Ecological Intensification to Increase Nutrient Use Efficiency while Maintaining Yield Levels: An Example from China

By Rongrong Zhao and Ping He

Results from an ecological intensification (EI) study conducted in a spring maize cropping system in Jilin found significantly greater grain yield in three of five years and higher nutrient use efficiency for all years under EI.

Researchers anticipate that widespread adoption of EI practices will bring sustained benefits to maize cropping systems in northeast China.

China is facing the challenges of maintaining both food security and sustainable agricultural development under the great pressure of its growing population. As one of the most important cereal crops in China, maize plays a significant role in expanding the overall grain production capacity.

The attainable yield for maize in northeast China could be as large as 16.8 t/ha through high input of nutrients, water, labor, and other cropping system improvements such as crop straw recycling, no-tillage, and application of organic manure (Fan et al., 2011). The cost of this high yield is the high input of fertilizer, pesticides, and higher environmental risks including the degradation of land and freshwater, greenhouse gas emissions, and the loss of biodiversity. Attaining high grain production while minimizing its environmental cost is an important goal for China. High fertilizer consumption and low nutrient use efficiency have raised concerns by both scientists and the fertilizer industry.

Between 2009 and 2013, a long-term field trial based on the EI concept was conducted in Gongzhuling, Jilin Province. Two main treatments were defined in the project to directly compare Farmer's Practice (FP) with EI (**Table 1**). Farmer's Practice used higher fertilizer application rates, which were not split across the growing season. Lower planting populations of local varieties are also common practice in northeastern China.

Crop Yield and Yield Gap

Among five years, grain yields for the EI treatment in 2010, 2012, and 2013 were not significantly different from FP; however, the grain yields of EI in 2009 and 2011 were significantly higher than FP treatment (p<0.01; **Figure 1**). The average grain yield of EI (180 N) and FP (250 N) treatments were 11.8 t/ha and 11.4 t/ha, respectively, which were less than the 12 t/ha of average irrigated maize grain yield in Nebraska and Southeast Asia, but higher than the 10.4 t/ha of average spring maize grain yield in northeast China (**Figure 1**). The water-limited potential yields (Y_W) of the EI treatment simulated by the Hybrid-Maize model ranged from 10.6 to 15.9 t/ha during 2009 to 2013 (**Table 2**). The mean grain yield of irrigated maize in Nebraska was 11 t/ha, while the experimental-field grain yield of irrigated maize was 13.8 t/ha (Setiyono et al., 2010). The average simulation of Y_W was 14.3 t/ha across five years, with averaged yields of 11.2 t/ha and 10.7 t/ha in EI and FP treatment, which reached 78 and 75% of the simulated Y_W, respectively. Using 85% Y_W as an exploitable level, the calculations of 85% Y_W with a range of 9.0 to 13.5 t/ha from 2009 to 2013 are shown in **Table 2**. The mean Y_G varied from 0.3 to 1.6 t/ha for EI 180 kg N/ha treatment, meanwhile, the mean Y_G ranged from 0.5 to 3.1 t/ha for the FP 250 kg N/ha treatment (**Table 2**). This means that agricultural technology or nutrient management could be the limiting factor when the potential yield ceiling exists.

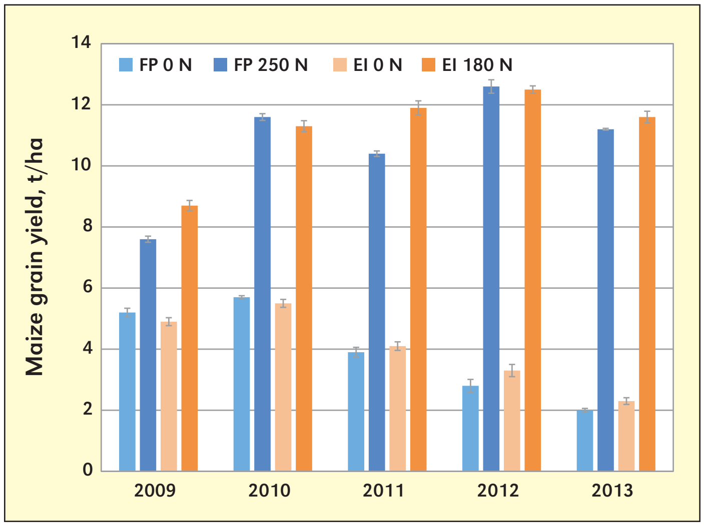

Figure 1. Maize grain yield (15.5% moisture content) at Gongzhuling city, Jilin Province (2009 to 2013). Error bars indicate standard errors of the mean.

Table 1. Treatments used in field trials in Gongzhuling, Jilin Province.

Treatment	Fertilizer applied[1], kg/ha N	P_2O_5	K_2O	N Timing[2]	Hybrid	Population
EI	180	70	90	1/4 basal: 2009-2013	Pioneer 335	65,000/ha
				2-way: 2009-2011		
				3-way: 2012-2013		
FP	250	145	100	All basal	Local variety	50,000/ha

[1] In 2009, 30 kg S/ha and 5 kg Zn/ha were applied in EI based on soil test results.
[2] Basal = planting day; For EI, 2-way = planting day + tasseling stage, 3-way = planting day + heading stage + tasseling stage.

Nutrient Use Efficiency

As integrative indices that quantify total economic output relative to the utilization of all nutrient resources in the system, agronomic efficiency (AE), partial factor productivity (PFP), recovery efficiency (RE), and partial nutrient

Abbreviations and notes: N = Nitrogen; P = phosphorus; K = potassium; S = sulfur; Zn = zinc. IPNI Project CHN-GM20.

He Ping/IPNI Image

Dr. He Ping comparing maize growth response to EI treatments at the Jilin Global Maize Research Site.

balance (PNB) are useful measures of nutrient use efficiency (NUE). Definitions of these metrics are provided by Norton et al. in this issue of *Better Crops*.

Agronomic efficiency of N (AE_N) in EI ranged from 20.6 to 51.8 kg/kg during the five years of study (**Table 3**) with the average being 39.7 kg/kg. Correspondingly, AE_N in FP ranged from 9.5 to 39.3 kg/kg with an average of 26.9 kg/kg, which was 32% lower than EI. Partial factor productivity of N (PFP_N) in EI ranged from 48.1 to 69.7 kg/kg with an average of 62 kg/kg. The PFP_N in FP varied from 30.3 to 50.2 kg/kg with an average of 42.5 kg/kg, which was 31% lower than EI. Recovery efficiency of N (RE_N) in EI ranged from 0.29 to 0.88 kg/kg with the average value being 0.66 kg/kg. The RE_N in FP ranged between 0.21 to 0.64 kg/kg with the average values being 0.50 kg/kg, which was 24% lower than EI. The partial nutrient balance of N (PNB_N) ranged between 0.50 to 0.73 kg/kg in EI and from 0.36 to 0.56 kg/kg in FP. The average PNB_N was 0.65 kg/kg in EI, which was 31% higher than FP, which had an average value of 0.45 kg/kg.

Table 2. Yield gap based on rain-fed yield potential (Y_W), calculated using Hybrid-Maize, ecological intensification (EI), and farmers' practice (FP) and the modeled yield for Jilin from 2009 to 2013.

	- - - Observed yield - - -		Y_W[a]	$85\%Y_W$[b]	Yield gap, $0.85Y_W$-EI	Yield gap, $0.85Y_W$-FP
	- - - - - - - - - - - -	- - - - - -	t/ha	- - - - - -	- - - - - -	- - - - - -
	Ecological Intensification	Farmers' Practice				
2009	8.7	7.6	10.6	9.0	0.3	1.4
2010	11.3	11.6	14.2	12.1	0.8	0.5
2011	11.9	10.4	15.9	13.5	1.6	3.1
2012	12.5	12.6	15.7	13.3	0.8	0.7
2013	11.6	11.2	15.0	12.8	1.2	1.6
Mean	11.2	10.7	14.3	12.1	0.9	1.5

[a] Potential yield of maize based on rain-fed conditions by using Hybrid Maize Model
[b] 85% of Y_W is the exploitable yield ceiling.

Table 3. Effects of the ecological intensification on agronomic N use efficiency (AE_N), partial factor productivity of applied N (PFP_N), recovery efficiency of N (RE_N), and partial nutrient balance of N (PNB_N) in maize from 2009 to 2013.

Year	Cultivation systems	AE_N, kg/kg	PFP_N, kg/kg	RE_N, kg/kg	PNB_N, kg/kg
2009	EI	20.6 a	48.1 a	0.28 a	0.50 a
	FP	9.5 b	30.3 b	0.21 a	0.36 b
2010	EI	32.0 a	62.7 a	0.63 a	0.73 a
	FP	23.0 b	46.1 b	0.42 b	0.44 b
2011	EI	43.0 a	64.8 a	0.71 a	0.68 a
	FP	26.1 b	41.6 b	0.64 b	0.56 a
2012	EI	51.1 a	69.7 a	0.80 a	0.71 a
	FP	39.3 b	50.2 b	0.62 a	0.50 b
2013	EI	51.8 a	64.6 a	0.88 a	0.65 a
	FP	36.6 b	44.5 b	0.63 b	0.42 b

Letters differing within a year indicate a statistically significant difference (Tukey-HSD) between EI and FP treatments.

Conclusions

The use of EI practices represents a more sustainable and economic way of employing knowledge and technologies in agriculture development than current farmer practices and aims to address food and environmental security. In our study, optimized planting density, fertilizer N rate and application timing were implemented to improve corn grain yield, and likely reduce any negative impacts on the environment during 2009 to 2013 in Jilin. Compared with FP, the EI treatment maintained crop grain yield, and improved nutrient use efficiency. BC

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