Crop Yield and Soil Fertility as Influenced by Nutrient Management in Rainfed Inner Mongolia

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Traditional nutrient management within the rainfed regions of Inner Mongolia usually results in poor crop productivity. In this study, six successive crop seasons found N, P, and K fertilizer to be responsible for a range of crop yield increases between 5 and 50%. The combined use of recommended NPK rates with manures sustained crop yields and improved soil fertility, but caution must be exercised to avoid the overuse of P and, in turn, the over accumulation of P in soil.

The Inner Mongolia Autonomous Region (IMAR) is a relatively arid, but yet important crop production zone of China. About 70% of its crops are rainfed, including cereals, potato, rapeseed, and sunflower, which are often grown with under 350 mm of annual rainfall **(Table 1)**. Most farmers in IMAR do not use fertilizer and crop yields are low. Little biomass production within this dry climate also results in inadequate recycling of straw to farm fields. This scenario results in the gradual decline in soil fertility and crop productivity. A prominent research priority is to develop the steps required to reverse this trend of declining soil fertility through improved nutrient management.

A 6-year fixed experiment was initiated in 2004 at the Arid Crop Station of IMAR, Wuchuan, to study changes in crop response and nutrient balance resulting from selected nutrient management practices. The site evaluated the application of a NPK recommendation (OPT), OPT-N, OPT-P, OPT-K, sheep manure (M), OPT+M, N alone, and a zero input check (CK).

Rates within the OPT were recommended based on soil analysis using Agro Services International (ASI) procedures (Portch and Hunter, 2002) and realistic yield targets for each crop tested. Beginning in 2004, the 3-year crop sequence was potato-rapeseed-oat.

Notes and abbreviations: N = nitrogen; NH_4^+ = ammonium; NO_3^- = nitrate; P = phosphorus; K = potassium.

Table 1. Rainfall from 2004 to 2009 compared with the average from 1961 to 2008 at the experimental site.

Year	2004	2005	2006	2007	2008	2009	Average 1961-2008
Annual rainfall, mm	397	279	223	223	419	199	346
Rainfall during growing season (May to August), mm	298	211	173	83	309	158	295

Application of N, P, or K fertilizer resulted in improved yields during the timeframe of the field study **(Table 2)**. In the startup year, potato yields increased by 4.3%, 14.4% and 11.6% after application of N, P, and K fertilizer, respectively. After 2004, the recommended NPK treatment produced 10 to 20% more yield than the N, P, or K omission plots, except in 2008 when N and P omission especially affected rapeseed production through 50% and 30% yield reductions, respectively. These larger than average responses are most probably a reflection of higher rainfall at the site, which produced more favorable growing conditions and a higher crop requirement for N and P. Yields under the combined application of NPK and sheep manure were similar or above that achieved with NPK alone. Application of manure alone failed to positively affect potato or oat yields, and reduced rapeseed yields by 20 to 30%. Reliance on N application alone decreased crop yield by 5 to 22%, while the CK reduced crop yield by 15 to 54%.

The nutrient balances calculated after the six successive crops suggest that recommended rates for N or K were not sufficient to balance crop removal, but the P recommendation was excessive and resulted in its accumulation in soil during

Table 2. Crop yield response to different nutrient management practices.

	Potato '04		Rapeseed '05		Oat '06		Potato '07		Rapeseed '08		Oat '09	
Treat.	t/ha	%	kg/ha	%	kg/ha	%	t/ha	%	kg/ha	%	kg/ha	%
NPK (OPT)	14.4b	100.0	1,476b	100.0	1,906a	100.0	13.9ab	100.0	1,458a	100.0	1,266ab	100.0
OPT-N	13.8bc	95.6	1,239cd	84.0	1,630b	85.5	12.4bc	89.3	883c	49.1	1,140bc	90.0
OPT-P	12.6bc	87.5	1,315c	89.1	1,557bc	81.7	12.4bc	89.5	1,029bc	70.6	1,133bc	89.5
OPT-K	12.9bc	89.5	1,271cd	86.1	1,573bc	82.5	11.4bc	82.3	1,417a	97.1	1,153bc	91.1
M[1]	13.9bc	96.2	1,182de	80.1	1,667b	87.4	13.5bc	97.5	1,038bc	71.1	1,270ab	100.4
OPT+M	17.1a	118.2	1,648a	111.7	2,005a	105.2	16.3a	117.7	1,483a	101.7	1,335a	105.5
N	13.2bc	91.5	1,240cd	84.0	1,490bc	78.1	12.0bc	86.7	1,167b	80.0	1,199abc	94.7
CK	11.9c	82.2	1,105e	74.9	1,354c	71.0	10.8c	78.0	671d	46.0	1,076c	85.0

[1]Sheep manure with 0.78-0.35-0.89% of N-P_2O_5-K_2O, 7,500 kg/ha each year, except in 2006 when 15,000 kg/ha was applied.
Randomly designed treatments (three replicates) applied to a plot area of 50 m^2. Numbers within each column followed by the same letter are not significantly different at p = 0.05.

Researchers characterized the impact of improved nutrient management within a three-crop rotation system including potato, rapeseed, and oat.

Table 3. Nutrient input, output, and balance during the six successive crops.

		OPT	OPT-N	OPT-P	OPT-K	M	NPK+M	N	CK
Nutrient input, kg/ha	N	395	0	395	395	411	806	395	0
	P_2O_5	320	320	0	320	185	505	0	0
	K_2O	250	250	250	0	468	718	0	0
Nutrient removal by crop seed and straw, kg/ha	N	497	353	381	433	348	562	426	298
	P_2O_5	173	129	122	144	125	198	117	102
	K_2O	439	334	317	304	329	517	319	290
Nutrient balance, kg/ha	N	-102	-353	14	-38	62	243	-31	-298
	P_2O_5	147	191	-122	176	60	307	-117	-102
	K_2O	-189	-84	-67	-304	139	201	-319	-290

the years of study **(Table 3)**. Accumulated recoveries for N, P, and K from the six crops were 36%, 16%, and 54%, respectively. Omission plots for N, P, and K generated large deficits of 353 kg N/ha, 122 kg P_2O_5/ha, and 304 kg K_2O/ha during this timeframe. Although manure applications did not affect the crop yields, soil N, P, and especially K were in surplus. Larger accumulations were created under continuous application of the NPK recommendation plus manure.

Soil testing (0 to 20 cm) at the end of the experiment found mineral N (NH_4^++NO_3^-) to be lower in all treatments compared with that measured prior to the trial's initiation **(Table 4)**. The recommended NPK treatment maintained the highest mineral N content followed by NPK plus manure. Soil Olsen-P increased in all treatments with the exception of the N or OPT-P treatments. NPK with manure resulted in the highest Olsen-P values after six crop seasons. Exchangeable soil K in all fertilizer treatments did not change significantly, while the manure-supplying treatments had a measurable positive impact on exchangeable K.

Under this rainfed rotation system the recommended NPK alone could not sustain the N and K balance, and only its combination with manure led to improved crop yields and soil fertility. It should be highlighted that although the combined use of recommended rates of NPK with manure supported yields and improved soil fertility under these conditions, special caution must be taken against the overuse of all nutrients and excessive accumulation in soil. Careful monitoring of soil P accumulation is stressed when fertilizer P is used in combination with manure. BC

Table 4. Surface soil (0 to 20 cm) nutrient levels before and after 6 years of experimentation.

Treat.	Mineral N[1] mg/L	Olsen-P, mg/L	Exchangeable K, mg/L
NPK (OPT)	33.4	28.5	73.0
OPT-N	23.2	22.8	64.7
OPT-P	18.7	10.6	73.8
OPT-K	18.5	25.9	70.9
M	21.1	16.5	83.5
OPT+M	25.9	34.5	103.9
N	25.2	12.4	67.0
CK	18.4	16.3	63.4
Soil before trial	75.0	14.5	70.4

[1]Mineral N includes NH_4^+-N and NO_3^--N. The general critical values for soil fertility evaluation are 20 mg/L, 12 mg/L, and 78 mg/L for mineral N, Olsen-P, and exchangeable K, respectively.

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