EFFECTS OF NITROGEN AND THREE SOIL TYPES ON MAIZE (*ZEA MAYS* L.) GRAIN YIELD IN NORTHEAST CHINA

FENG, G. Z.[1,2] – WANG, Y.[1,2] – YAN, L.[1,2] – ZHOU, X.[1,2] – WANG, S. J.[1,2] – GAO, Q.[1,2] – MI, G. H.[4] – YU, H.[3*] – CUI, Z. L.[4*]

[1]*College of Resources and Environmental Science, Jilin Agricultural University Changchun 130118, China*

[2]*Key Laboratory of Soil Resource Sustainable Utilization for Jilin Province Commodity Grain Bases, Changchun, China*

[3]*College of Agriculture, Jilin Agricultural University, Changchun 130118, China*

[4]*Center for Resources, Environment and Food Security, College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China*

[*]*Corresponding authors*
e-mail: yuhan991225@126.com (Han Yu)
e-mail: zhenlingcui@163.com (Zhenling Cui)

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Abstract. The study aimed to understand the effects of nitrogen (N) and soil types on maize (*Zea mays* L.). Grain yield (GY) is essential for identifying optimal N fertilizer management practices and agricultural policies. In this study, we report results from an on-farm experiment carried out from 2009 to 2012 with five N levels and three soil types in Northeast China. Results revealed that the GY was affected significantly by soil types, with loam soil having an average GY of 10225 kg ha^{-1}, followed by clay soil (9218 kg ha^{-1}) and sandy soil (6434 kg ha^{-1}). The optimal N rates required to achieve maximum GY were on average 182, 173, and 160 kg ha^{-1}, and the corresponding maximum GYs were 10872, 9999, and 7266 kg ha^{-1} for loam, clay, and sandy soils, respectively. The optimum N treatment (168 kg N ha^{-1}) reduced residual nitrate N content and N losses by 97 and 451 kg N ha^{-1}, respectively, and improved N recovery efficiency (RE_N) by 17%. In conclusion, within-field soil management zones based on soil textural classes could be used to guide soil sampling and establish soil-specific N fertilizer recommendations to achieve high GY with high RE_N in Northeast China.

Keywords: *maize, grain yield, nitrogen recovery efficiency, nitrogen balance, yield stability*

Introduction

The global population is expected to peak at 8.5–10 billion by 2050. Maize (*Zea mays* L.) grain yield (GY) must increase by 101% to feed the livestock industry given the rising meat and poultry consumption, especially in developing countries (Ray et al., 2013). Global maize GY increased slowly and then stagnated for the past 10 years (FAO, 2014), although the GY gap is large, with a 50% GY potential. Grain yield variation among regions, climates, and management practices reduces productivity and contributes to this large GY gap (Liu et al., 2010; Zhang et al., 2013; Tesfaye et al., 2015).

For rain-fed maize production, water is one of the foremost constraints on GY which is dependent on soil water availability at sowing and on rainfall during the cropping season (Calvino et al., 2003; Gang et al., 2019). In a given region with similar climates, soil type often affects the ability to store and use rainfall, which impacts maize GY. Recent research has indicated that GY variability could be as great as 5000-6000 kg ha^{-1}, depending on the soil type and regions in Northeast China (NEC)

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(Lu et al., 2014). However, other research has reported no significant variation in GY between soil types (Tan et al., 2007; Xie et al., 2008).

Nitrogen (N) dynamics and crop responses to N often vary with soil properties, climate, and management (Marjerison et al., 2016; Zhang et al., 2016; Mesbah et al., 2018; Doltra et al., 2019). For example, weather might influence organic N availability, the extent of leaching and denitrification, and crop uptake and residual N at the end of the growing season (Luce et al., 2011; Alotaibi et al., 2018; Bean et al., 2018; Iqbal et al., 2018). Soil texture is another important factor that influences soil productivity and GY by potentially controlling water supply (Cambouris et al., 2006), crop N requirements (Lu et al., 2019), and N mineralization (Luce et al., 2011; Smith, 2018). Variation in the response of maize to N application often leads to poor synchronization between N supply from the soil and fertilizer, and crop requirements resulting in low N-use efficiency (NUE) and low GY (Gao et al., 2012).

NEC is a typical rain-fed maize cultivation region in which the maize planting area was 1121 × 10^4 ha and accounted for 30.4% of the total maize crop in China in 2016 (Chinese Farming Management Department, 2017). Soil conditions, climatic factors, and weather conditions in a given year also influence GY significantly (Benjamin et al., 2003; Yao et al., 2011). A short-term effect could be inconsistent with the results of long-term observations. Agricultural research, as well as other types of research, generally involves short-term studies, but sustainable agriculture requires long-term field and laboratory experiments to understand the complex soil-plant-climate-management interactions (Army, 1991).

In this study, we conducted on-farm experiments with various N levels in three villages in close proximity (< 4 km apart) with the same climatic conditions and differing soil types (loam, clay, and sandy soil) from 2009 to 2012 in Lishu County, Jilin Province. The objectives of this study were: (1) to evaluate GY variation among soil types and years, (2) to evaluate the GY response to N application rate among soil types and years to determine the optimal N rate for different soil types, and (3) to evaluate the soil N balance for different soil types.

Materials and Methods

Study Site

The climate of the study area was warm-temperate, subhumid, and continental monsoon with cold winters and hot summers. Maize was planted at the beginning of May and harvested in early October. The time from maize planting to harvest was 1400–1500 growing degree days (McMaster and Wilhelm, 1997). The annual precipitation was 500–800 mm, with 60–70% of the rainfall occurring during the summer. No irrigation was supplied during the maize growing season. The precipitation and temperature at the experimental site during the maize growing season from 2009 to 2012 are listed in *Figure 1*.

Experimental Design and Management

The experiment was conducted from 2009 to 2012 on three typical soil types (loam, clay, and sandy) in Lishu County, Jilin province. These three soils were located in three nearby villages: Wang-jia-Qiao with loam soil (N43°14’49’’, E124°29’10”), San-Ke-Shu with clay soil (N43°20’17”, E124°00’29”), and Fu-Jia-Jie with sandy soil

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(N43°21’48”, E124°05’02”; FAO 2006) (*Figure 2*). The distance between the three sites was < 4 km.The physical and chemical properties of these three soil types are listed in *Table 1*.

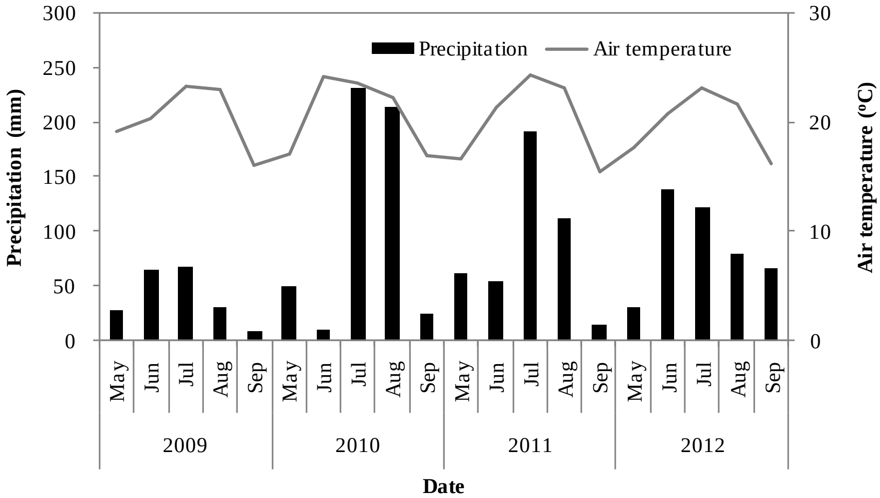

Figure 1. *Precipitation and temperature at the Li-shu experimental site during the maize growing season from 2009 to 2012*

Figure 2. *Distribution of experimental site in the Li-shu County, Jilin province*

Table 1. *Selected soil physical and chemical properties in 2009*

Locations	Texture	Bulk density (mg m^{-3})	Organic matter (gkg^{-1})	Total N (gkg^{-1})	pH	NaOH-N (gkg^{-1})	Olsen-P (gkg^{-1})	NH_4OAc-K (gkg^{-1})
Wang-Jia-Qiao	clay loam	1.32	12.2	1.04	5.15	91.6	29.1	52
San-Ke-Shu	loamy clay	1.42	25.3	1.69	6.16	128.2	43.9	122
Fu-Jia-Jie	sandy loam	1.51	13.2	1.01	6.71	58.8	13.6	43

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For the three soil types, the experiments from 2009 to 2012 were designed as a randomized block with three replicates of five nitrogen (N) treatments were as follows: control (N0), 70% recommendation N rate (N168), recommendation N rate based on local government recommend fertilization (N240), 130% recommendation N rate (N312), and the typical N dose used by farmers (N270). The N application rates were as follows: 0, 168, 240, 270, and 312 kg N ha^{-1} applied as urea. All N fertilizer was granular urea with one-third applied before planting and the remaining two-thirds applied at the V8 stage. All plots received 100 kg P_2O_5 ha^{-1} as calcium superphosphate and 120 kg K_2O ha^{-1} as K_2SO_4 before planting.

The plot size was 60 m^2 (6 × 10 m). Maize was planted continuously from 2009 to 2012. The planting density was 65,000 plants ha^{-1} with a row spacing of 60 cm. Seeds of the XY335 cultivar were hand-sown on May 5, 8, 5, and 4 during 2009, 2010, 2011, and 2012, respectively. The maize was rain-fed and harvested on October 5 during each of the four years. Weeds were controlled by applying atrazine and acetochlor before seedling emergence, and no obvious pest stress was observed during the maize growing season.

Sampling and Laboratory Procedures

At physiological maturity, when more than 50% of the plants showed a visible black layer at the base of the kernel, plants were removed manually from an area of 18 m^2 (six rows, approximately 3.6-m wide × 5-m long) in the middle of each plot to measure GY. Plant samples were taken at harvest. Aboveground biomass was collected by clipping five plants in three rows near the middle of each plot to measure plant dry matter weight and N concentration. Plants were divided into grain and straw. All plant samples were dried at 70°C in a forced-draft oven to constant weight and then weighed. Subsamples were passed through a 1-mm screen in a sample mill and mineralized using H_2SO_4-H_2O_2, after which the N concentration was determined using the Kjeldahl method (Horowitz et al., 1970).

At least five soil samples were taken in every plot to a depth of 100 cm at 20-cm increments before planting and after harvest. Fresh soil samples were sieved, extracted with 0.01 mol L^{-1} $CaCl_2$ solution and NH_4^+-N and NO_3^--N were analyzed by continuous flow analysis (TRAACS2000; Bran + Luebbe, Norderstedt, Germany) in the laboratory. Soil water content was measured by oven drying at 105°C. Soil samples were collected at the 0–20-cm soil layer before planting, air-dried, and sieved through a 0.2-mm mesh to remove undecomposed plant materials. The sieved samples were used to measure organic material (OM), total N, Olsen-P, and NH_4OAc-K.

Data Analysis

After verifying the homogeneity of error variances, all of the data across soil types, N levels, and years were pooled for analysis of variance using the ANOVA procedure of SAS/STAT (SAS Institute, 1993). Differences were compared using the least significant difference test (LSD) at the 0.05 level of probability.

Three response models were evaluated to describe the relationship between N application and GY: quadratic, quadratic with a plateau, and linear with a plateau (Cerrato and Blackmer, 1990). The models were generated using SAS software (SAS Institute, 1993). The calculated optimum N rate for GY was given with a 95% confidence interval.

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The increase in GY with applied N fertilizer (IY_N) was defined as the difference between the maximum GY and the GY of the zero-N (N0) treatment for each experiment. The agronomic N efficiency (AE_N) and N partial factor productivity (PFP_N) were calculated using *equations (1)* and *(2)* below (Ladha et al., 2005). AE_N was the GY increase per unit of N applied, and PFP_N was the most important index for farmers since it integrates the use efficiency of both indigenous and applied N resources.

$$AE_N = (Y_N - Y_0)/N \quad \text{(Eq.1)}$$

$$PFP_N = Y_N/N \quad \text{(Eq.2)}$$

where Y_N and Y_0 are GY values for N application plots and N_0 plots, respectively, and N is supplied by the applied fertilizer.

Results

Grain YieldVariance among Soil Types and Years

Considering all four years and five N treatments, GY was affected significantly by soil type (*Table 2*). The rank order of the GYs for the three soil types was loam > clay > sandy soil with GY values of 10225, 9218, and 6434 kg ha^{-1}, respectively (*Table 2*).

Table 2. *Analysis of variance of maize grain yield, ear number, grain number,and 100 grain weight for various nitrogen treatments in three soil types across 4 years*

Treatments	Yield (kg ha^{-1})	Earnumber (ha^{-1})	Grain number (ear^{-1})	100 Grain weight (g)
Soil				
Loam soil	10225a	58951a	522.6a	33.3a
Clay soil	9218b	54942b	526.3a	31.6b
Sandy soil	6434c	49251c	398.7b	28.9c
Year				
2009	7276c	48787d	421.9c	30.2c
2010	9522a	56287b	513.8a	33.0a
2011	8366b	54119c	515.8a	29.8c
2012	9339a	58330a	478.5b	32.0b
Nitrogen				
0	5732c	51938b	389.8c	26.9b
168	9257b	55019a	492.1b	32.5a
240	9554a	54827a	516.6a	32.4a
270	9379ab	55262a	505.0ab	32.3a
312	9207b	54859a	509.1ab	32.2a
Source of variation				
Soil(S)	**	**	**	**
Year (Y)	**	**	**	**
Nitrogen(N)	**	**	**	**
Y×S	**	**	**	**
Y×N	**	**	**	**
S×N	**	NS	**	NS
Y×S×N	**	*	**	NS

Within soil, nitrogen or year, numbers followed by different letters indicate significant differences ($P < 0.05$).
NS: not significant ($P > 0.05$).
*Significant at $P < 0.05$.
**Significant at $P < 0.01$

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Plant density was uniform for all three soil types. The numbers of ears at maturity were significantly different with a rank order of loam > clay > sandy soil (*Table 2*). Similar results were obtained for 100 grain weight among the soils, with a rank order of loam > clay > sandy soil. The grain number was essentially the same for the loam (523 per ear) and clay (526 per ear) soils, which were approximately 31.6% higher than the 399 grains per ear for sandy soil (*Table 2*).

Considering all three soil types and the five N treatments, GY was affected significantly by year (*Table 2*). The highest GYs were observed in 2010 and 2012, which might be explained by greater precipitation during those years (583 and 437 mm for 2010 and 2012, respectively; *Fig. 1*). The lowest GY in 2009 might be explained by rainfall during the maize growth period of only 207 mm and drought during the flowering and early grain filling stages between July and August (*Fig. 1*). Meanwhile, the average GYs in the loam and clay soils were 9574 and 10142 kg ha^{-1}, respectively, which were significantly higher than the GY in sandy soil (981 kg ha^{-1}, *Fig. 3*).

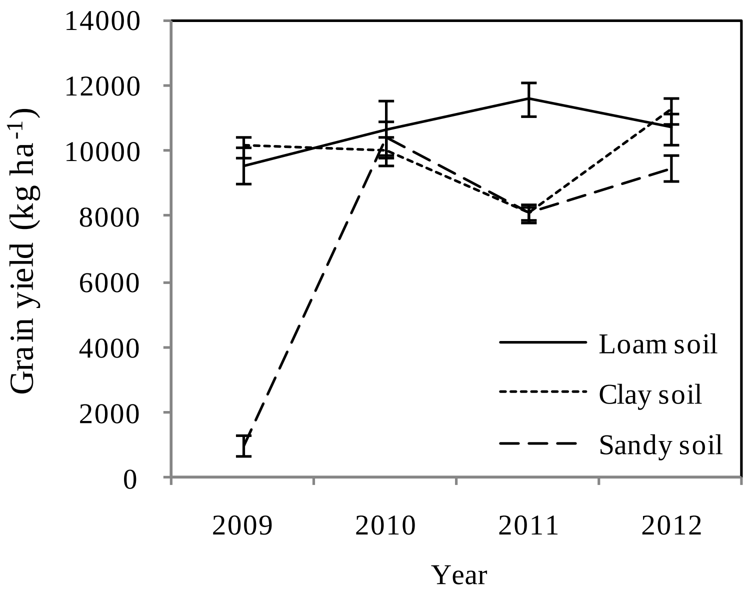

Figure 3. *Yield stability in three soil types with under optimal nitrogen application. Data were pooled across four years (n = 36)*

The low GY in 2011 might have been due to lodging between July 30 and August 1. Due to different lodging rates among the three soil types, with a rank order of clay > loam > sandy soil and values of 29.2, 13.1, and 8.2%, respectively (*Table 3*), the GY for clay and sandy soils averaged 8089 and 8126 kg ha^{-1}, respectively, which was significantly less than the GY in loam soil (11600 kg ha^{-1}; *Fig. 3*).

The effect of year × soil interaction on GY was significant, indicating that the effects of soil on GY differed among years. During the four years (2009–2012), GYs for the N168 treatment in the loam, clay, and sandy soils averaged 10638 kg ha^{-1} with a range of 8960–12021 kg ha^{-1}, 9882 kg ha^{-1} with a range of 7861–11713 kg ha^{-1}, and 7252 kg ha^{-1} with a range of 695–10913 kg ha^{-1}, respectively (*Fig. 3*).

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Table 3. *Analysis of variance of lodging rates for three soil types under nitrogen application in 2011*

Treatments	Soil type		
	Loam soil	**Clay soil**	**Sandy soil**
N0	3.7c	9.1c	1.4e
N168	11.1b	24.6b	4.7d
N240	12.0b	25.5b	8.5c
N270	12.9b	29.6b	11.7b
N312	25.6a	57.3a	14.7a

Means followed by the same lowercase letter within a column for a given year are not significantly different

Grain Yield Response to N Application Rate among Soil Types and Years

Grain yield response to increasing N rate differed among the soil types and years as indicated by a significant soil type × year × N interaction effect. A linear-plateau GY response to increasing N rate was the most appropriate model for the three soil types. Across the four years, the optimal N rate required to achieve maximum GY averaged 182, 173, and 160 kg ha^{-1} for loam, clay, and sandy soils, respectively. The corresponding maximum GYs for loam, clay, and sandy soils were 10872, 9999, and 7266 kg ha^{-1}, respectively.

The GY in loam soil increased quadratically with increasing N rate in 2010, while a linear-plateau model was most appropriate for 2009, 2011, and 2012. The minimum N rates needed to achieve maximum GY were 270, 180, 150, and 186 kg ha^{-1} for 2009 (*Fig. 4a*), 2010 (*Fig. 4d*), 2011 (*Fig. 4g*), and 2012 (*Fig. 4j*), respectively. Grain yields for the N0 rate were 8810, 9560, 6538, and 6397 kg ha^{-1} in 2009 (*Fig. 4a*), 2010 (*Fig. 4d*), 2011 (*Fig. 4g*), and 2012 (*Fig. 4j*), respectively.

Similar results were observed for clay soil during the experiment years. The linear-plateau GY responses to N were the most appropriate models for clay soil (*Fig. 4*). Grain yield increased from 9539 kg ha^{-1} for the N0 rate to a maximum GY of 10521 kg ha^{-1} obtained with 320 kg N ha^{-1} in 2009 (*Fig. 4b*). Maximum GYs for 2010 (*Fig. 4e*), 2011 (*Fig. 4h*), and 2012 (*Fig. 4k*) were 10148, 8241, and 11256 kg ha^{-1}, respectively, at minimum N rates of 175, 174, and 155 kg N ha^{-1}, respectively.

A linear-plateau GY response to increasing N rate was the most appropriate model for the sandy soil from 2010 to 2012, while there was no relationship in 2009 (*Fig. 4c*). The minimum N rates needed to achieve maximum GY were 158, 90,and 175 kg ha^{-1} for 2010 (*Fig. 4f*), 2011 (*Fig. 4i*), and 2012 (*Fig. 4l*), respectively. Maximum GYs for 2010, 2011, and 2012 were 9944, 8108, and 9829 kg ha^{-1}, respectively. Grain yields for the N0 rate in 2010 (*Fig. 4f*), 2011 (*Fig. 4i*), and 2012 (*Fig. 4l*) were 4296, 5387, and 1272 kg ha^{-1}, respectively.

Under drought conditions in 2009 (206 mm rainfall during the maize growing season) (*Fig. 1*), a linear-plateau GY response to increasing N rate was the most appropriate model for the loam (*Fig. 4a*) and clay soils (*Fig. 4b*), while there was no relationship in sandy soil (*Fig. 4c*). The total rainfall values during the maize growing seasons in 2010 and 2012 were 583.2 and 437.2 mm, respectively, which were greater than for 2009 (*Fig. 1*). Despite the relatively small GY for the N0 rate in sandy soil, the maximum GY in sandy soil (9944 and 9829 kg ha^{-1} for 2010 and 2012, respectively)

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was similar to the maximum GY observed for loam soil (10428 and 11170 kg ha^{-1} for 2010 and 2012, respectively) and clay soil (10148 and 11256 kg ha^{-1} for 2010 and 2012, respectively).

Across the experiment years, the optimal N rate required to achieve maximum GY was 160–180 kg ha^{-1} for the three soil types. The PFP_N ranged from 57.0 to 69.0 kg kg^{-1} in loam soil and from 48.0 to 67.1 kg kg^{-1} in clay soil. In contrast, the PFP_N ranged from 5.8 to 61.9 kg kg^{-1} in sandy soil, indicating that N efficiencies in loam and clay soils were stable compared with sandy soil, for which the PFP_N of 5.8 kg kg^{-1} was affected by drought in 2009.

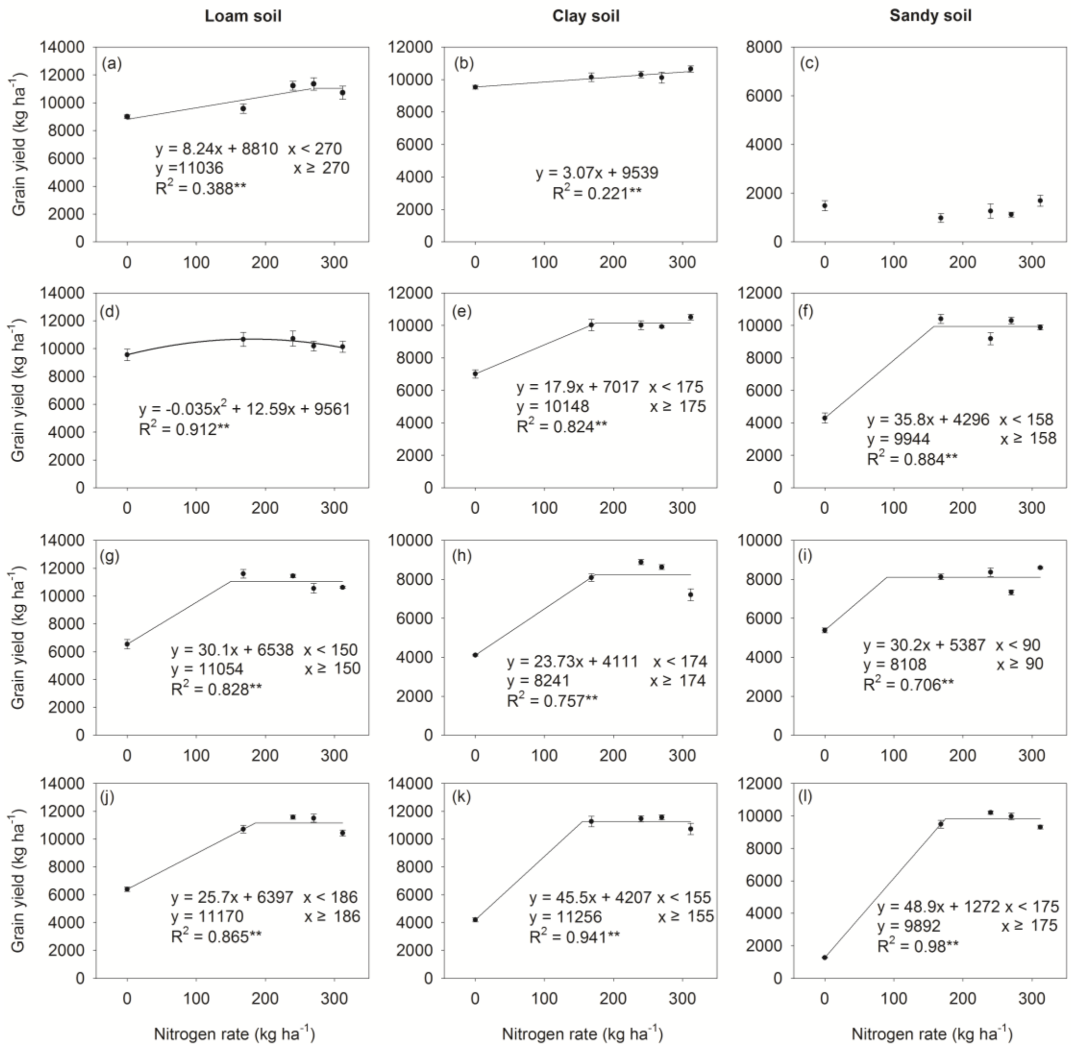

Figure 4. *Effects of nitrogen application on grain yield (at 14% moisture) on loam (left), clay (middle), and sandy soils (right) from 2009 to 2012*

Considering all four years and three soil types, GY was affected significantly by N treatments. Nitrogen fertilizer increased the maize GY significantly, with the GYs of the N168, N240, N270,and N312 treatments increased by 3525 (62%), 3822 (67%), 3647 (64%), and 3475 kg ha^{-1} (61%), respectively, compared with the N0 control (P < 0.05, *Table 2*). Compared with the N312 treatment, the N240 treatment increased the maize

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GY significantly (347 kg ha^{-1}, P < 0.05), despite applying an average of 72 kg less N ha^{-1}. The average maize N uptake was affected significantly by the N treatments. The average maize N uptake values for the N240, N270, and N312 treatments were 178, 178, and 176 kg ha^{-1}, respectively, which were significantly higher than for the N0 and N168 treatments (100 and 169 kg ha^{-1}, respectively). The average PFP_N was affected significantly by the N treatments with a rank order of N312 < N270 < N240 < N168 and values of 30, 35, 40, and 55 kg kg^{-1}, respectively (*Table 4*).

Table 4. *Analysis of variance of nitrogen partial factor productivity (PFP_N) and agronomic efficiency (AE_N) on three soil types across four years*

Treatments	PFP_N(kg kg^{-1})	AE_N(kg kg^{-1})
Soil		
Loam soil	46.0a	12.5c
Clay soil	42.4b	16.0b
Sandy soil	30.9c	17.7a
Nitrogen		
168	55.1a	21.0a
240	39.8b	15.9b
270	34.7c	13.5c
312	29.5d	11.1d
Source of variation		
Soil(S)	**	**
Nitrogen(N)	**	**
S×N	**	ns

Within soil, nitrogen, numbers followed by different letters indicate significant differences (P < 0.05).
NS: not significant (P > 0.05).
*Significant at P < 0.05.
**Significant at P < 0.01

Residual Nitrate-N and Soil N Balance

Across the experiment years (2009–2012), residual minimum soil N_{min} data showed an average of 87.2 kg N ha^{-1} with a range of 61.7 to 126.8 kg N ha^{-1} and an average of 183.7 kg N ha^{-1} with a range from 76.5 to 321.3 kg N ha^{-1} in the 0–100-cm soil profile for the N168 and N312 treatments, respectively, after harvest (*Table 5*). Presumably, some of the residual soil N_{min} would be subject to environmental loss, particularly in the period after maize harvest. Soil types affected the residual soil N_{min} significantly, with residual soil N_{min} in the 0–100-cm soil layer of clay soil being significantly higher than that in the loam and sandy soils (*Table 5*). Compared to sandy soil (73.2 and 76.5 kg N ha^{-1} for the N168 and N312 treatments, respectively) and loam soil (61.7 and 153.4 kg N ha^{-1} for the N168 and N312 treatments, respectively), more residual soil nitrate-N was present in clay soil (126.8 and 321.3 kg N ha^{-1} for the N168 and N312 treatments, respectively). Similar results were observed for residual soil NO_3^--N in the 0–100-cm soil layer. The residual soil NO_3^--N in the 0–100-cm soil layer in sandy soil was 26.0 kg ha^{-1} as compared with 74.2 and 57.2 kg ha^{-1} for clay and loam soils, respectively. We attributed these differences to soilfertility and soil texture in addition to high soil silt and clay content (*Table 1*).

The calculated total apparent N losses across the experiment years (2009–2012) ranged from 315 to 481 kg N ha^{-1} with a mean of 372 kg N ha^{-1} and from 678 to 965 kg N ha^{-1} with a mean of 823 kg N ha^{-1} for the N168 and N312 treatments, respectively

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(*Table 5*). The calculated total apparent N losses across the experiment years were affected significantly by the soil type. The calculated total apparent N losses in loam and sandy soils increased to 965 and 827 kg N ha^{-1}, respectively, compared with 678 kg N ha^{-1} in clay soil for the N312 treatment.

Table 5. *Calculated N balances for three soil types from 2009–2012 (kg N ha^{-1})*

Treatments	N0			N168			N312		
	Loam	**Clay**	**Sandy**	**Loam**	**Clay**	**Sandy**	**Loam**	**Clay**	**Sandy**
Overall summary (2009-2012)									
A. N Input									
1. N fertilizer	0	0	0	672	672	672	1248	1248	1248
2. 0–100 cm N min before sowing	222.4a	178.3a	70.0b	222.4a	178.3a	70.0b	222.4a	178.3a	70.0b
3. Apparent N mineralization†	447.9a	328.1b	146.3c	447.9a	328.1b	146.3c	447.9a	328.1b	146.3c
Total input: 1+2+3	670.3a	506.4b	216.3c	1342.3a	1178.4b	888.3c	1918.3a	1754.4b	1464.3c
B. N output									
4. N removed by grain and straw	616.1a	409.6b	178.7c	799.1a	731.7a	500.0b	800.4a	755.3a	561.1b
5. 0–100 cm N min after harvest	54.2b	96.8a	37.6c	61.7b	126.8a	73.2b	153.4b	321.3a	76.5c
Total output: 4+5	670.3a	506.4b	216.3c	860.9a	858.5a	573.2b	953.7b	1076.6a	637.6c
Apparent N losses‡:A-B				481.4a	319.9b	315.0b	964.6a	677.8b	826.7a
Nitrogen-use efficiency§ (%)				27.2b	47.9a	47.8a	14.8b	27.7a	30.6a

† Apparent N mineralization was calculated as the difference between the N output (plant N uptake plus residual soil Nmin) and the N input (initial soil Nmin in0–100cm soil layers) in no N treatment (Meisinger, 1984).
‡ Apparent N losses were calculated as the difference between the N input (initial soil Nmin plus apparent N mineralization and N fertilizer) and the N output(plant N uptake plus residual soil Nmin) in N-applied treatments (Zhao et al., 2006).
§ N recovery = (N uptake in N fertilization plot - N uptake in no N fertilization plot)/the amount of N fertilizer ×100.
*Different letters indicate significant difference at P = 0.05.

Considering all four years and the three soil types, RE_N was affected significantly by the N treatments compared with the N312 treatment. RE_N for the N168 treatment increased significantly by 17%, from 24 to 41% (*Table 5*). The soil types affected RE_N significantly for loam soil (27.2 and 14.8% for N168 and N312, respectively) and RE_N was higher in clay soil (48 and 28% for N168 and N312, respectively) and sandy soil (48 and 31% for N168 and N312, respectively).

Discussion

Across the experimental years, grain yield was significantly affected by soil types, especially in 2009 and 2011. In 2009, the rainfall during the maize growth period was only 207 mm, and there was a drought in May and early grain filling stage (*Fig. 1*). Drought in seedling stage affected emergence resulted lower seedling emerge rate (Fu et al., 2008), drought stress in flowering and early grain filling stage limited photosynthesis and reduced the flux of assimilates to the developing ears and filling

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grain (Saini and Westgate, 2000; Beyene et al., 2016; Tao et al., 2016; Kim et al., 2017), and the higher evaporation on sandy soil (Lu et al., 2014), which resulted lower ear number and 100 grain weight, further decreased the GY in sandy soil (*Table 2*). Due to differing degrees of drought vulnerability of the loam, clay, and sandy soils (Egamberdiyeva, 2007), the average GYs in the loam and clay soils were significantly higher than the GY in sandy soil (*Fig. 3*). Root lodging can reduce harvestable yield of many crops including maize (Brune et al., 2018). Root lodging tends to be associated with environmental factors such as heavy rains coinciding with wind (Farkhari et al., 2013), such as in 2011, there was a heavy rain (80.7 mm) with wind in July 30-31. Higher lodging rate in clay soil might be explained by a plow pan which prevent the root grow into deep soil (He, 2006; Qin, 2008).

Grain yield for the zero-N treatment in loam soil, clay soil and sandy soil averaged 7873, 6216 and 3110 kg ha^{-1} respectively, indicated that greater soil N availability supply contributed to greater GY. Additional soil characteristics, especially soil texture (Ziadi et al., 2013), soil water content (Cambouris et al., 2006), and N mineralization (Luce et al., 2011; Smith, 2018), appeared to have contributed to variation in soil N availability, soil productivity and yield potential among in-field location (Tolk et al., 1999).

In general, sandy soil had lower productivity due to lower soil fertility (soil organic matter content), nutrient preserved capability and water retaining capacity, compared with loam and clay soil (Egamberdiyeva, 2007). Such as in 2012, grain yield for the zero-N treatment in sandy soil averaged 1272 kg ha^{-1}, which was significantly lower than that in loam soil (6397 kg ha^{-1}) and clay soil (4206 kg ha^{-1}). The grain yield stability in loam and clay soil soil is significantly higher than that in sandy soil, the coefficients of variation for GY over the four years were 7.8, 13.4, and 59.1% for the loam, clay, and sandy soils, respectively.

In rain-fed maize system, yield response to N fertilizer may various, which has been attributed to differences in soil N supply, N use efficiency, and environments (Meisinger, 1984; Lory and Scharf, 2003). In this study, the GY response to nitrogen was various among the three soil type. The linear-plateau model of GY response to increasing N rate was showed that maximum GY of three soil type followed by loam soil (10872 kg ha^{-1}) > clay soil (9999 kg ha^{-1}) > sandy soil (7266 kg ha^{-1}). However, the IY_N followed by sandy soil (4156 kg ha^{-1}) > clay soil (3783 kg ha^{-1}) > loam soil (2999 kg ha^{-1}). Across the experimental years, the optimal N rate required to achieve the maximum GY maintained 160-180 kg ha^{-1} for the three soil types. Nitrogen partial factor productivity maintained from 57.0 to 69.0 kg kg^{-1} in loam soil, from 48.0 to 67.1 kg kg^{-1} in clay soil. In contrast, the nitrogen partial factor productivityvaried from 5.8 to 61.9 kg kg^{-1} in sandy soil, indicated that nitrogen efficiency in loam soil and clay soil were stable compared with sandy soil, such as nitrogen partial factor productivity just 5.8 kg kg^{-1} affected by drought in 2009.

To achieve satisfactory agronomic performance while minimizing negative environmental impact, N fertilization recommendations must consider the dynamics between N supply from the soil and N demand by the crops (Ayoub et al., 1995; Cassman et al., 2002; Cui et al., 2009). However, in China, pursuing high grain yield has been the top priority in policy and in practice. The typical N rate applied by maize farmers in the Northeast China (NEC) is excess (Chen et al., 2014). As expected, the RE_N in Northeast China maize production systems is low, the potential environmental impact from over fertilization and low N recovery can be substantial. In this study, the

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optimum N treatment (N168) reduced residual nitrate N content in the top 100-cm soil layer and N losses by 97 and 451 kg N ha^{-1}, respectively, compared with the excessive N treatment (N312).

In the current corn production system, the big difference in IY_N (increased yield for applied N fertilizer) was attributed to the differences among soil types, suggesting that soil type led to a high degree of field-to-field variability in the yield response to applied N fertilizer. Consequently, the big challenge is how to reduce variation among different soil types and decrease yield gaps.

Conclusions

The challenge of meeting food demand in China during the next 50 years must be met by simultaneously increasing GY and NUE; however, the rain-fed maize GY differed among soil types, indicating a conflict between high GY and improved NUE under current maize production practices. An improved fundamental understanding of GY and NUE in response to management practices and soil types is needed to rectify this situation. Our study demonstrated that higher GY was obtained in loam and clay soils compared to sandy soil, which implies that recommended N fertilizer rates need to be adjusted and take into account soil type. Across the four years, the optimal N rates required to achieve the maximum GY averaged 182, 173, and 160 kg ha^{-1} for loam, clay, and sandy soils, respectively. The corresponding maximumGYs for loam, clay, and sandy soils were 10872, 9999, and 7266 k g ha^{-1}, respectively. The PFP_N averaged 46.0, 42.4, and 30.9 kg kg^{-1} for loam, clay, and sandy soils, respectively. The average RE_N, AE_N, and PFP_N values under the optimum N treatment (N168) were 41%, 21 kg kg^{-1}, and 55 kg kg^{-1}, respectively, which were all significantly higher than for N312 (RE_N, 24%; AE_N, 11 kg kg^{-1}; and PFP_N, 30 kg kg^{-1}). As a result, the optimum N treatment (N168) reduced residual nitrate N content in the top 100-cm soil layer and N losses by 97 and 451 kg N ha^{-1}, respectively, compared withthe excessive N treatment (N312). Such knowledge could be used todevelop robust N management practices to provide effective N management practice recommendations over a wide range of soil-climate combinations.

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