A Systematic Approach to Balancing Soil Nutrients in Broad Bean-Rice Rotation in Yunnan

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The 'systematic approach' was used to study soil nutrient status and balanced fertilizer use in a common broad bean-rice crop rotation in Yunnan province. Inadequate potassium (K) was found to sharply limit bean yields in all cases, while phosphorus (P), boron (B), zinc (Zn), and magnesium (Mg) either strongly or weakly limited yields. Residual effects of K, nitrogen (N), and B were inconsistent, indicating the significant adsorption (fixing) capacities of soils in the region. The systematic approach is a cost effective and useful method for developing sound fertilizer recommendations.

The systematic approach for determining soil nutrient status can be used to develop a soil nutrient balance that becomes the basis of soil analysis and fertilizer recommendations (Portch, 1988). The procedure consists of determining the availability of essential plant nutrients in test soils, the adsorption of important nutrients by the soil, and conducting greenhouse studies to evaluate crop responses to nutrient additions. Experience shows that this approach allows for the development of more definitive field experiments.

Experimental Methods

Paddy soils from Yunnan province were sampled at Kunming, Yimen and Luliang. Each 70 kg bulk sample was comprised of 15 to 20 sub-samples randomly taken from the plow layer. From this well-mixed bulk sample, 1.5 kg was used in the laboratory. Soil nutrient analyses were conducted using the ASI procedure (Hunter, 1980). Nitrogen as ammonium-N (NH_4-N), extractable acidity, calcium (Ca), and Mg were extracted using 1N KCl. Available P, K, copper (Cu), iron (Fe), and Zn were measured using the ASI extraction procedure. Available sulfur (S) and B were extracted using 0.08M $CaH_4(PO_4)_2$. Soil organic matter content and pH were also determined.

Nutrient adsorption (fixation) studies were based on nutrient analysis results and were used to detect abnormal reactions between the test soil and each nutrient applied. Nutrient adsorption was determined by adding various rates of nutrients to soil and allowing them to react under moisture regimes ranging from complete saturation to air-dry.

This procedure simulated chemical reactions expected under actual field conditions. After incubation, the soils were extracted and analyzed for available P, K, Cu, manganese (Mn), Zn, S, and B.

Greenhouse experiments using sorghum as the test crop were conducted based on both laboratory and adsorption results. The amount of each nutrient applied in the optimum treatment was determined by the previously established balance of soil nutrients. Ratios of Ca/Mg and Mg/K were also considered when establishing the optimum treatment. Nutrients were omitted in test treatments to determine plant availability. Normally, nutrients considered adequate are not included in the optimum treatment; however, this study included these as test treatments to assure accurate interpretation of laboratory results. Each greenhouse trial had four replications in a randomized complete block (RCB) design. Five sorghum plants were harvested from each pot after one month's growth.

Su Fan compares the growth of broad beans with and without K. Plants at left received 180 kg K_2O/ha, while those shown at right received no K.

Field experiments on broad bean and rice conducted in Kunming, Luliang and Yimen were based on results of each soil's nutrient analysis, adsorption data, and greenhouse results. The treatments were applied to broad bean and, in most instances, residually evaluated on rice (**Table 1**).

Table 1. Fertilizer treatments (kg/ha) for broad bean and rice field trials in Yunnan province, China.

	Location					
	Kunming		Yimen		Luliang	
Treatment	Broad bean $N-P_2O_5-K_2O-Mg-B$	Rice $N-K_2O$	Broad bean $N-P_2O_5-K_2O-Mg-Zn$	Rice $N-K_2O$	Broad bean $N-P_2O_5-K_2O-B-Zn$	Rice $N-K_2O$
1	0-0-120-30-7.5	120-0	0-0-120-30-30	120-0	0-0-120-7.5-30	120-0
2	0-60-120-30-7.5	120-0	0-60-120-30-30	120-0	0-60-120-7.5-30	120-0
3	0-120-120-30-7.5	120-0	0-120-120-30-30	120-0	0-120-120-7.5-30	120-0
4	0-180-120-30-7.5	120-0	0-180-120-30-30	120-0	0-180-120-7.5-30	120-0
5	0-120-0-30-7.5	120-0	0-120-0-30-30	120-0	0-120-0-7.5-30	120-0
6	0-120-60-30-7.5	120-0	0-120-60-30-30	120-0	0-120-60-7.5-30	120-0
7	0-120-180-30-7.5	120-0	0-120-180-30-30	120-0	0-120-180-7.5-30	120-0
8	0-120-200-30-7.5	120-0	0-120-200-30-30	120-0	0-120-200-7.5-30	120-0
9	45-120-120-30-7.5	120-60	45-120-120-30-30	120-60	45-120-120-7.5-30	120-60
10	0-120-120-0-7.5	120-0	0-120-120-0-30	120-0	0-120-120-0-30	120-0
11	0-120-120-30-0	120-0	0-120-120-30-0	120-0	0-120-120-7.5-0	120-0

At the three locations, each soil received four levels of P_2O_5 (0, 60, 120, 180 kg/ha), and five levels of K_2O (0, 60, 120, 180, 200 kg/ha). Magnesium and Zn were tested at 0 and 30 kg/ha, B at 0 and 7.5 kg/ha. Nitrogen was added only at 45 kg/ha in treatment 9. Field experiments were laid out using an RCB design with four replications. The plot area of 14 m^2 was planted to a population of 285,735 broad bean plants/ha. Local, high yielding varieties were used as well as normal cultural practices for growing broad beans in Yunnan.

After broad bean harvest, all rice plots received 120 kg N/ha. In addition, treatment 9 received 60 kg K_2O/ha to test the immediate effect of K fertilizer on rice. The rice plant population was approximately 525,000 seedlings/ha. Normal management and cultural practices for the local high yielding variety were followed.

Broad beans without K application (left) showed no pod formation. Plant at right received 180 kg K_2O/ha.

Results

Soil Analyses and Adsorption Studies – Soil analysis indicated below critical levels for available N, K and B in the Kunming sample; N, P, K, Zn, and Mg in the Yimen sample; and N, P, K, Zn, and B in the Luliang sample (**Table 2**). Potassium was especially low in the three soils. Each soil showed a relatively strong capacity for P and K adsorption with correlation coefficients being highly significant for these two plant nutrients (data not shown). The soils at Kunming and Yimen also had a strong capacity for adsorbing Mn. Adsorption of B and Zn was moderate when compared to the other plant nutrients tested. All three soils had a relatively low capacity for adsorbing S and Cu. Considering the laboratory analyses and adsorption studies, P and K had the highest potential to limit yield, although the probability for B and Zn to limit yield was also high at each site.

Greenhouse Experiments with Sorghum – Greenhouse results with the Kunming soil showed N, P, K, and B to be the main yield limiting factors (**Table 3**). Omission of these nutrients reduced dry matter yield by 56.4, 63.9, 23.3, and 10.5 percent, respectively. Relative yield was increased by 10.3 percent with Mg application even though available soil Mg was indicated to be above the critical level. Nutrient deficiencies in Kunming, in order of magnitude, were P > N > K > B > Mg. These nutrients were used in the field evaluation trials.

Omission of N, P, K, and Zn from the Yimen soil markedly reduced yield while showing severe deficiency symptoms. Adding Cu, molybdenum (Mo), Fe, and S had no effect on yield. Adding Mn reduced yield, which indicated levels at or near toxicity. An 8.5 percent yield increase was achieved by adding Mg, which indicated a need to test this nutrient in the field. The order of magnitude of nutrient deficiencies evaluated in field trials was P > N >> K > Zn > Mg.

The Luliang soil showed Mg, Cu, Fe, Mn, Mo, and S to be sufficient, while addition of N, P, K, Zn, and B increased relative yields by 79, 78, 31, 23, and 12 percent, respectively. Thus, these five nutrients were selected for field evaluation.

Field Experiments – Application of N or P to broad bean had no effect on yield at Kunming, which was most likely a result of nutrient adsorption (**Table 4**). However, residual N and P effects were apparent in the following rice crop grown under flooded conditions as yields increased by 656 and 492 kg/ha, respectively. Potash application increased broad bean yields up to 2,063 kg/ha. Application of 180 kg K_2O/ha on broad bean increased subsequent rice crop yields by 632 kg/ha. Adding 60 kg K_2O/ha directly to rice (Treatment 9) was equal to the residual effect of applying 180 or 200 kg K_2O/ha in the previous broad bean crop. There was no obvious effect of Mg on broad bean; however, an application of 7.5 kg B/ha increased broad bean yield by nearly 11 percent. No obvious effect from either Mg or B was noted in the rice crop.

Neither N nor P application provided any broad bean yield response at Yimen. However, application of N and K to rice resulted in a 14 percent yield increase, equal to 1,178 kg/ha. Magnesium and Zn

Table 2. Nutrient status of soils from Kunming, Yimen and Luliang, in Yunnan province, China.

Location	pH	OM, %	Ca	Mg	K	Ca/Mg	Mg/K	N	P	S	B	Cu	Fe	Mn	Zn
			····· meq/100 ml soil ·····					···· ppm soil[1] ····							
Kunming	6.1	1.3	6.9	1.79	0.03	3.8	59.7	7	25	65	0.24	7.8	236	12.9	2.1
Yimen	7.5	1.2	12.8	1.27	0.03	10.1	42.3	9	9	56	0.34	5.8	55	20.5	1.3
Luliang	5.9	1.1	6.7	1.63	0.07	5.0	19.0	8	12	79	0.28	4.0	241	5.5	0.7
Critical level				1.50	0.20	4.1	23.3	50	14	14	0.30	1.0	10	5.0	2.0

[1] ppm = parts per million

Table 3. Results and comments from greenhouse studies with three soils, Yunnan province, China.

	Location					
	Kunming		Yimen		Luliang	
Treatment	Relative yield, %	Comment	Relative yield, %	Comment	Relative yield, %	Comment
Optimum	100	Set value	100	Set value	100	Set value
+$^1/_4$ K	98.4	No effect on yield	95.0*	More K needed	75.8**	More K needed
+$^1/_2$ K	109.3	Suitable amount	111**	Suitable amount	89.8**	More K needed
+$^3/_4$ K	92.5	No effect on yield	95.3	No effect on yield	98.0	Suitable amount
+Mg	110.3**	Yield increase	108**	Yield increase	81.5**	Sufficient
-N	43.6**	Deficient	50.7**	Deficient	20.9**	Deficient
-P	36.1**	Deficient	30.1**	Deficient	21.8**	Deficient
-K	76.7**	Deficient	81.4**	Deficient	68.6**	Deficient
-B	89.5*	Deficient	100	Adequate	88.0**	Deficient
+Cu	92.9	Sufficient	104	None needed	97.0	None needed
+Fe	82.4**	Sufficient	99.4	None needed	108**	None needed
-Mn	92.7	None needed	–	–	95.0	None needed
+Mn	–	–	88.4*	Sufficient	–	–
-Mo	95.9	None needed	–	–	101	None needed
+Mo	–	–	102	None needed	–	–
+S	81.5**	Sufficient	104	None needed	89.6**	Sufficient
-Zn	106.4	None needed	87.6**	Deficient	76.8**	Deficient
Check	30.4**	Low yield	24.8**	Low yield	14.6**	Low yield
**LSD (.01)	0.1562†		0.0685		0.1504	
*LSD (.05)	0.1160		0.0508		0.1117	

†LSD calculations are based on actual yields in grams per pot.

applications produced 229 and 449 kg/ha more broad bean yield, respectively, but had no residual effect on the following rice crop. A very large K response produced up to 3,534 kg/ha more broad bean yield, and the residual K effect produced 6.2 to 26.5 percent more rice. Inadequate K in the optimum treatment applied to broad bean may have masked potential responses to other plant nutrients tested. Further fieldwork is needed, including an optimum treatment with at least 180 kg K_2O/ha.

Phosphorus, K, B, and Zn increased broad bean yields at Luliang by 662, 534, 522, and 26 kg/ha, respectively. Some residual yield effects from N and B application in broad bean were seen on the following rice crop, but residual effects were not obvious with any other nutrient.

Table 4. Treatment yields (kg/ha) and calculated relative yield (%) in field trials with a broad bean-rice rotation at Kunming, Yimen and Luliang, Yunnan province, China.

		Broad bean							Rice						
			Relative yield, %							Relative yield, %					
Location	Treatment	Yield, kg/ha	N	P	K	Mg	B	Zn	Yield, kg/ha	N	P	K	Mg	B	Zn
Kunming	1	3,580		100					5,553		100				
	2	3,401		95.0					6,045		109				
	3	3,378	100	94.4	201	101	111		5,837	100	105	102	102	103	
	4	3,441		96.1					5,856		106				
	5	1,680			100				5,717			100			
	6	2,516			150				5,417			94.8			
	7	3,661			218				6,349			111			
	8	3,743			223				6,458			113			
	9	3,326	98.5						6,493	111					
	10	3,351				100			5,736				100		
	11	3,049					100		5,691					100	
Yimen	1	2,786		100					8,123		100				
	2	2,822		101					8,415		104				
	3	2,972	100	107	1,943	108		118	8,432	100	104	111	98.1		97.4
	4	2,795		100					8,625		106				
	5	153			100				7,589			100			
	6	1,227			802				8,057			106			
	7	3,687			2,410				8,816			116			
	8	3,002			1,962				9,600			126			
	9	2,641	88.9						9,610	114					
	10	2,743				100			8,591				100		
	11	2,523						100	8,654						100
Luliang	1	2,389		100					7,973		100				
	2	2,690		113					8,046		101				
	3	2,881	100	121	121		122	101	8,165	100	102	102		106	102
	4	3,051		128					8,283		104				
	5	2,379			100				8,020			100			
	6	2,701			114				8,257			103			
	7	2,913			122				8,269			103			
	8	2,863			120				7,065			88.1			
	9	2,812	97.6						8,888	109					
	10	2,359					100		7,669					100	
	11	2,855						100	8,045						100

Conclusions

Generally, the main limiting factors found in the greenhouse were also detected in the field. That is, nutrients found deficient in the greenhouse, if omitted, also reduced yields in the field. Differences in plant responses can be attributed to the less controlled environment outside the greenhouse. Under the broad bean-rice rotation, the main limiting plant nutrients at Kunming were K, B and N, while P and Mg could be considered of secondary importance. Potassium and Zn mainly limited yield at Yimen, and P and Mg were of secondary concern. Residual responses to N, P and K were also significant at Yimen. The main yield limiting nutrients at Luliang were P and K, while B and Zn were of secondary importance.

There can be considerable difference in the nutrient adsorption and supply capacity amongst soils. The systematic approach uses soil analyses, adsorption studies, and greenhouse experiments to create more definitive field trials by reducing the number of treatments that need to be tested. This approach provides preliminary information on soil nutrient status and identifies the magnitude of existing nutrient limitations in a cost effective manner. Success in field experiments may be based on using such techniques. This process can be applied to varietal screenings, plant population, new cultural practice studies, etc.

Compensating for possible nutrient deficiencies assures a balanced nutrient supply so the effect of tested factors on yield are not masked. Furthermore, nutrients not shown to be limiting in the greenhouse are highly unlikely to limit yields in the field, thereby allowing the researcher to exclude them from field trials with reasonable confidence. This allows for efficient use of space, which is particularly limited on farmer fields. Determination of the nutrient status for each essential nutrient and the soil's nutrient adsorbing capacity should be considered as the first steps to developing a sound fertilizer recommendation program. **BCI**

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