Establishing a Scientific Basis for Fertilizer Recommendations for Wheat in China

By Limin Chuan, Ping He, Mirasol F. Pampolino, Adrian M. Johnston, Jiyun Jin, Xinpeng Xu, Shicheng Zhao, Shaojun Qiu and Wei Zhou

Inappropriate application of fertilizers has become a common phenomenon in wheat production systems in China. This has led to nutrient imbalances, inefficient fertilizer use, and large losses to the environment. Using datasets from 2000 to 2011, this paper describes and validates a new fertilizer recommendation method for wheat in China based on yield response and agronomic efficiency (AE).

Wheat (*Triticum aestivum* L.) is one of the important cereal crops in China, and fertilizers have played a critical role in increasing wheat yields. However, in pursuing food security in China, over-application of N fertilizer has become a common practice in wheat production systems, which has led to nutrient imbalances, inefficient fertilizer use, and large losses to the environment (Ju et al., 2009). Having access to a science-based fertilizer recommendation method is critical to improve fertilizer use efficiency in a high yielding wheat crop, especially for smallholder farmers in China.

Nutrient Expert® for Wheat (NE) is a decision support system that has been developed by the International Plant Nutrition Institute (IPNI) with the goal of supporting advisers who make fertilizer recommendations to farmers. The science behind this fertilizer recommendation method is based on yield response and AE. This is an alternative approach developed for use when soil testing is limited or not available. The method uses soil indigenous nutrient supply in an attempt to avoid excessive nutrient accumulation in the soil and has been applied with success in rice, maize and wheat crops in some Asian countries (Witt et al., 2007; Buresh et al., 2010; Pampolino et al., 2011). This is a unique approach as it also considers N, P and K interactions.

The determination of fertilizer N requirements from NE has been modified to use a target AE and an estimation of yield response to applied N (Witt et al., 2007; Pampolino et al., 2011). Similarly, the determination of fertilizer P and K requirements considers internal nutrient efficiency combined with estimates of attainable yield, nutrient balances and yield responses from added nutrient within specific fields.

Datasets for grain yield, fertilizer application, and N, P and K uptake in mature aboveground plant dry matter were compiled using published literature from 2000 to 2011 in China, along with published and unpublished datasets from the IPNI China Program. The datasets contained different nutrient management practices including farmers' practice (FP), optimum treatments (OPT), long-term field experiments, and treatments with different fertilizer rates across wheat-growing regions of China. These regions include the MLYR, North Central and Northwest China (**Figure 1**). The data included a wide range of soil types and climatic conditions.

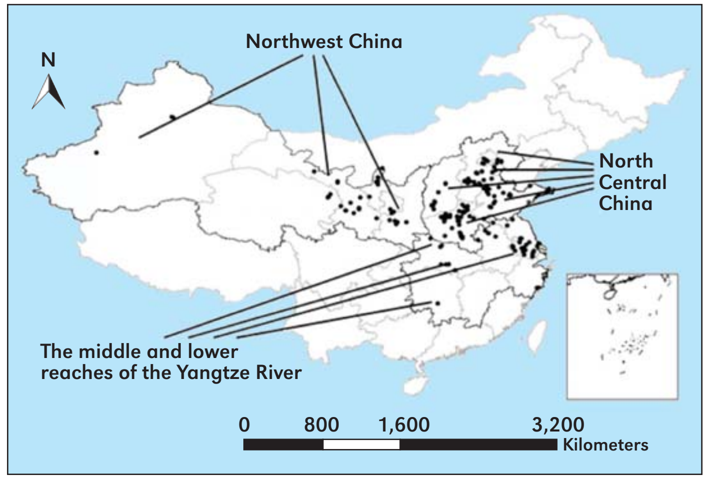

Figure 1. Geographical distribution of studied locations in North Central China, the middle and lower reaches of the Yangtze River, and Northwest China.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Fe = iron; Mn = manganese; Zn = zinc; AE_N = agronomic efficiency of N; RE_N = recovery efficiency of N; PFP_N = partial factor productivity of N; YD = maximum dilution; YA = maximum accumulation; YU = balanced uptake; MLYR = Middle and Lower Reaches of the Yangtze River.

Field validation of Nutrient Expert® for wheat in progress in Hebei (left) and Shanxi (right).

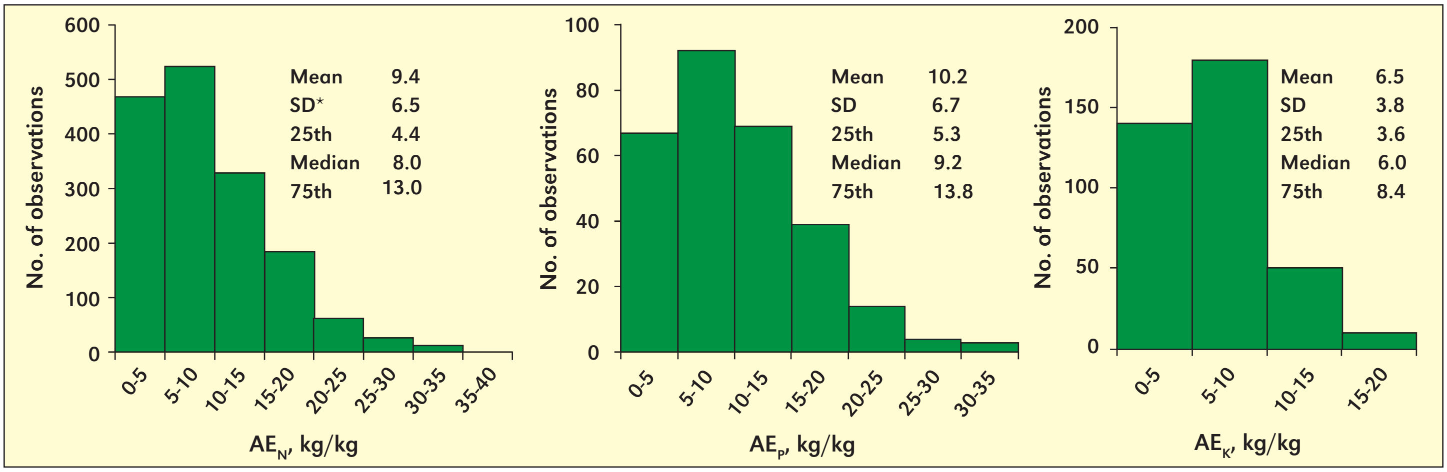

Figure 2. Frequency distribution of agronomic efficiencies of N (AE_N), P (AE_P) and K (AE_K) for wheat in China. * SD = standard deviation.

Experiments were conducted in farmers' fields of North Central China including in Hebei (32 fields), Henan (20 fields), Shandong (30 fields), and Shanxi (10 fields) provinces to validate the fertilizer recommendations provided by NE. All farms had a winter wheat/summer maize rotation and fluvo-aquatic or cinnamon soil.

Treatments included a CK (check, no fertilizer applied), balanced OPT-NE (fertilizer application based on the NE decision support system), balanced OPT-STB (soil test-based), FP, and a series of nutrient omission plots that excluded N, P or K from the OPT-NE treatment. Treatments were arranged using a randomized complete block design, where one-farm represented one-replicate design. In Hebei, the application rates in OPT-STB were the same as OPT-NE, so only OPT-NE was considered at that location. Fertilizer sources used were urea, single superphosphate, and potassium chloride. Urea was split applied two (basal and top-dressed by broadcasting at the jointing stage) or three times (basal, and top-dressed at the jointing stage and filling stage), depending on soil fertility or expected yield response to N. Phosphorus and K fertilizers were both broadcasted and incorporated as basal before seeding. The rates of fertilizer application are listed in **Table 1**.

Table 1. Rates of fertilizer application in different treatments used in the study.

		Fertilizer application, kg/ha		
Province	Treatment	N	P_2O_5	K_2O
Hebei	FP[a]	278 (196~344)[d]	42 (30~68)	24 (0~68)
	OPT-NE[b]	135 (130~150)	52 (50~56)	60 (48~70)
Henan	FP	184 (113~289)	124 (72~225)	127 (27~225)
	OPT-STB[c]	210	90	120
	OPT-NE	144 (140~155)	67	70 (60~80)
Shandong	FP	317 (215~400)	161 (75~276)	13 (0~36)
	OPT-STB	242	150	60
	OPT-NE	140	78	70 (60~80)
Shanxi	FP	262 (179~502)	110 (19~194)	28 (14~72)
	OPT-STB	180	75 (67~90)	76 (60~80)
	OPT-NE	137 (125~140)	67	78 (60~80)

[a]FP= fertilizer application based on farmers' traditional practice; [b]OPT-NE= fertilizer application based on Nutrient Expert for Wheat decision support system; [c]OPT-STB = fertilizer application based on soil testing; [d]Data in parentheses indicates the range of fertilizer application.

Irrigation and other cultural practices were done using the best local management practices.

Results

The frequency distribution of AE for wheat is shown in **Figure 2**. The mean AE for N, P and K were 9.4, 10.2 and 6.5 kg/kg respectively, indicating that 62, 55 and 84% of the observations had AE values less than 10 kg/kg, respectively. Dobermann (2007) reported that AE_N for cereals in developing countries ranged between 10 to 30 kg/kg, and also indicated that AE_N could reach an average value >25 kg/kg in a well-managed system with low levels of N use or with low soil N supply. However, compared with developed countries, the nutrient use efficiency in China was still only at the baseline reported by Dobermann (2007), and only reached about 52% of the world average (18 kg/kg) reported by Ladha et al. (2005). Agronomic efficiency of N remains low in China, thus highlighting the need to improve nutrient management practices in modern production systems.

The indigenous nutrient supply (y) determined from unfertilized plots showed a significant negative exponential relationship with yield response (x) ($p < 0.05$) with 36, 28 and 43% of the variability for N, P and K, respectively (**Figure 3**). For a specific field site, when the indigenous nutrient supply was high, the yield response to the applied nutrient was low. These results support the approach that yield responses could be used as an indicator of soil nutrient supplying capacity.

The yield in an unfertilized plot is mainly supported by the soil indigenous nutrient supply. Yield response between the unfertilized plot and the target yield is supplied by fertilizer application. Yield response varies as the soil indigenous nutrient supply changes. The AE is also determined by the indigenous nutrient supply, fertilizer application, management practices and climatic conditions. The results showed that there was a significant quadratic relationship between yield response (x) and AE (y) ($p < 0.05$) (**Figure 4**).

Initially, the AE for a nutrient increased with increasing yield response, but these increases became smaller as the yield responses became larger. A lower yield response indicates higher soil nutrient indigenous supply or higher soil fertility, resulting in lower AE. In contrast, a larger yield response means lower soil nutrient supply and relatively higher AE. Based on this, the principles of nutrient recommendations were formed and incorporated into the NE decision support system. Nitrogen

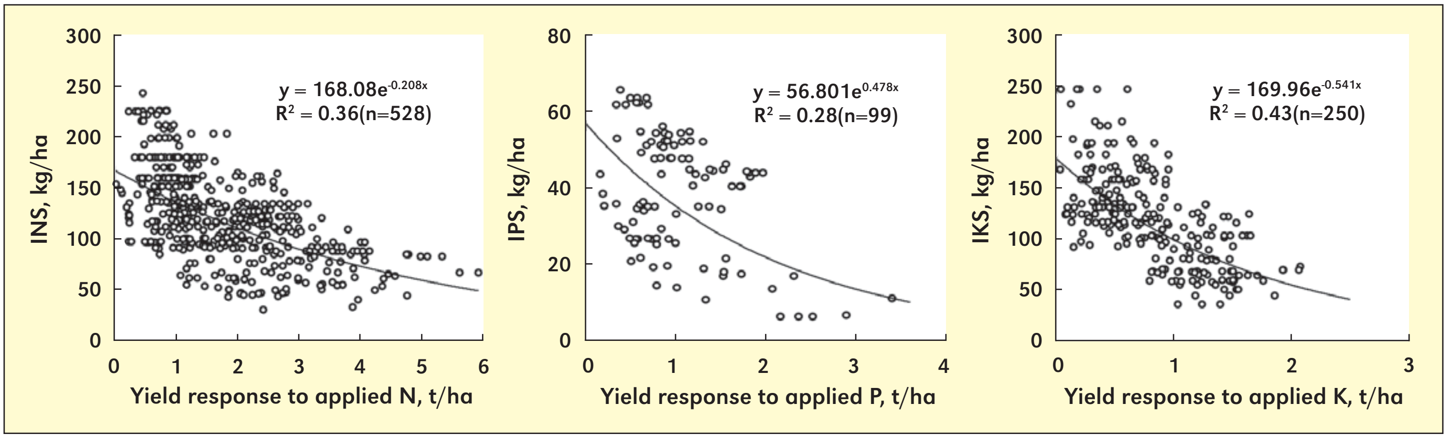

Figure 3. Relationships between yield response to N, P and K, and their indigenous nutrient supplies in different farms across China. INS, IPS and IKS represent indigenous N, P and K supplies, respectively.

fertilizer recommendations were calculated from yield response divided by AE. However, the P and K fertilizer recommendation considered both the nutrient requirement for the yield gain and maintenance of soil fertility. The nutrient requirements for yield gain were calculated from the yield response and AE, and the maintenance of soil fertility was calculated from the nutrient removal estimated by the QUEFTS model (Chuan et al., 2013). Trace elements (Zn, Fe, Mn and Mg) were applied when soil tests showed a deficiency or when their applications were part of established local recommendations.

Field validation trials of the NE decision support system showed that the OPT-NE plots increased grain yields by 3.7 (275.1 kg/ha), 0.1 (5.3 kg/ha) and 1.1% (88.3 kg/ha) compared with that in FP plots in Hebei, Henan and Shandong, respectively. This occurred with a net reduction in fertilizer N application in Hebei by 51%, 22% in Henan, and 56% in Shandong. There was a gross improvement in profits for these three provinces by US$158, US$103 and US$168/ha, respectively (**Figure 5**). However, in Shanxi, with N and P fertilizer application reduced by 48 and 39%, respectively, yields were decreased slightly, but the gross profit was maintained. Overall, compared to the OPT-STB treatment, the yield in OPT-NE treatment was slightly lower, but gross profit remained the same statistically ($p < 0.05$), while AE_N, RE_N, and PFP_N in OPT-NE were significantly increased at most sites ($p < 0.05$) (data not shown).

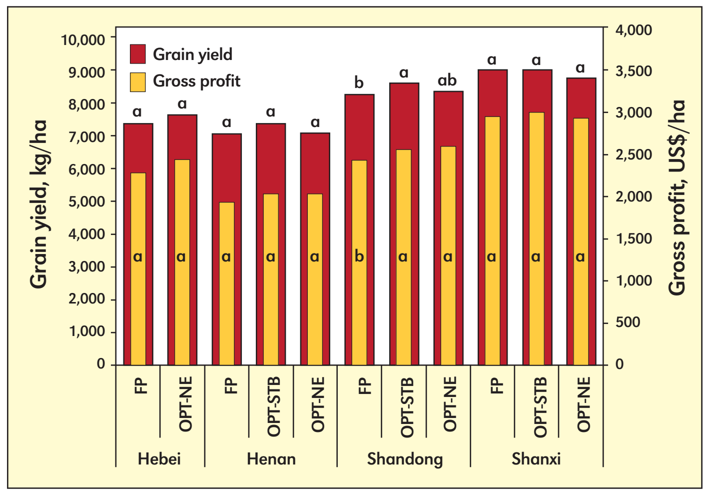

Figure 5. Grain yield and gross profit in Hebei, Henan, Shandong and Shanxi provinces in 2010-2011.Different letters above the columns denote a significant difference ($p < 0.05$).Wheat prices (¥ = Chinese Yuan Renminbi) were 2.2, 2.0, 2.1, and 2.3/kg in Hebei, Henan, Shandong, and Shanxi, respectively. Prices for N, P_2O_5 and K_2O were 5.0, 6.3 and 7.3/kg in Hebei; 4.0, 5.6 and 5.0/kg in Henan; 4.4, 4.8 and 5.3/kg in Shandong; and 5.0, 6.3 and 7.3/kg in Shanxi, respectively. A conversion rate of ¥6.3 was used for US$1.

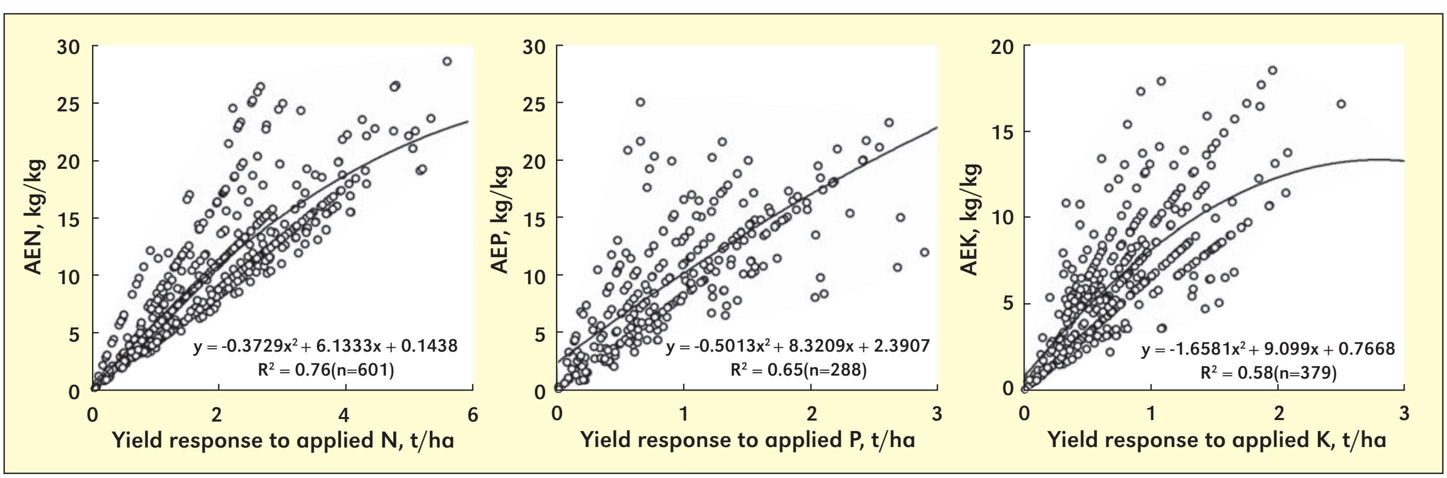

Figure 4. Relationships between yield response and AE for wheat, where AEN, AEP and AEK are mean agronomic efficiencies of N, P and K, respectively.

Summary

There was a significant negative exponential relationship between yield response and soil indigenous nutrient supply, and a significant negative linear correlation between yield response and relative yield. A quadratic equation described the relationship between yield response and AE. Based on the above analysis, the principles of nutrient recommendations were formed and incorporated as part of the NE decision support system. Field validation, based on yield response and AE, showed an increase in both grain yield and gross profits, and AE_N, RE_N and PFP_N were all improved in most sites. It was concluded that NE could be used as an alternative method to soil testing when making fertilizer recommendations for wheat in China.

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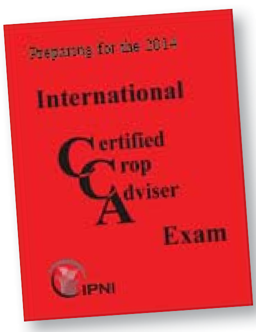

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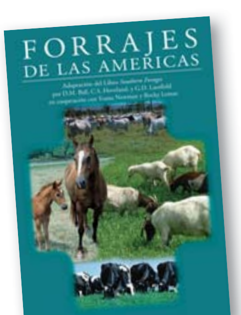

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