiao Wang[1*], Xinhua Zhao[1], Qi Du[1], Yue Zhao[1], Xiaoguang Wang[1], Chunji Jiang[1], Shuli Zhao[1], Minjian Cao[1], Haiqiu Yu[1#], Dawei Wang[2#]

[1]College of Agronomy, Shenyang Agricultural University, Shenyang, China
[2]Corn Research Institute, Liaoning Academy of Agriculture Science, Shenyang, China
Email: [#]haiqiuyu@163.com, wdawei@vip.126.com

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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 T_2 (CK) and T_1 were the lowest compared to other treatments in 2011 and 2012, respectively, whereas the soil bulk density of T_5 in 2011 and T_3 in 2012 were higher than other treatments. The soil porosity and field capacity of T_5 in 2011 and T_3 in 2012 were lower than other treatments, but those of CK in 2011 and T_1 in 2012 were higher than other treatments. The pH values of T_3 to T_7 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 T_3 were the highest in both 2011 and 2012, the yield of T_4 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

[*]Both authors contributed equally.
[#]Corresponding author.

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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 T_1 (N 0 kg/ha), T_2 (CK, compound fertilizer 108.75 kg/ha, N 29%, P 10% and K 11%), T_3 (N 138.0 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T_4 (N 241.5 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T_5 (N 345.0 kg/ha, 30% at sowing and 70% as side-dressing at jointing stage), T_6 (N 241.5 kg/ha, 20% at sowing, 60% as side-dressing at jointing stage and 20% at big flare period), T_7 (N 241.5 kg/ha, 30% at 7 cm soil layer and 70% at 15 cm soil layer), T_8 (N 205.2 kg/ha, Jin zhengda slow-released urea of N 35% at 15 cm soil layer), T_9 (N 241.5 kg/ha, Jin zhengda slow-released urea of N 35% at 15 cm soil layer), respectively. In seven treatments from T_3 to T_9, phosphorus (P_2O_5 103.5 kg/ha) and potassium (K_2O 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 T_5 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 T_1 was the lowest, significantly less than other treatments and 10.44% less than CK. Soil bulk density of T_3 to T_9 varied from 1.37 to 1.42 g/cm^3, which of T_3 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 T_1 was the highest, 10.51% higher than CK, which of T_3 was the lowest, 17.13% lower than CK. The moisture values in 2012 were higher than those in 2011. The moisture of T_7 was the highest, significantly 9.72% more than CK, while that of T_8 was the lowest, and 7.03% less than CK.

In 2011, field capacity of T_1 was the highest, while that of T_3 was the lowest, 23.33% significantly lower than CK. There were no significant different among treatments. In 2012, field capacity of T_1 was significantly higher than other treatments. Field capacity of T_4 was the lowest, 8.22% lower than CK, whereas that of T_1 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 T_5 was the lowest, 10.7% less than CK. soil porosities in 2012 were lower than those in 2011 except T_1. Soil porosity of T_1 was the highest, 8.9% higher than CK, whereas that of T_3 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 T_3 in 2011 and CK, T_4 in 2012 were lower than other treatments, whereas the values of T_8 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 T_3 was the highest and 2.93% higher than CK, which were significantly higher than T_6, T_7, T_8 and T_9. Soil organic matter content of T_8 was the lowest, significantly lower than CK. In 2012, soil organic matter content of T_3 was also the highest and 3.01% higher than CK, significantly higher than T_7, T_8 and T_9. Soil organic matter content of T_9 was the lowest and 8.79% lower than CK.

In 2011, soil total N content of T_3 was the highest, 13.87% significantly higher than CK, whereas that of T_1 was the lowest, 27.72% lower than CK. In 2012, soil total N content of T_3 was also the highest, 10.53% higher than CK, whereas that of T_1 was still the lowest, 23.17% lower than CK. Soil alk-hydr. N content of T_9 was the highest, significantly 79.14% higher than CK, while that of T_1 was the lowest, and 7.29% lower than CK.

In 2011, soil available P content of T_6 was the highest, 5.13% higher than CK, whereas that of T_4 was the lowest, 16.28% lower than CK. In 2012, soil available P content of T_5 was the highest, 33.76% higher than CK, whereas that of CK was the lowest.

In 2011, soil available K content of T_8 was the highest, significantly 45.4% higher than CK, while that of T_1 was the lowest, significantly 21.2% lower than CK. In 2012, soil available K content of T_5 was the highest, significantly 45.39% higher than CK, whereas that of T_1 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 T_3 was the highest and significantly 14.77% higher than CK, whereas that of T_6 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 T_9 was the least. Available P content in leaf of T_3 was the highest, 4.9% higher than CK, while available P content in leaf of T_8 was the lowest, 13.64% higher than CK. Available K content of T_3 was the highest, 13.64% higher than CK, whereas that of T_1 was the lowest, 15.61% lower than CK.

At big flare period, shoot dry weight of T_7 was the highest, 12.48% higher than CK, whereas that of T_4 was the lowest, significantly 63.64% lower than CK (**Table 4**). Alk-hydr. N content in leaf of T_1 was significant 51.98% lower than CK. Available P content in leaf of T_5 was the highest, 67.79% higher than CK. Available P content in leaf of T_1 was the lowest, significant 39.07% higher than CK. Available K content of T_5 was the highest, significant 41.29% higher than CK, while that of T_1 was the lowest, 12.48% lower than CK. Alk-hydr. N content in stem of CK was the lowest, whereas that of T_5 was the highest. Available P content in stem of T_6 was the lowest, 13.61% higher than CK, whereas available K content in stem of T_4 was the highest, 97.97% significantly higher than CK, whereas that of T_1 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 T_4 was the largest, 1094.4 kg/ha more than CK, whereas that of T_9 was the least, 948.9 kg/ha less than CK. In 2012, the yield of T_4 was still the highest, 224.4 kg/ha higher than CK, whereas that of T_1 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 T_1 and CK were lower than other treatments in 2011 and 2012, whereas the soil bulk density of T_5 in 2011 and T_3 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 T_2 in 2011 and T_1 in 2012 were higher than other treatments. On the contrary, those of T_5 in 2011 and T_3 in 2012 were lower than other treatments.

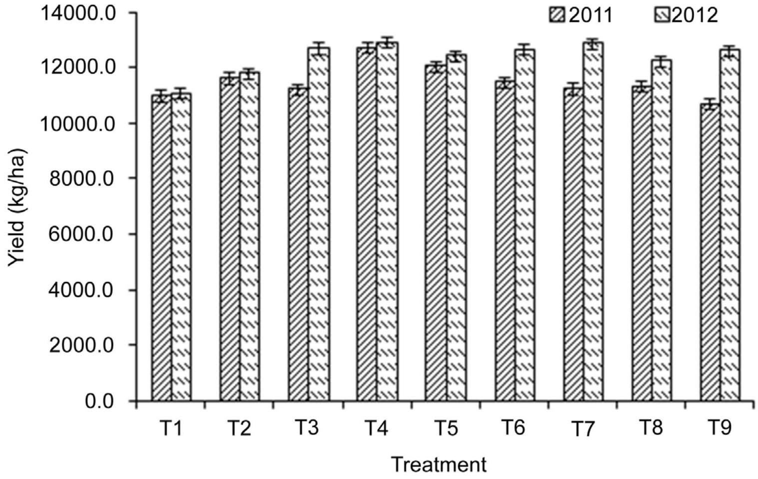

Figure 1. Effects of different N applications on yield.

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 T_3 to T_7 were significant higher than T_1, T_2, T_7 and T_8 at big flare period. Specially, N content of leaf in T_4 and T_5 was the higher than other treatments. Although the N, P, K contents of leaf and stem in T_5 treatment were higher than other treatments, yield of T_5 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 T_4 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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References

[1] Barber, S.A. (1995) Soil Nutrient Bioavailability: A Mechanistic Approach. John Wiley & Sons, New York.

[2] Marschner, H. (2012) Marschner's Mineral Nutrition of Higher Plants. Elsevier, London.

[3] Havlin, J., Tisdale, S., Nelson, W. and Beaton, J. (2004) Soil Fertility and Fertilizers: An Introduction to Nutrient Management. Prentice Hall, Upper Saddle River.

[4] Lynch, J.P. (2013) Steep, Cheap and Deep: An Ideotype to Optimize Water and N Acquisition by Maize Root Systems. *Annals of Botany*, **112**, 347-357. http://dx.doi.org/10.1093/aob/mcs293

[5] Jin, J.Y. (2012) Changes in the Efficiency of Fertiliser Use in China. *Journal of the Science of Food and Agriculture*, **92**, 1006-1009. http://dx.doi.org/10.1002/jsfa.4700

[6] Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C. (2005) Efficiency of Fertilizer Nitrogen in Cereal Production: Retrospects and Prospects. *Advance in Agronomy*, **87**, 86-156. http://dx.doi.org/10.1016/S0065-2113(05)87003-8

[7] Ye, Y.S., Liang, X.Q., Chen, Y.X., Li, L., Ji, Y.J. and Zhu, C.Y. (2014) Carbon, Nitrogen and Phosphorus Accumulation and Partitioning, and C:N:P Stoichiometry in Late-Season Rice under Different Water and Nitrogen Managements. *PLoS ONE*, 9, e101776. http://dx.doi.org/10.1371/journal.pone.0101776

[8] Li, S.X., Wang, Z.H., Miao, Y.F. and Li, S.Q. (2014) Soil Organic Nitrogen and Its Contribution to Crop Production. *Journal of Integrative Agriculture*, **13**, 2061-2080. http://dx.doi.org/10.1016/S2095-3119(14)60847-9

[9] Janzen, H.H., Beauchemin, K.A., Bruinsma, Y., Campbell, C.A., Desjardins, R.L., Ellert, B.H. and Smith, E.G. (2003) The Fate of Nitrogen in Agroecosystems: An Illustration Using Canadian Estimates. *Nutrient Cycling Agroecosystems*, **67**, 85-102. http://dx.doi.org/10.1023/A:1025195826663

[10] Ge, J.Z., Li, S.Y., Zhong, X.Y., Yuan, G.Y., Xu, Y., Tian S.Y., Cao, C.G., Zhai, Z.B., Liu, S.Q., Zhan, M. and Zhao, M. (2014) Effects of Nitrogen Application and Film Mulching on Yield Performance Parameters and Nitrogen Use Efficiency of Spring Maize in the Middle Reaches of Yangtze River. *Acta Agronomica Sinica*, **40**, 1081-1092. (In Chinese)

[11] Zhao, J.Y. and Yu, Z.W. (2006) Effects of Nitrogen Rate on Nitrogen Fertilizer Use of Winter Wheat and Content of Soil Nitrate-N under Different Fertility Condition. *Acta Ecologica Sinica*, **26**, 815-822. (In Chinese)

[12] Li, S.X., Wang, Z.H., Miao, Y.F. and Li, S.Q. (2014) Soil Organic Nitrogen and Its Contribution to Crop Production. *Journal of Integrative Agriculture*, **13**, 2061-2080. http://dx.doi.org/10.1016/S2095-3119(14)60847-9

[13] Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R.L. and Polasky, S. (2002) Agricultural Sustainability and Intensive Production Practices. *Nature*, **418**, 671-677. http://dx.doi.org/10.1038/nature01014

[14] Wang, J.J., Ke, F.L., Bai, O. and Huang, R.D. (2008) Effect of Dry Weight Accumulation and Yields of Maize under Different Nitrogen Application. *Journal of Shenyang Agricultural University*, **39**, 392-395. (In Chinese)

[15] Li, S.Q., Li, S.X. and Li, F.M. (2000) Mineralization and Nitrification of Soil Nitrogen in Calcareous Soil Profile. *Journal of Lanzhou University*, **36**, 98-104. (In Chinese)

[16] Canfield, D.E., Glazer, A.N. and Falkowski, P.G. (2010) The Evolution and Future of Earth's Nitrogen Cycle. *Science*, **330**, 192-196. http://dx.doi.org/10.1126/science.1186120

[17] Palm, C.A., Machado, P.L.O.A., Mahmood, T., Melillo, J., Murrell, S.T., Nyamangara, J., Scholes, M., Sisworo, E., Olesen, J.E., Pender, J., Stewart, J. and Galloway, J.L. (2004) Societal Responses for Addressing Nitrogen Fertilizer needs: Balancing Food Production and Environmental Concerns. In: Mosier, A.R., Syers, J.K. and Freney, J.R., Eds., *Agriculture and the Nitrogen Cycle*: *Assessing the Impacts of Fertilizer Use on Food Production and the Environment*, SCOPE 65, Paris, 71-89.

[18] Yu, H., Yang, G.H. and Wang, Z.J. (2010) Nitrogen Rate and Timing Considerations on Yield and Physiological Parameters of Corn Canopy. *Plant Nutrition and Fertilizer Science*, **16**, 266-273. (In Chinese)

[19] Zhang, A.P., Liu, R.L., Gao, J., Yang, S.Q. and Zhe, C. (2014) Regulating N Application for Rice Yield and Sustainable Eco-Agro Development in the Upper Reaches of Yellow River Basin, China. *The Scientific World Journal*. (Published Online)

[20] Zhang, J.J., Wang, Y., Fan, T.L., Guo, T.W., Zhao, G., Dang, Y., Wang, L. and Li, S.Z. (2013) Effects of Different Tillage and Fertilization Modes on the Soil Physical and Chemical Properties and Crop Yield under Winter Wheat/Spring Corn Rotation on Dryland of East Gansu, Northwest China. *Ying Yong Sheng Tai Xue Bao*, **24**, 1001-1008. (In Chinese).

[21] Fang, Q., Ma, L., Yu, Q., Malone, R.W., Saseendran, S.A. and Ahuja, L.R. (2008) Modeling Nitrogen and Water Management Effects in a Wheat-Maize Double-Cropping System. *Journal of Environmental Quality*, **37**, 2232-2242. http://dx.doi.org/10.2134/jeq2007.0601

[22] Arvidsson, J. (1999) Nutrient Uptake and Growth of Barley as Affected by Soil Compaction. *Plant and Soil*, **208**, 9-19. http://dx.doi.org/10.1023/A:1004484518652

[23] Zhong, Y.Q. and Shangguan, Z.P. (2014) Water Consumption Characteristics and Water Use Efficiency of Winter Wheat under Long-Term Nitrogen Fertilization Regimes in Northwest China. *PLOS ONE*, **9**, e98850. http://dx.doi.org/10.1371/journal.pone.0098850

[24] Guo, J.H., Liu, X.J., Zhang, Y., Shen, J.L., Han, W.X., *et al.* (2010) Significant Acidification in Major Chinese Croplands. *Science*, **327**, 1008-1010. http://dx.doi.org/10.1126/science.1182570

[25] Li, Q., Xu, M.X., Liu, G.B., Zhao, Y.G. and Tuo, D.F. (2013) Cumulative Effects of a 17-Year Chemical Fertilization on the Soil Quality of Cropping System in the Loess Hilly Region, China. *Journal of Plant Nutrition and Soil Science*, **176**, 249-259. http://dx.doi.org/10.1002/jpln.201100395

[26] Cui, Z.L., Zhang, F.S., Miao, Y.X., Sun, Q.P., Li, F., Chen, X.P., Li, J.L., Ye, Y.L., Yang, Z.P. and Zhang, Q. (2008) Soil Nitrate-N Levels Required for High Yield Maize Production in the North China Plain. *Nutrient Cycling in Agroecosystems*, **82**, 187-196. http://dx.doi.org/10.1007/s10705-008-9180-4

[27] Rhoads, F.M. and Stanley, R.L. (1981) Fertilizer Scheduling, Yield, and Nutrient Uptake of Irrigated Corn. *Agronomy Journal*, **73**, 971-974. http://dx.doi.org/10.2134/agronj1981.00021962007300060015x

[28] Meng, Q.F., Yue, S.C., Chen, X.P., Cui, Z.L., Ye, Y.L., Ma, W.Q., Tong, Y.A. and Zhang, F.S. (2013) Understanding Dry Matter and Nitrogen Accumulation with Time-Course for High-Yielding Wheat Production in China. *PLoS ONE*, 8, e68783. http://dx.doi.org/10.1371/journal.pone.0068783

[29] Ma, B.L. and Dwyer, L.M. (1998) Nitrogen Uptake and Use of Two Contrasting Maize Hybrids Differing in Leaf Senescence. *Plant and Soil*, **199**, 283-291. http://dx.doi.org/10.1023/A:1004397219723

[30] Zhang, J.T., Liu, Y.P., Li X.H., Liang, X.G., Zhou, L.L. and Zhou, S.L. (2013) Dynamic Responses of Nitrogen Accumulation and Remobilization in Summer Maize Organs to Nitrogen Fertilizer. *Acta Agronomica Sinica*, **39**, 506-514. (In Chinese).

[31] Zhou, Z.C., Gan, Z.T., Shangguan, Z.P. and Zhang, F.P. (2013) Effects of Long-Term Repeated Mineral and Organic Fertilizer Applications on Soil Organic Carbon and Total Nitrogen in a Semi-Arid Cropland. *European Journal of Agronomy*, **45**, 20-26. http://dx.doi.org/10.1016/j.eja.2012.11.002

[32] Gong, F.F., Zha, Y., Wu, X.P., Huang, S.M., Xu, M.G., Zhang, H.M., Liu, H.L., Jiang, Z.W., Wang, X.B. and Cai, D.X. (2013) Analysis on Basic Soil Productivity Change of Winter Wheat in Fluvo-Aquic Soil under Long-Term Fertilization. *Transactions of the Chinese Society of Agricultural Engineering*, **29**, 120-129. (In Chinese)

[33] Wang, X.Y., Tong, Y.A., Gao, Y.M., Gao, P.C., Liu, F., Zhao, Z.P. and Pang, Y. (2014) Spatial and Temporal Variations of Crop Fertilization and Soil Fertility in the Loess Plateau in China from the 1970s to the 2000s. *PLoS ONE*, **9**, e112273. http://dx.doi.org/10.1371/journal.pone.0112273

[34] Bassoa, B., Cammarano, D., Troccoli, A., Chen, D.L. and Joe, T. (2010) Long-Term Wheat Response to Nitrogen in a Rained Mediterranean Environment: Field Data and Simulation Analysis. *European Journal of Agronomy*, **33**,132-138. http://dx.doi.org/10.1016/j.eja.2010.04.004