Optimum Fertilization Effect on Maize Yield, Nutrient Uptake, and Utilization in Northern China

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Field experiments were conducted in northeast, northcentral, and northwest China in order to explore and compare regional yield responses, nutrient uptake, and nutrient utilization in maize. The results showed that spring maize yields in northeast and northwest China were higher than summer maize yield in northcentral China. Total macronutrient accumulation was higher in the northwest compared to other regions.

In the last 50 years, maize yields in northern China have improved rapidly. From 1961 to 1988, maize mean yield increased from 1,180 kg/ha to 5,000 kg/ha with a mean annual growth rate of 5.3% (Zhen et al., 2006). This rapid increase in productivity has been mainly dependent on chemical fertilizer application, especially N. However, lack of science-based fertilization has prevented farmers from obtaining their attainable yields and profits. Cases of over use or unbalanced fertilization have resulted in low nutrient use efficiency and increased risk of environmental harm. The area presently planted to maize in the northern regions now represents about 20 million (M) ha or about 70% of China's total maize area. Rational nutrient management is needed to increase the sustainability of maize-based crop production systems in northern China and enhance the environmental protection of the surrounding areas.

This study included field experiments in the northeast (Heilongjiang, Jilin, and Liaoning), northcentral (Hebei, Henan, and Shanxi), and northwest (Xinjiang; Zhenyuan, Gansu; and Wuwei, Gansu) regions of China in 2006 to explore and compare yield responses, nutrient uptake, and nutrient utilization. All sites used the same maize cultivar (Zhengdan 958), but the northeast and northwest sites conducted spring maize trials (April to October) while the northcentral sites grew during the summer maize season (June to October).

Prior to each sowing, soil samples (0 to 20 cm) were collected and analyzed (**Table 1**) following National Laboratory of Soil Testing and Fertilizer Recommendations as described by Portch and Hunter (2002). This procedure generated a soil test-based balanced "optimum" nutrient application (OPT) that was compared against farmer practice (FP), and a series of nutrient omission treatments including: OPT-N, OPT-P, and OPT-K. **Table 2** shows the OPT and FP rates used at each experiment site. Each experiment was designed in a randomized complete block with three replications. Urea, single superphosphate, and potassium chloride were used as sources for N, P, and K, respectively. Plots received all the P and K, plus half of the N fertilizer as a basal broadcast application, while the remaining N was topdressed at V6 stage.

Abreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Experimental site in Henan Province.

Table 1. Soil pH, organic matter, and available N, P, and K of test soils.

Experiment sites	Soil type	pH	OM, %	NH_4^+-N	NO_3^--N	P	K
				mg/L			
Heilongjiang	Black soil	5.6	2.4	22.5	32.4	2.5	93.9
Jilin	Aeolian soil	5.3	2.4	9.0	16.9	11.9	86.0
Liaoning	Meadow soil	5.8	1.0	16.6	38.2	16.5	97.8
Hebei	Fluvo aquic soil	8.2	0.6	20.6	40.8	26.8	77.5
Henan	Fluvo aquic soil	7.8	0.7	7.6	12.6	91.9	215.0
Shanxi	Fluvo aquic soil	8.4	0.6	12.7	28.2	25.1	126.9
Xinjiang	Gray desert soil	8.3	0.8	18.8	47.9	23.3	136.9
Gansu (Wuwei)	Irrigated desert soil	7.9	0.9	10.2	23.1	34.3	96.8
Gansu (Zhenyuan)	Yellow mien soil	8.1	0.9	10.5	13.4	7.6	90.2

The general critical values for soil fertility evaluation are 12 mg/L for P, 78 mg/L for K, and 20 kg/L for NH_4-N + NO_3-N. Detailed N, P_2O_5, and K_2O recommendations also considered a yield goal as well as local soil and climatic conditions.

Table 2. Fertilization rates of the optimum (OPT) and farmer practice (FP) treatments used at each experiment site.

	Rate of fertilizer application (N - P_2O_5 - K_2O), kg/ha	
Experiment sites	OPT	FP
Heilongjiang	160-68-90	175-45-45
Jilin	150-75-75	180-100-100
Liaoning	180-30-135	180-90-90
Hebei	240-75-150	300-0-75
Henan	225-90-180	180-0-0
Shanxi	225-90-120	345-0-0
Xinjiang	233-71-35	275-138-0
Gansu (Wuwei)	210-45-75	350-120-0
Gansu (Zhenyuan)	225-150-150	225-150-0

Table 3. Maize yield and yield response to OPT fertilization at different experiments sites.

Region/Season	Site	Grain yield, kg/ha		Yield response to each nutrient, kg/ha		
		OPT	FP	N (OPT-N)	P (OPT-P)	K (OPT-K)
Northeast/ Spring	Heilongjiang	11,672 a	11,098 a	2,161	443	1,783
	Jilin	10,474 a	9,009 b	4,065	1,508	1,273
	Liaoning	10,372 a	9,425 b	1,850	1,595	2,193
Northcentral/ Summer	Hebei	8,625 a	7,980 b	1,594	996	1,337
	Henan	9,221 a	6,125 b	3,606	2,218	1,162
	Shanxi	8,299 a	7,408 b	2,012	378	74
Northwest/ Spring	Xinjiang	12,381 a	12,251 a	950	2,000	900
	Gansu (Wuwei)	14,533 a	12,727 b	5,158	2,485	900
	Gansu (Zhenyuan)	14,720 a	12,940 b	5,333	2,513	1,133

Means within a row followed by the same letter are not significantly different at p = 0.05

Yield and Nutrient Uptake

Across regions, grain yields under OPT treatments tended to be highest in the spring maize trials conducted in the northwest, followed by spring maize sites in the northeast, and then the summer maize trials in northcentral China (**Table 3**). The OPT treatment generated significantly higher grain yield compared to the FP treatment at all sites except Heilongjiang and Xinjiang.

The OPT treatment achieved higher N, P, and K uptake compared to FP at 4, 2, and 3 sites, respectively, out of all 9 sites (**Table 4**). Thus, any yield benefit attributed to balanced fertilization over FP could not be consistently linked to improved nutrient uptake. The cultivar expressed higher N and P uptake potential in the northwest, as a spring maize crop, compared to the other two regions. The effective growing period for the spring season at the northeast and northwest sites is known to be much longer compared to summer conditions in northcentral China and this has a significant effect on grain yield. The high cumulative degree days and great differences in diurnal temperature in the northwest contributed greatly to the highest yields and nutrient accumulations across sites. Total K accumulation at northeast sites was lowest among the three regions, which likely reflects low available soil K and historically low non-exchangeable soil K contents in the northeast (Huang et al, 1999). Significant differences in crop K uptake were observed between the OPT and FP at sites located in the northcentral and northwest regions.

Nutrient Use Efficiency

Nutrient use efficiency can be expressed as agronomic efficiency (AE) and crop recovery efficiency (RE) (Fixen, 2007). Here we use AE and RE to evaluate the effect of balanced fertilization on N utilization, where AE refers to the crop yield increase per unit N applied, and RE refers to the increase in plant nutrient uptake per unit N applied (**Table 5**).

The highest AE values for N were found in the northeast and the northwest at the two spring maize sites in Jilin (27.1 kg grain/kg N) and Gansu, Zhenyuan (24.6 kg grain/kg N). The lowest AE values (6.6 to 16.0 kg grain/kg N) were in the northcentral summer maize sites. Higher AE values for N were more commonly found with OPT than FP.

The measurements for RE of N for the group of spring maize sites in the northeast (range = 31 to 50%), were distinctly higher than those obtained from the summer maize sites (range = 15 to 28%). Recovery of N from the northwest spring maize sites was similar or slightly lower than that determined for the northcentral sites.

As compared with developed countries, N use efficiency in China is still very low. Dobermann et al. (2007) reported that AE of N and RE of N in cereals varied between 10 to 30 kg grain/kg N and 30 to 50%, respectively, and could exceed 25 kg/kg and 50 to 80% in a well-managed system, with low levels of N use, or with low soil N supply.

In this study, some AE values for N in the northeast and northwest sites were between 20 to 30 kg grain/kg N, but were often lower in the northcentral region. In regard to RE of N, values were lower than 35% (with the exception of Jilin) because of continuous high N input in recent years, especially in northcentral China (He et al., 2008; Cui, 2005). Excessive N use, and imbalanced N, P, and K practices lead to low N use and recovery efficiency in these maize growing regions.

The low N use efficiency in this study means that additional in-season N management strategies are needed. Designing a N management strategy that involves a combination of anticipatory (N applied as a basal dressing at the beginning of the growing season based on available soil information and an expected target yield) and reactive (N topdressing during the growing season guided by a chlorophyll meter or leaf color chart) decisions may improve the performance of SSNM by accounting for seasonal variation and therefore matching crop need with nutrient supply.

It should also be noted that yield potential in maize is, to a large degree, determined by factors such as solar radiation, temperature, moisture, and nutrient supply during grain filling, long after most of the N has been applied. Hence, for optimal

Maize was most limited by N at some sites (foreground), but analysis of soil test -based OPT treatments (background) found lower than optimum N use efficiency.

Table 4. Nutrient accumulation for maize at different experimental sites in northern China.

Region	Site	OPT	FP	OPT-N
		Total N uptake, kg/ha		
Northeast	Heilongjiang	172 a	153 b	116 c
	Jilin	144 a	137 a	68 b
	Liaoning	149 a	169 a	121 b
Northcentral	Hebei	189 a	163 a	163 a
	Henan	174 a	150 b	119 c
	Shanxi	165 a	146 b	102 c
Northwest	Xinjiang	217 a	197 ab	190 b
	Gansu (Wuwei)	238 a	219 b	190 b
	Gansu (Zhenyuan)	196 a	178 a	155 a
		Total P uptake, kg/ha		
Region	Site	OPT	FP	OPT-P
Northeast	Heilongjiang	22 a	16 a	14 a
	Jilin	35 a	31 a	24 b
	Liaoning	40 a	33 a	34 a
Northcentral	Hebei	51 a	40 a	43 a
	Henan	46 a	38 b	33 c
	Shanxi	47 a	37 b	31 c
Northwest	Xinjiang	56 a	55 a	40 b
	Gansu (Wuwei)	53 a	50 a	50 a
	Gansu (Zhenyuan)	47 a	36 a	42 a
		Total K uptake, kg/ha		
Region	Site	OPT	FP	OPT-K
Northeast	Heilongjiang	120 a	108 a	109 a
	Jilin	98 a	80 ab	62 b
	Liaoning	122 a	114 a	84 b
Northcentral	Hebei	278 a	248 b	271 a
	Henan	296 a	259 ab	273 b
	Shanxi	249 a	226 b	197 b
Northwest	Xinjiang	277 a	235 b	226 b
	Gansu (Wuwei)	276 a	251 a	243 a
	Gansu (Zhenyuan)	316 a	245 a	260 a

Means within a row followed by the same letter are not significantly different at p = 0.05

Table 5. Agronomic efficiency (AE) and recovery efficiency (RE) for N fertilizer applied in maize grown in northern China.

		AE-N, kg grain increase/kg N		RE-N, %	
Region	Experiment sites	OPT	FP	OPT	FP
Northeast	Heilongjiang	23.0 a	12.8 b	34 a	18 b
	Jilin	27.1 a	15.2 b	50 a	39 a
	Liaoning	10.3 a	7.8 a	31 a	24 a
Northcentral	Hebei	6.6 a	2.7 b	15 a	7 a
	Henan	16.0 a	8.3 b	26 a	21 a
	Shanxi	7.9 a	3.9 b	28 a	16 b
Northwest	Xinjiang	4.1 a	7.7 a	15 a	14 a
	Gansu (Zhenyuan)	24.6 a	11.4 b	27 a	6 b
	Gansu (Wuwei)	23.7 a	17.9 a	24 a	21 a

Means within a row followed by the same letter are not significantly different at p = 0.05

performance, reactive N management should be integrated with predictive algorithms that aim at preventing deficiencies, or excess, of N at the critical stages for yield component formation.

Research on improving N conservation and efficiency should be strengthened for this highly intensified cropping system in China. In addition, improvements in best management practices, by alleviating other crop management constraints, should be integrated to improve fertilizer (especially N) use efficiency. BC

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