Fertilizer Plays an Important Role in Current Crop Production: A Case Study from Hubei

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Results from large-scale multipoint field experiments with rice, winter wheat, rapeseed, and cotton showed that site-specific combinations of N, P and K fertilizers significantly increased crop yields, and that fertilizers play a much more important role in crop production today than in the past.

Worldwide experience in agricultural development has provided much evidence that fertilizer application is the most efficient measure for sustainably increasing crop production and ensuring food security (Bockman et al., 1990) and that sustained yield growth is almost impossible without fertilizer supply (Larson and Frisvold, 1996). At the global scale, crop yields have increased by at least 30 to 50% as a result of fertilization (Stewart et al., 2005). In China, the fertilizer contribution rate (FCR) to cereal crop yield, from the national network on chemical fertilizer experiments, was 40.8% (Shi et al., 2008).

During the past 20 years the consumption of inorganic fertilizers in China has increased every year, leading to a decline in fertilizer use efficiency and therefore a slow-down in the rate of crop productivity improvement (Zhang et al., 2008). This has led many to doubt, or minimize, the importance of the role of fertilizers in crop production. In reality though, increasing consumption of fertilizers can be attributed to the numerous factors in China like its large population and limited farmland (Chen et al., 2011) where fertilizer has contributed greatly to increasing crop yields over the past few decades. However, lack of knowledge on scientific fertilization techniques has resulted in low fertilizer use efficiency. Therefore, developing scientific fertilization methods through research, and then helping farmers adopt balanced nutrient management practices through extension, is of primary concern to agricultural scientists today. We conducted large-scale multipoint field experiments with rice, wheat, rapeseed, and cotton crops in 21 counties of Hubei province in Central China from 2006 to 2009 to investigate the combined effect of N, P and K on crop yields as well as on FCR and agronomic efficiency (AE) under present production conditions.

Hubei province is situated in the subtropical region with an average annual temperature of 15 to 17°C, precipitation of 750 to 1600 mm, and a mean frost-free period of 230 to 300 days (Shen and Zhang, 2006). Field experiments on rice, winter wheat, winter rapeseed, and cotton were conducted at 251, 47, 62, and 26 sites, respectively, in 21 counties from 2006 to 2009. The soils where rice and rapeseed were grown had higher organic matter, available N and available P contents than the soils at sites where wheat and cotton were grown (**Table 1**).

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

All trials had two fertilization treatments including a check (no fertilization) and NPK (full fertilization) and three replications. The application rates of fertilizer N, P and K were different for each crop-type and site (**Table 2**). Fertilizers used in the study were urea (46% N), calcium superphosphate (12% P_2O_5) and potassium chloride (60% K_2O). Seed cotton yield was taken as the cotton yield in the study. FCR (Yu et al., 2007) and AE (Yadav, 2003) were calculated as follows:

$$FCR = (Y_{NPK} - Y_{CK}) / Y_{NPK} \times 100\%$$
$$AE = (Y_{NPK} - Y_{CK}) / (Nr + Pr + Kr)$$

where Nr, Pr and Kr are the amounts of fertilizer N, P_2O_5 and K_2O applied, Y_{NPK} is the crop yield with applied fertilizer, and Y_{CK} is the crop yield without fertilizer applied.

Effect of NPK Fertilization on Crop Yields

At all locations, the yields of rice, winter wheat, rapeseed, and cotton in plots receiving NPK fertilization were significantly greater than those in check plots (**Table 3**). These differences, however, varied widely due to differences in crop cultivars, soil fertility, climatic conditions, and cultivation practices at different sites. Also, the effect of fertilization on yields among crops varied in the following order rapeseed (174%), winter wheat (110%), cotton (69%), and rice (47%). In other words, rapeseed showed the strongest response to fertilizer N, P and K application, while rice had the smallest response.

The variations and distributions in the fertilization effect encountered during these trials are shown in **Figure 1**. Among the 251 rice experimental sites, 69% of the sites showed yield increases between 1 and 3 t/ha, and 6.4% of the sites showed increases in yield by over 4 t/ha. In addition, 28% of rice sites had yield increases above 60%. Among the 47 winter wheat experimental sites, 34% of the sites had yield increases between 2 and 2.5 t/ha and 13% had yield increases of more than 3 t/ha. About 40% of the winter wheat sites had yield

Table 1. Organic matter and available N, P and K status of experimental soils (0 to 20 cm depth) in Hubei province, 2006 to 2009.

	Organic matter, g/kg		Available N, mg/kg		Available P, mg/kg		Available K, mg/kg	
Crop	Range	Average	Range	Average	Range	Average	Range	Average
Rice (n=251)	4.8-56.4	28.8±10.4*	13.5-233	124±35.5	1.1-60.2	12.8±8.6	6.2-276	87.1±44.0
Wheat (n=47)	5.0-29.3	17.6±5.7	14.0-206	92.9±45.5	2.7-37.2	11.8±7.5	39.8-205	98.0±38.7
Rapeseed (n=62)	8.6-57.4	25.2±9.1	38.5-199	114±41.9	3.4-32.6	12.5±6.9	29.7-246	96.0±44.8
Cotton (n=26)	6.0-25.3	16.3±4.4	42.0-160	89.2±32.4	4.5-18.0	9.9±3.9	23.9-165	83.8±34.3

* ± denotes the standard deviation.

increases over 120%. The distributions for rapeseed and cotton were similar, with 39% of rapeseed sites and 35% of cotton sites showing yield increases between 1 and 1.5 t/ha; and 16% of rapeseed sites and 27% of cotton sites showing yield increases over 2 t/ha. Rapeseed yields in 32% of sites increased by over 200% due to fertilization and 50% of cotton sites had yield increases that exceeded 60%.

Table 2. Fertilizers application rates for rice, winter wheat, rapeseed, and cotton in Hubei province, 2006 to 2009.

	N, kg/ha		P_2O_5, kg/ha		K_2O, kg/ha	
Crop	Range	Average	Range	Average	Range	Average
Rice	83-248	172±29*	30-90	62±16	45-150	95±25
Wheat	120-180	153±16	45-75	58±7	45-90	75±14
Rapeseed	150-270	190±35	45-113	76±19	60-180	100±28
Cotton	225-330	291±39	72-225	97±40	120-300	195±50

* ± denotes the standard deviation.

Fertilizer Contribution Rate and Agronomic Efficiency

Fertilizer contribution rate reflects the contribution of fertilizer to crop yield. The mean values of FCR were obviously different in the four different crops and amounted to 30% for rice, 49% for winter wheat, 56% for rapeseed, and 38% for cotton (**Table 4**). The FCR distribution frequency placed 31% of rice sites in the 20 to 30% range, 28% of winter wheat sites in the 50 to 60% range, 24% of rapeseed sites in the 40 to 50% range, and 42% of cotton sites in the 30 to 40% range. In addition, the FCRs were over 50% in 4.8% of rice sites, 53% of winter wheat sites, 61% of rapeseed sites, and 12% of cotton sites.

Table 3. Effect of fertilizer application on rice, winter wheat, rapeseed, and cotton yields in Hubei province, 2006 to 2009.

		Yield, t/ha		Yield Increase, t/ha		Yield increase rate, %	
Crop	Treatment	Range	Average	Range	Average	Range	Average
Rice	CK	1.30-9.27	5.43±1.43b[+*]				
	NPK	3.05-13.06	7.70±1.55a	0.21-6.65	2.27±1.04	3.1-166	46.7±28.7
Wheat	CK	1.24-4.42	2.32±0.80b				
	NPK	2.33-6.15	4.52±0.82a	0.08-3.52	2.20±0.74	3.4-269	110±56.6
Rapeseed	CK	0.28-2.61	1.16±0.54b				
	NPK	1.08-4.04	2.60±0.63a	0.49-2.80	1.44±0.53	23.3-576	174±136
Cotton	CK	1.36-4.13	2.60±0.60b				
	NPK	2.96-5.89	4.22±0.64a	0.40-2.88	1.62±0.62	9.7-213	68.6±40.4

[+]Values followed by different letters (a, b) among treatments for each crop indicate significance at 5% level.
* ± denotes the standard deviation.

Agronomic efficiency, an incremental efficiency from applied fertilizer N, P and K over a control, is proportional to the benefit-to-cost ratio from purchased N, P and K inputs (Yadav, 2003). The mean values of AE of cereal crops (7.2 kg/kg for rice and 7.7 kg/kg for winter wheat) were obviously higher than those of cash crops (4.0 kg/kg for rapeseed and 3.0 kg/kg for cotton) (**Table 4**). However, compared with results from India (i.e., 12.3 kg/kg for rice and 10.4 kg/kg for wheat), the AE of both rice and wheat in this study were lower because of higher fertilizer inputs (Yadav, 2003). The AE distribution frequency for rice had 34% of sites between 3 to 6 kg/kg, 36% of winter wheat sites between 7 to 9 kg/kg, 27% of rapeseed sites between 4 to 5 kg/kg, and 50% of cotton between 2 to 3 kg/kg (data not shown). In addition, the AE in 28% of rice sites and 30% winter wheat sites exceeded 9 kg/kg; and 21% of rapeseed sites and 8% of cotton sites exceeded 5 kg/kg.

Table 4. Fertilizer contribution rate (FCR) and agronomic efficiency (AE) of rice, winter wheat, rapeseed, and cotton in Hubei province, 2006 to 2009.

	FCR, %		AE, kg/kg	
Crop	Range	Average	Range	Average
Rice	3.0-62.4	29.6±12.1*	0.8-21.2	7.2±3.8
Wheat	3.3-72.9	48.6±15.0	0.3-12.7	7.7±2.7
Rapeseed	18.9-85.2	56.2±16.7	1.2-7.8	4.0±1.5
Cotton	8.9-68.0	38.0±12.2	0.8-7.8	3.0±1.5

* ± denotes the standard deviation.

Table 5. Fertilizer application rates, nutrient ratios, yield increase, fertilizer contribution rate to yields (FCR), and agronomic efficiencies (AE) of rice, winter wheat, rapeseed, and cotton in the 1980s.

	Fertilizer application rate, kg/ha				Yield	Yield		
Crop	N	P_2O_5	K_2O	$N:P_2O_5:K_2O$	increase, t/ha	increase, %	FCR, %	AE, kg/kg
Rice	108	37	38	1:0.34:0.35	1.70	40.8	29.0	9.3
Wheat	105	66	0	1:0.63:0	1.65	56.6	36.1	9.6
Rapeseed	87	58	19	1:0.67:0.22	0.82	64.4	39.2	5.0
Cotton	137	74	49	1:0.54:0.36	0.82	48.6	32.7	3.2

Data derived from China national network on chemical fertilizer experiments (Lin and Li, 1989).

Comparison of Fertilization Effect on Crop Yields between the 1980s and 2006-2009

When compared with the results from the China national network on chemical fertilizer experiments during the 1980s (**Table 5**), the yield increases with NPK fertilization in rice, winter wheat, rapeseed, and cotton under more current conditions were higher by 568, 550, 622, and 798 kg/ha, respectively. The corresponding rates of yield increase were also higher by 6%, 53%, 109%, and 20%. The FCRs in rice, winter wheat, rapeseed, and cotton from 2006 to 2009 were higher by 0.6%, 12%, 17%, and 5.3%, respectively, than the corresponding values extracted from the 1980s. These data suggest that fertilizer plays a much more important role in

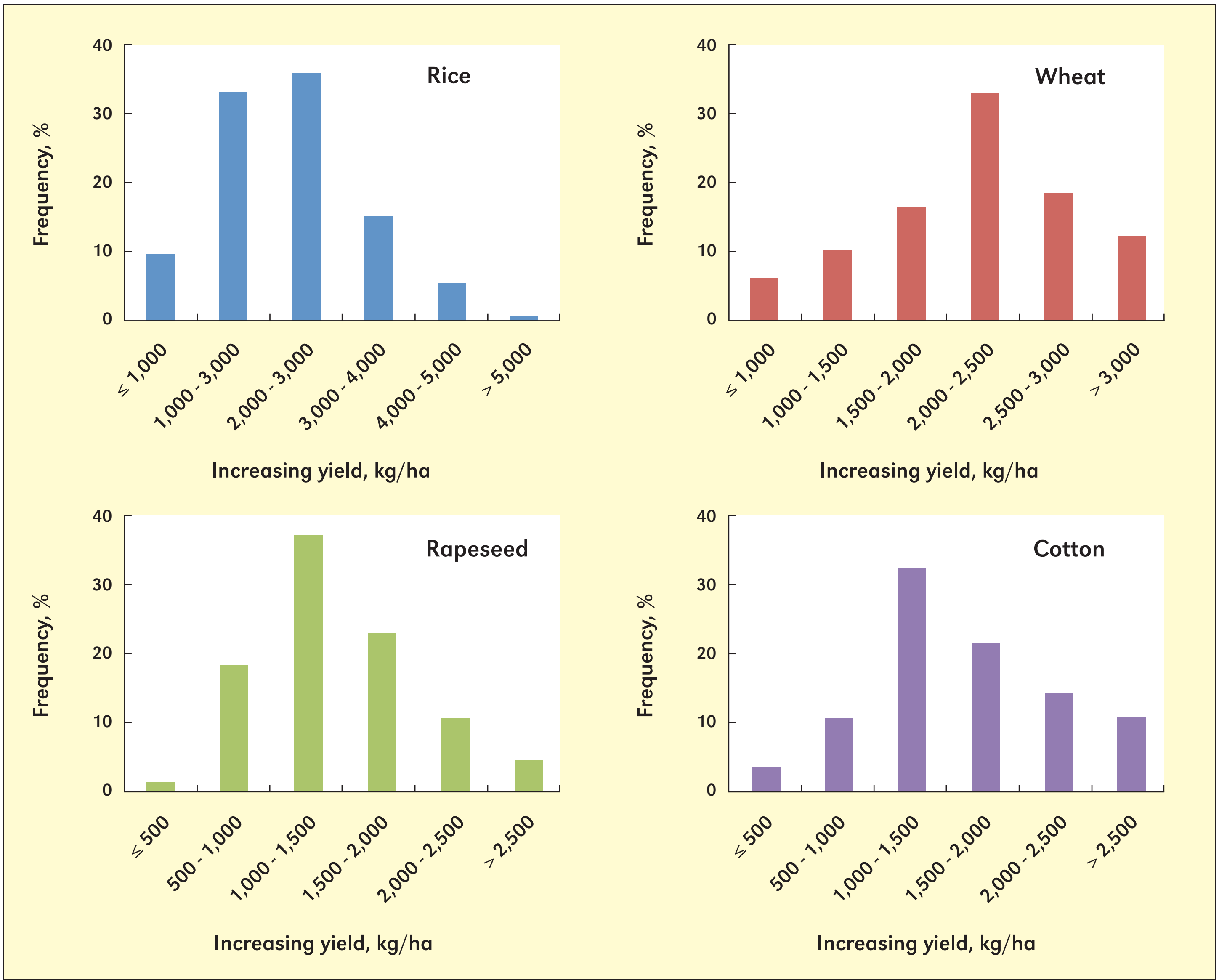

Figure 1. Frequency distributions of yield increase with fertilizer in rice, winter wheat, rapeseed and cotton, Hubei province, 2006 to 2009.

agricultural production today than it did in the past. This is likely due to the use of higher yielding varieties today.

The AEs of fertilizers ($N+P_2O_5+K_2O$) in rice (9.3 kg/kg), winter wheat (9.6 kg/kg), rapeseed (5.0 kg/kg), and cotton (3.2 kg/kg) in 1980s were all higher than those from 2006 to 2009 (**Table 4**). The results clearly indicated that the AE has dropped with the increase in fertilizer application rates, and this challenge needs to be addressed. However, the ratios of applied NPK ($N:P_2O_5:K_2O$) were 1:0.36:0.55 for rice, 1:0.38:0.49 for winter wheat, 1:0.40:0.53 for rapeseed, and 1:0.33:0.67 for cotton from 2006 to 2009 (**Table 2**) with higher application rates of fertilizer K and higher K/N ratios than the corresponding rates in 1980s (**Table 5**). This indicated that farmers are paying more attention to the application of K, and thus to balanced nutrition, today than in the past.

Summary

The results from 386 field experiments in Central China indicated that NPK fertilization increased all crop yields significantly. Similarly, both the rate of yield increase with fertilizer and the FCR for the four experimental crops were higher today than in the 1980s. However, the AE values today are lower than in the 1980s, and this needs to be addressed urgently through more scientific research and extension. BC

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