Dr. Ping He examines maize plants within a field experiment testing fertilizer application rates derived from different recommendation systems.

Field-Specific Fertilizer Recommendations for Better Nitrogen Use in Maize

By Jiajia Zhang and Ping He

SUMMARY
China is emphasizing a need to optimize nutrient management for maize to secure high yields without jeopardizing the environment. Nutrient Expert (NE)-based fertilizer management in summer maize production systems in north-central China significantly increased grain yield and nitrogen use efficiency, and lowered greenhouse gas emissions.

KEYWORDS:
Nutrient Expert; nitrogen use efficiency; agronomic efficiency; recovery efficiency; greenhouse gas

ABBREVIATIONS AND NOTES:
N = Nitrogen; P = phosphorus; K = potassium; NUE = nitrogen use efficiency; GHG = greenhouse gas.

https://doi.org/10.24047/BC102312

Our shared food security goal of producing more food per hectare of land requires sustainable intensification of crop production systems (Cui et al., 2010). Maize plays a significant role in securing food and feed production in China. But in many places in China, excessive or imbalanced fertilization has become a common challenge in the pursuit of higher production. High fertilizer input, especially N fertilizer, is the primary reason for stagnant yields and low NUE. Imbalanced fertilization can cause harmful impacts on the environment, such as GHG emission, water pollution, and nutrient leaching (Zhao et al., 2016).

Nutrient Expert® (NE) for Hybrid Maize is a fertilizer decision support tool developed by the International Plant Nutrient Institute (IPNI). The tool uses the site-specific nutrient management (SSNM) principles and the QUantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model to develop field-specific fertilizer recommendation. It fits in with the 4R Nutrient Stewardship strategy, which is an approach to managing the right source, rate, timing, and placement of fertilizer nutrients in a cropping system aimed at environmental, economic, and social benefits to the society. The NE tool can work with or without soil testing, and provides an alternative to smallholders when soil testing is not affordable, unavailable or not timely. Nutrient Expert has been used to more closely match nutrient supply and demand within a specific field in a particular cropping system, and has improved crop yield and increased NUE (Chuan et al., 2013a, 2013b; Xu et al., 2014a, 2014b).

Study Description

To date, a medium-term evaluation of NE-based recommendations on yield, NUE, and environmental benefits has been lacking for summer maize crops in north-central China. In this five-year study, an on-farm research approach was used to assess the continued performance of NE for hybrid maize across four major provinces.

The experiments were conducted in farmers' fields from 2010 to 2014 in Hebei (111 fields), Henan (130 fields), Shandong (81 fields), and Shanxi (67 fields). Here summer maize is grown in sequence with winter wheat. The treatments included NE-based fertilizer recommendations, farmers' fertilizer practice (FP), and fertilizer recommendations based on soil testing (ST). The per ha nutrient application rates ranged between 105 to 231 kg N, 37 to 89 kg P_2O_5, and 44 to 105 kg K_2O for NE; 48 to 460 kg N, 0 to 252 kg P_2O_5, and 0 to 158 kg K_2O for FP; and 105 to 330 kg N, 0 to 98 kg P_2O_5, and 25 to 120 kg K_2O for ST.

Total GHG emission, expressed as kg CO_2 eq/ha, was estimated to evaluate an environmental effect of the different fertilizer application methods. The total N_2O emission in each treatment was expressed as kg N_2O/ha, and included direct and indirect N_2O emissions related to the N fertilizer rate. The calculation method for estimation of direct and indirect N_2O emissions (Cui et al., 2013), including ammonia (NH_3) volatilization and nitrate (NO_3^-) leaching for spring maize, is provided below (Klein et al., 2006):

$$\text{Direct } N_2O \text{ emission} = 0.576 \times e^{(0.0049 \times \text{N rate})} \quad (1)$$
$$NH_3 \text{ volatilization} = 0.24 \times \text{N rate} + 1.30 \quad (2)$$
$$\text{N leaching} = 4.46 \times e^{(0.0094 \times \text{N rate})} \quad (3)$$

Indirect N_2O emission was estimated as 1% and 0.75% of NH_3 volatilization and N leaching, respectively.

Total GHG emissions during the entire life cycle of maize production, including CO_2, CH_4, and N_2O (CH_4 emission could be ignored in agro-ecosystems), consisted of three components shown in the equation below (Zhang et al., 2013):

$$GHG = (GHG_m + GHG_t) \times \text{N rate} + \text{total } N_2O \times 44/28 \times 298 + GHG_{others} \quad (4)$$

where GHG (kg CO_2 eq/ha) is the total GHG emission and GHG_m is the GHG emission originating from fossil fuel consumption for the industry's energy source to N product manufacturing. The GHG_t is the N fertilizer transportation emission factor. The GHG_m and GHG_t were 8.21 and 0.09 kg CO_2 eq/kg fertilizer N. N rate is the N fertilizer application rate (kg N/ha). The GHG_{others} represents GHG emission of P (0.73 and 0.06 kg CO_2 eq/kg fertilizer P_2O_5) and K (0.5 and 0.05 kg CO_2 eq/kg fertilizer K_2O) for fertilizer production and transportation, respectively.

Table 1. Comparison of grain yield and economic benefit amongst Nutrient Expert (NE), Farmers' Practice (FP), and Soil Testing (ST) in four provinces in China.

	Grain yield*, t/ha			Gross return above fertilizer cost, $/ha		
Site	NE	FP	ST	NE	FP	ST
Hebei	8.9 a**	8.7 b	8.9 a	2,486 a	2,422 b	2,483 a
Henan	10.0 b	9.9 c	10.2 a	2,845 a	2,765 b	2,867 a
Shandong	8.4 ab	8.4 ab	8.5 a	2,634 a	2,557 b	2,581 b
Shanxi	10.1 a	10.0 b	10.2 a	3,090 a	3,045 b	3,070 ab
Average	9.4 b	9.3 c	9.5 a	2,741 a	2,672 b	2,733 a

*The values for each province are the average across five years of all experiments, and the average values are data from all sites and years.
**Values followed by different letters for different treatments are significantly different ($p < 0.05$).

Yield and Economic Benefits

The NE recommendations increased grain yields compared to FP in all provinces except for Shandong where yields were the same (8.4 t/ha) for NE and FP (**Table 1**). Across all sites, the average increase in gross return above fertilizer cost (GRF) for NE versus FP was US$69/ha.

Nitrogen Use Efficiency

In these small-scale production systems, achieving synchrony between N supply and crop demand without an excess or deficiency is the key factor while optimizing tradeoffs between yield, NUE, and environmental quality. In this study, NUE was assessed as the agronomic efficiency (AE), recovery efficiency (RE), and partial factor productivity (PFP) of applied N, which are terms outlined in the box provided below. In the majority cases, NUE values achieved

Table 2. Comparison of nitrogen use efficiency amongst Nutrient Expert (NE), Farmers' Practice (FP), and Soil Testing (ST) in four provinces in China.

	AE_N, kg/kg			RE_N, %			PFP_N, kg/kg		
Site	NE	FP	ST	NE	FP	ST	NE	FP	ST
Hebei	6.5 a*	3.4 b	6.1 a	22.3 a	10.2 b	22.0 a	55.9 a	34.6 b	55.6 a
Henan	13.8 a	10.3 b	11.2 b	35.3 a	24.0 c	28.0 b	64.4 a	52.2 b	47.8 c
Shandong	8.6 a	6.0 b	8.5 a	21.4 a	12.4 c	18.3 b	56.6 a	35.3 c	43.1 b
Shanxi	8.3 a	5.1 c	7.0 b	25.9 a	17.0 c	23.8 b	66.5 a	43.8 c	54.3 b
Average	9.5 a	6.3 c	8.1 b	27.0 a	16.1 c	23.3 b	60.7 a	42.2 c	50.1 b

*Values followed by different letters for different treatments are significantly different ($p < 0.05$).

with NE were significantly higher than with FP or ST (**Table 2**). On average, NE increased AE_N by 51% and 17%, RE_N by 68% and 16%, and PFP_N by 44% and 21% compared to FP and ST, respectively.

Selected definitions of nutrient use efficiency (NUE).	
Term	**Calculation**
PFP - Partial factor productivity of applied nutrient	Y/F
AE - Agronomic efficiency of applied nutrient	$(Y-Y_0)/F$
RE - Apparent crop recovery efficiency of applied nutrient	$(U-U_0)/F$
F = amount of fertilizer nutrient applied Y = crop yield with applied nutrient Y0 = crop yield in control with no applied Nlete U = total nutrient uptake in aboveground crop biomass with fertilizer applied U_0 = total nutrient uptake in aboveground crop biomass with no fertilizer applied	

Estimated GHG Emission

The GHG emission in this study was estimated from a calculation based on fertilizer production and transportation related to N, P, and K rates (Zhao et al., 2016). Average N_2O and GHG emissions under NE were significantly lower than that for the FP and ST treatments (**Table 3**). The total N_2O and GHG emission were 35.1% and 17.5% and 35.2% and 18.4% lower in the NE treatment when compared with FP and ST, respectively. The GHG emission in this study is presumed higher than other places in the world since China mainly uses coal for its fertilizer production rather than natural gas.

Summary

Compared with FP or ST, the NE treatment maintained higher yields, profitability, and N use efficiency parameters while lowering GHG emission. The advantage of NE over ST and FP lies in the balancing of crop nutrients and adoption of 4R Nutrient Stewardship, which strives for better synchrony between crop nutrient demand and supply through the site-specific application of right nutrient source, rate, timing, and placement combinations. Nutrient Expert is an easy-to-use tool that can help local extension personnel to provide farm-specific fertilizer recommendation to large number of farmers even when soil testing is not available. Large-scale on-farm application of NE-based fertilizer recommendations can help smallholder farmers increase and sustain high yields and NUE, and reduce environmental impact of N fertilizer use in the summer maize production systems of north-central China. **BC**

Table 3. Estimated total N_2O and GHG emission amongst Nutrient Expert (NE), Farmers' Practice (FP), and Soil Testing (ST) in four provinces in China.

Site	Treatment	N_2O emission, kg N_2O/ha	GHG emission, kg CO_2 eq/ha
Hebei	NE	2.8	2,240
	FP	5.0	3,760
	ST	2.8	2,240
Henan	NE	2.8	2,230
	FP	3.8	2,980
	ST	3.8	3,020
Shandong	NE	2.7	2,070
	FP	4.6	3,480
	ST	3.6	2,860
Shanxi	NE	2.7	2,200
	FP	4.6	3,470
	ST	3.3	2,620
Average	NE	2.7	2,200
	FP	4.2	3,390
	ST	3.3	2,690

Acknowledgement

This paper is a summary of the manuscript entitled *Nutrient Expert Improves Nitrogen Efficiency and Environmental Benefits for Summer Maize in China*, published by Zhang, J. et al. 2017. Agron. J. 109:1-9. doi:10.2134/agronj2016.08.0477

Ms. Jiajia Zhang is Ph.D. student with the Institute of Ag. Resources and Regional Planning, Chinese Academy of Agricultural Sciences (CAAS), Beijing, China; e-mail: zhangjiajia_91@163.com. Dr. He is director, IPNI China Program, Beijing, China..

References

Cui, Z.L. et al. 2013. Environ. Sci. Technol. 47:6015-6022.
Chuan, L.M. et al. 2013a. Field Crops Res. 140:1-8.
Chuan, L.M. et al. 2013b. Field Crops Res. 146:96-104.
Klein, C.D. et al. 2006. *In*, Chapter 11, IPCC Guidelines for National Greenhouse Gas Inventories (S. Eggleston et al., eds.), Intergovernmental Panel on Climate Change. p.5-54. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf
Xu, X.P. et al. 2014a. Field Crops Res. 163:10-17.
Xu, X.P. et al. 2014b. Field Crops Res. 157:27-34.
Zhao, R.R. et al. 2016. Agric. Ecosyst. Environ. 224:123-130.
Zhang, W.F. et al. 2013. Proc. Natl. Acad. Sci. USA. 110:8375-8380.