Optimizing Yield and Benefit in Doublecropped Wheat-Maize Rotations

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Balanced fertilization based on soil testing generated high crop yields, while mean net returns over common farm practice were significant regardless of the chosen price scenario for grain and fertilizer.

The single year winter wheat-summer maize rotation is the most important agricultural production system in the North Central China Plain. High cropping intensity can commonly expose this doublecrop system to risks associated with unbalanced and excess use of N fertilizer (Zhao, 2006). Continuous winter wheat and summer maize cropping without balanced and efficient use of fertilizers has not only contributed to losses in yield and profit, but also to environmental problems such as groundwater NO_3-N contamination and eutrophication of rivers.

Rational nutrient management on these farmlands is needed for sustainable crop production and environmental protection. This study conducted field experiments within the North Central China Plain to explore the potential benefits associated with soil test-based balanced fertilizer application within an improved nutrient management system. Given the recent increases in both grain prices and fertilizer cost, an opportunity also arose to compare a series of price/cost scenarios within a simple 'what-if' analysis.

The field research included four winter wheat and four summer maize experiments placed within farmer fields in Hebei, Henan, Shandong, and Shanxi Provinces from 2006 to 2007 (**Table 1**). Prior to each sowing, soil samples (0 to 20 cm) were collected and analyzed for nutrient status. Soil nutrients were determined with procedures applied by the National Laboratory of Soil Testing and Fertilizer Recommendation as the method described by Porch and Hunter (2002). According to a typical winter wheat/summer maize rotation system, wheat was sown at the beginning of October and harvested at mid June of the next year (**Table 2**). Maize was sown immediately after the wheat harvest, without tillage, and was harvested at the end of September.

Each experiment was designed in a randomized complete block with six treatments and three replicates. Treatments included a check without fertilizer (CK), a soil test-based balanced "optimum" nutrient application (OPT), and a series of nutrient omission treatments including OPT-N, OPT-P, OPT-K, and farmer practice (FP) (**Table 3**). Urea, single superphosphate, potassium chloride, and zinc sulfate were selected as fertilizer sources. All other limiting nutrients in addition to N, P, and K were applied to all treatments prior to sowing.

The timing of fertilizer application differed between sites, but with the exception of the Henan site, followed traditional farm practice. In Shanxi, all N, P, and K fertilizers were applied basally before sowing for winter wheat and summer maize. For wheat in Shandong, 60% of the N and all of the P and K were applied basally and the remaining N was top dressed in early spring before tillering. In maize, half of the N and all of the P and K were applied basally, and the remaining N was top dressed during stalk elongation. In Hebei, wheat and maize both received one third of the N and all of the P and K basally, and the remaining N was top dressed. In Henan, both wheat and maize received half of the N, all of the P, and half of the K basally and the remaining nutrients were topdressed. This differed from the FP treatment which received all of the K at planting time. Irrigation, insect-control, inter-row tillage and other management activities were conducted according to farmers' practice.

Harvested seed and straw samples were randomly collected and oven-dried at 60°C for determination of dry matter weight, and analyzed for total N, P, and K. Plant samples were

Table 1. Physical and chemical properties of tested soils.

Location	Year	Soil type	pH	OM	K	NH_4-N	P	Zn
				%	mg/L			
Shanxi	2006/07	Calcic cinnamon	8.1	0.35	72.2	3.1	21	1.1
Shanxi	2007	Calcic cinnamon	8.4	0.55	126.9	2.7	25	1.8
Hebei	2006/07	Fluvo-aquic	8.4	0.70	78.4	4.9	22	1.1
Hebei	2007	Fluvo-aquic	8.3	0.78	71.1	5.8	45	1.1
Shandong	2006/07	Brown	4.4	1.20	45.2	8.9	59	2.1
Shandong	2007	Brown	4.7	1.00	57.2	21.6	94	1.7
Henan	2006/07	Brown	7.7	1.16	98.9	25.1	21	2.0
Henan	2007	Brown soils	7.9	0.86	77.2	29.6	20	1.0

Table 2. Schedule of crop planting and harvests.

Province	Year	Crop/Variety	Seeding rate	Seeding date	Harvest date	Plot size, m^2
Shanxi	2006/07	Wheat/Jinmai 81	225 kg/ha	Oct. 8, 2006	June 12, 2007	26
Shanxi	2007	Maize/Jindan 958	57,600 plants/ha	June 12, 2006	Oct. 16, 2007	25
Hebei	2006/07	Wheat/Shimai 17	225 kg/ha	Oct. 12, 2006	June 10, 2007	45
Hebei	2007	Maize/Zhengdan 958	63,000 plants/ha	June 17, 2007	Oct. 9, 2007	40
Shandong	2006/07	Wheat/Jinan 17	225 kg/ha	Oct. 12, 2006	June 19, 2007	20
Shandong	2007	Maize/Zhengdan 958	60,000 plants/ha	June 23, 2007	Oct. 10, 2007	32
Henan	2006/07	Wheat/ZM98165	150 kg/ha	Oct. 14, 2006	June 5, 2007	32
Henan	2007	Maize/Zhengdan 958	75,000 plants/ha	June 12, 2007	Oct. 3, 2007	32

Abbreviations and notes for this article: N = nitrogen; P = phosphorus. K = potassium; NO_3^- = nitrate; NH_4^+ = ammonia.

Table 3. Fertilizer treatment design for wheat and maize in 2006-2007.

		Wheat			Maize		
		Nutrient application, kg/ha					
Province	Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Shanxi	OPT	195	90	150	225	90	120
	OPT-N	0	90	150	0	90	120
	OPT-P	195	0	150	225	0	120
	OPT-K	195	90	0	225	90	0
	FP	173	144	0	345	0	0
	CK	0	0	0	0	0	0
Hebei	OPT	180	100	75	270	45	120
	OPT-N	0	100	75	0	45	120
	OPT-P	180	0	75	270	0	120
	OPT-K	180	100	0	270	45	0
	FP	300	150	0	160	48	72
	CK	0	0	0	0	0	0
Shandong	OPT	240	30	120	150	0	120
	OPT-N	0	30	120	0	0	120
	OPT-P	240	0	120	150	60[1]	120
	OPT-K	240	30	0	150	0	0
	FP	113	113	113	75	75	75
	CK	0	0	0	0	0	0
Henan	OPT	210	90	60	240	90	120
	OPT-N	0	90	60	0	90	120
	OPT-P	210	0	60	240	0	120
	OPT-K	210	90	0	240	90	0
	FP	360	210	135	450	225	225
	CK	0	0	0	0	0	0

[1]60 kg/ha P_2O_5 was applied for the OPT-P treatment to verify the accuracy of the zero P level in the OPT treatment predicted by soil test results.

Table 4. Grain yields of wheat and maize in 2006-2007.

	Shanxi				Hebei			
	Wheat		Maize		Wheat		Maize	
Treatments	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
OPT	6,652 a	100	8,298 a	100	6,317 a	100	8,811 a	100
OPT-N	5,848 b	88	6,286 c	76	4,767 bc	75	7,735 b	88
OPT-P	6,218 ab	94	7,921 ab	96	5,750 ab	91	7,984 ab	91
OPT-K	6,164 ab	93	8,224 a	99	6,167 a	98	7,922 ab	90
FP	6,196 ab	93	7,408 b	89	5,625 ab	89	7,568 b	86
CK	5,712 b	86	5,627 d	68	3,883 c	61	7,489 b	85
	Shandong				**Henan**			
	Wheat		Maize		Wheat		Maize	
Treatments	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
OPT	6,199 a	100	5,032 a	100	8,760 a	100	12,051 a	100
OPT-N	4,291 cd	69	3,750 b	75	7,987 c	91	11,156 b	93
OPT-P	3,855 d	62	4,393 ab	87	8,277 ab	94	11,583 ab	96
OPT-K	4,978 bc	80	4,650 ab	92	8,212 ab	94	11,239 b	93
FP	5,881 ab	95	4,756 ab	95	8,688 ab	99	11,754 ab	98
CK	3,855 d	62	4,493 ab	89	7,887 c	90	10,400 c	86

The same letter in the same column indicated no significant at P=0.05

digested using wet oxidation, total N was determined using the Kjeldahl method, P was determined by vanadomolybdate yellow color development, and K was analyzed by flame spectrophotometers (Analysis Approach of Soil Agrochemical Analysis, 2000).

Yields of Wheat and Maize

Crop yield comparisons across sites indicate that yields in Shanxi and Hebei were higher than those in Shandong where yields were severely limited under nutrient omission (**Table 4**). Yields of both wheat and maize in Henan were highest among provinces as this site benefits from being situated within a highly productive zone having continuous and high input of fertilizers and therefore higher residual soil fertility. High yields within the unfertilized check treatments, and a relatively small response to applied N in wheat (773 kg/ha) and maize (895 kg/ha), further supports the high yield potential ranking for the Henan site. Nitrogen was generally the most limiting factor for the wheat/maize system in all provinces, followed by P and K. The OPT treatments significantly increased maize yields over FP by 12% and 16% in Shanxi and Hebei, respectively. However, maize yields under the OPT treatments in Shandong and Henan were not statistically better than FP, and the set of OPT treatments were unable to significantly increase winter wheat beyond those obtained under FP at any of the sites.

Nutrient uptake followed trends similar to those observed for yields. The OPT treatments achieved the highest values in each crop followed by FP (data not shown). Nutrient use efficiency can be expressed as partial factor productivity (PFP), agronomic efficiency (AE), and crop recovery efficiency (RE) (Fixen, 2007). Here we use AE and RE to evaluate balanced fertilization, where AE refers to the crop yield increase per unit nutrient applied, and RE refers to the increase in plant nutrient uptake per unit nutrient applied. Measurements of AE for applied N, P, and K resulted in large crop-to-crop and location-to-location variability. Mean AE values were 6.1 kg/kg N, 23.5 kg/kg P_2O_5, and 6.1 kg/kg K_2O for wheat, and 6.3 kg/kg N, 9.6 kg/kg P_2O_5, and 4.5 kg/kg K_2O for maize (**Table 5**). The high AE value of 78.1 kg/kg P_2O_5 resulted from the low P_2O_5 application rate (30 kg P_2O_5/ha) on winter wheat in Shandong. Under the OPT treatment, each 100 kg seed required 2.95 kg N, 0.87 kg P_2O_5 and 2.42 kg/kg K_2O for wheat, and 2.29 kg N, 0.67 kg P_2O_5 and 2.31 kg/kg K_2O for maize. Nutrients taken up by plants are not only derived from fertilizer applied, but also from the indigenous supplies from soil, atmosphere, irrigation water, etc. The mean RE values of N, P_2O_5, and K_2O for the first season were 27%, 23%, and 26% for wheat, and 24%, 12%, and 33% for maize, respectively.

The economic benefit from fertilizer application was calculated under three scenarios: (a) using actual crop product values and fertilizer prices at the time

Table 5. Nutrient use efficiency[1] of N, P_2O_5, and K_2O.

		Shanxi		Hebei		Shandong		Henan		Mean	
	Nutrient	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
Agronomic efficiency, kg/kg	N	4.1	8.9	8.6	4.0	7.9	8.5	3.7	3.7	6.1	6.3
	P_2O_5	4.8	4.2	5.7	18.4	78.1	10.6	5.4	5.2	23.5	9.6
	K_2O	3.2	0.6	2.0	7.4	10.2	3.2	9.1	6.8	6.1	4.5
Nutrient uptake, kg/100 kg seed	N	3.17	2.31	2.63	2.15	2.39	2.77	3.62	1.92	2.95	2.29
	P_2O_5	0.79	0.76	0.94	0.58	0.50	0.61	1.25	0.74	0.87	0.67
	K_2O	2.05	2.11	1.98	1.79	2.21	3.09	3.44	2.26	2.42	2.31
Recovery efficiency, %	N	36.8	33.8	29.0	13.5	19.6	24.2	24.2	22.9	27.4	23.6
	P_2O_5	9.9	15.0	6.6	14.7	48.9	ND[2]	25.7	13.4	22.8	12.2
	K_2O	25.3	17.6	10.0	18.9	25.0	51.8	43.7	41.9	26.0	32.6

[1]Nutrient use efficiency was calculated with nutrient uptake by OPT treatment. [2]ND = no data.

of the experiment – which preceded the current period of escalating values for both; (b) using current domestic prices which include some government subsidies; and (c) using current international market prices for crops and fertilizers. Crop profitability mirrored the yield responses and despite some marginal differences in yield the OPT treatment was more profitable than FP in each crop/rotation and each location. Comparing the OPT over FP, the mean added net return from the entire rotation under scenarios a, b, and c was US$331/ha, US$307/ha, and US$568/ha, respectively. From these results it is apparent that the Chinese Government subsidies in place failed to fully compensate for the higher cost structure faced by farmers. It is also apparent that profits based on the international market would be significantly higher.

With rising fertilizer prices in international markets, the average value-to-cost ratio (VCR) for the OPT and FP treatments decreased between pricing scenarios from 7.1 and 5.8 to 4.1 and 3.1 for wheat, and 8.7 and 8.4 to 5.5 and 5.1 for maize (**Table 6**). These VCR values also suggested that more return could be obtained from maize than from wheat, and provide another indicator of the advantage of adopting the OPT over FP. It is worth noting that although higher yields could be obtained with high inputs at the high-yielding site in Henan, the VCR was lowest for both wheat and maize under FP and provides a good example of the opportunity cost of excess and imbalanced fertilizer input. As a comparison, the balanced OPT treatments at Henan did produce the highest VCRs for both crops under all three of the price/cost scenarios.

Although balanced fertilization increased both yields and benefits, AE and RE were relatively lower since N responses were less than 2 t/ha, and even less than 1 t/ha in Henan. Therefore, further best management practices (BMPs) should be integrated into common practice to improve fertilizer (especially N) efficiency in this highly intensified cropping system. BC

Table 6. Value-to-cost ratio in wheat-maize rotation system.

		VCR[a]		VCR[b]		VCR[c]	
Province	Crops	OPT	FP	OPT	FP	OPT	FP
Shanxi	Wheat	5.3	6.3	4.0	5.0	3.5	3.6
	Maize	6.8	8.3	4.7	6.3	4.7	5.7
Hebei	Wheat	6.6	4.8	4.6	3.4	3.8	2.5
	Maize	7.8	10.4	5.3	6.8	5.3	6.7
Shandong	Wheat	7.3	7.4	4.4	4.3	3.9	3.7
	Maize	9.9	10.1	4.9	4.9	5.5	4.8
Henan	Wheat	9.0	4.5	6.5	3.3	5.2	2.6
	Maize	10.2	4.8	6.7	3.2	6.6	3.1
Average	Wheat	7.1	5.8	4.9	4.0	4.1	3.1
	Maize	8.7	8.4	5.4	5.3	5.5	5.1

Value cost ratio (VCR) = crop value/fertilizer cost. Small letters a, b, and c denote scenarios using prices for crops and fertilizer at: (a) the time of the experiment (2006/07) = 3.4 to 3.9 RMB/kg N, 4.4 to 6.5 RMB/kg P_2O_5, 3.4 to 4.3 RMB/kg K_2O; wheat = 1.4 to 1.6 RMB/kg, maize = 1.5 to 1.8 RMB/kg); (b) current domestic prices for May 2008 = 4.7 RMB/kg N, 7.1 RMB/kg P_2O_5, and 6.0 RMB/kg K_2O, wheat = 1.474 RMB/kg, maize = 1.376 RMB/kg); and (c) current international market prices for May 2008 = 8.2 RMB/kg N, 13.8 RMB/kg P_2O_5, and 6.3 RMB/kg K_2O, wheat = 1.987 RMB/kg, maize = 2.162 RMB/kg); exchange rate: US$1 = 6.9 RMB.

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