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In This Issue:

Phosphorus and Potassium Application in a Wheat-Corn Rotation in Hebei (China)

Phosphorus and Potassium Fertilization and Mineral Nutrition of Soybean in Guarico (Venezuela)

Boosting Spice Production through Balanced Nutrition under Coconut Gardens of Kerala (India)

and much more…

Vol. 14, Issue 2,
November 2000

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Table of Contents

Our Cover: Spreading rice to dry in the sun after harvest in rural India.
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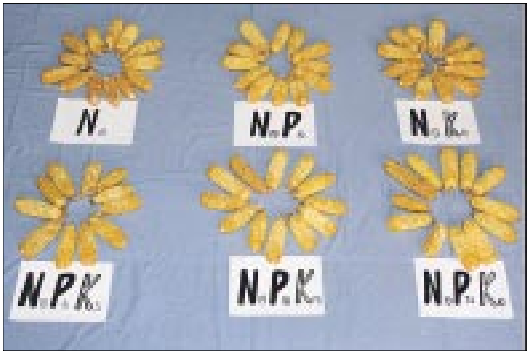
Responses to Phosphorus and Potassium Application in a Wheat-Corn Rotation in Hebei Province

By Guo Jianhua, Xing Zhu, and Liu Zongheng

Results of an experiment in the Hebei Plain show the importance of balanced fertilization for higher yields and economic returns in a wheat-corn rotation.

A wheat-corn rotation is the main cropping system in the Hebei Plain. It has been fertilized with nitrogen (N) and phosphorus (P) for the past several years. However, insufficient P rates and no potassium (K) application have resulted in imbalanced levels of soil P and K.

Crop yields have improved with newer crop varieties, but the experiment outlined in this article shows winter wheat grain yield increased by 39 percent using N and P compared to N alone. Corn yield increased by 15 percent by applying N and K compared to N alone. Proper balancing of N, P and K in the wheat-corn rotation produced the highest yields and economic benefits for farmers.



Proper balancing of N, P and K in the wheat-corn rotation produced the highest yields and economic benefits for farmers.

The experiment was located in Zhengding county, Hebei province. Annual precipitation in the region ranges between 500 to 600 mm. Soil organic matter was 1.0 percent, and available soil N and P (P_2O_5) were 62 and 38 mg/kg, respectively. The established system of crop rotation was winter wheat followed by summer corn. The wheat variety was Jimai-26 planted at about 2.7 million plants/ha. The corn variety was Yedan-2, planted at about 67,500 plants/ha. All crop management practices were optimum for the two crops.

Treatments were arranged in a randomized complete block design with four replications. Nitrogen was held constant at 195 kg/ha for wheat and 210 kg/ha for corn. Three levels (0, 112.5 and 150 kg/ha) of both P_2O_5 and K_2O were applied only to wheat and were tested in varying combinations. The subsequent corn crop received only N while the residual effects of P and K were studied. Fertilizer sources were urea, single superphosphate (SSP), and potassium chloride (KCl).

Results and Discussion

Response to P and K application in a wheat-corn rotation. Results showed that P application could improve both wheat root and tiller growth before the onset of winter. Comparing P and non-P treatments without added K, tillers increased 3.92 million/ha (**Table 1**), and average tillers per plant increased by 0.77 (data not shown). In addition, wheat spikes increased 2.12 million/ha, above ground dry matter weight increased 70 percent (data not shown), and wheat grain yield increased 1,533 kg/ha (39 percent).

The treatment with P absent, but K added, increased wheat yield by only 0.9 percent, indicating the importance of P to wheat at this location. Even when P was added at 112.5 kg P_2O_5/ha and K at 150 kg K_2O/ha, wheat yield failed to reach the same level (5,445 kg/ha) as that obtained with 150 kg/ha P_2O_5 and no K.

Only when P_2O_5 was applied at 150 kg/ha and K_2O at 112.5 kg/ha was there a positive response (349 kg/ha) to K application. This clearly indicates the importance of applying at least 150 kg/ha P_2O_5 to this rotation for both efficient use of applied K and high yields.

The corn experiment studying the residual effects of P and K application to wheat showed corn yield increased 1,543 kg/ha (25 percent) with 150 kg P_2O_5/ha compared to no P (**Table 1**). The corn kernel number per ear increased 11.0, and the barren part of the ear shortened 0.7 cm with application of K fertilizer.

Table 1. Yield and agronomic responses to P and K applied to wheat in a wheat-corn rotation in Hebei.

		.... Winter wheat			.... Corn		
P_2O_5	K_2O	Yield, kg/ha	Maximum tillers	Spikes	Kernel number	Bare ear length, cm	Yield, kg/ha
.... kg/ha			.... million/ha				
0	0	3,912	9.59	3.59	399	1.9	6,261
150	0	5,445	13.51	5.71	464	1.3	7,804
0	150	3,949	9.24	3.96	410	1.2	7,230
112.5	150	5,350	14.67	5.11	479	1.2	8,410
150	112.5	5,794	13.09	5.99	485	1.1	8,902

Table 2. Economic benefit (Yuan/ha) of P and K applied to wheat in a wheat-corn rotation in Hebei.

P_2O_5	K_2O	Wheat income[1]	Corn income[2]	Total income	Total input cost	Net income
.... kg/ha		.... Yuan/ha				
0	0	3,912	4,383	8,295	810	7,485
150	0	5,445	5,463	10,908	1,185	9,723
0	150	3,949	5,061	9,010	1,035	7,975
112.5	150	5,350	5,887	11,237	1,316	9,921
150	112.5	5,794	6,231	12,025	1,354	10,672

[1] Wheat price = 1 Yuan/kg, [2] Corn price = 0.7 Yuan/kg

As with wheat, application of K in the absence of P did not produce as high a corn yield as P application in the absence of K. This confirms the importance of P over K even though there was a yield response to K (969 kg/ha).

The best combination of fertilizer was a balanced application of 150 kg P_2O_5 and 112.5 kg K_2O/ha to wheat. This treatment produced 444 more kg grain/ha than the yield obtained with 112.5 kg P_2O_5 and 150 kg K_2O/ha. These results emphasize the importance of applying adequate P for consistently high yields and a most economic response to applied K. However, for more definitive results, higher levels of all three plant nutrients should be tested at this location. In particular, P at 150 kg/ha may be limiting response to applied K.

Application of P fertilizer was important in achieving higher economic response to K fertilizer.

The economic benefit of P and K applications in a wheat-corn rotation. As is often the case, the highest net income was achieved with the highest yield, using balanced NPK fertilization (**Table 2**). Phosphorus alone increased farmer profit 2,238 Yuan/ha compared to plots receiving no P. Response to K was only 490 Yuan/ha compared to yields with no applied K, when both received adequate N. However, when balanced P and K were used, the profit was 3,187 Yuan/ha over plots with only N applied. Balanced fertilization gave a total profit of 10,672 Yuan/ha for the two crops. (Note: US$1 = approximately 8.2 Yuan.)

Conclusions

Results from this experiment clearly demonstrated the need for applying both P and K in soils of the Hebei Plain, once thought to be 'rich' in K. Such applications need to be large enough to produce high, economic yields. The results are not definitive because the treatment with the highest level of applied P was also the highest yielding. And while K response seemed to peak at 112.5 kg K_2O/ha, it is not known what the response would have been had P – the more limiting of the two – been tested at higher levels with K.

Regardless, information from this trial indicates that at the N levels used, the minimum P_2O_5 application for this rotation should be 150 kg/ha while K should be added at 112.5 kg K_2O/ha. Following such a recommendation will make the farmer money and will also help maintain the fertility level of the soil.

Further research at different locations and with higher levels of all three plant nutrients would seem a practical recommendation to achieve more definitive results in the future. **BCI**

Guo Jianhua, Xing Zhu, and Liu Zongheng are staff members of the Soil and Fertilizer Institute, Hebei Academy of Agricultural and Forestry Sciences, in Shijiazhuang, Hebei.

Phosphorus and Potassium Fertilization and Mineral Nutrition of Soybean in Guarico State

By E.F. Casanova

Although soybean yields are improving in Venezuela, current production levels fall far short of the amounts needed to satisfy local feed markets. This research helps to identify best management practices needed for sustained, high yields on Venezuela's acid, low fertility savanna soils.

Venezuela imports around 800,000 tonnes of soybeans every year to be used mainly for swine and poultry production. The largest area planted during the last 15 years was 7,850 ha in 1988, while the average yield for 1986 to 1996 was 1,517 kg/ha (**Figure 1**). These data show how dependent Venezuela is on soybean imports.

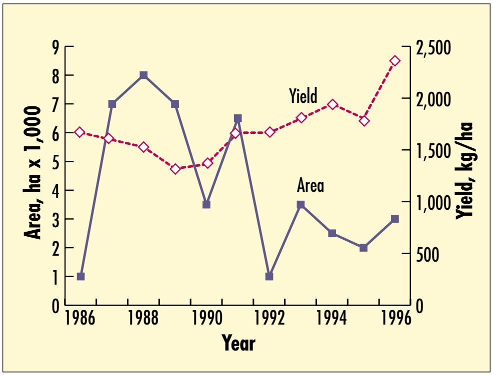


Figure 1. Area harvested and soybean yields in Venezuela (1986-1996).

Agriculture in Guarico state, located in north central Venezuela, has been rapidly developing and several crops, including soybean, are grown successfully. The state's prevalent soils were developed under savanna and have low natural fertility. These soils are acid. The primary plant nutritional limitations are phosphorus (P), potassium (K), nitrogen (N), and calcium (Ca). Other nutrients such as magnesium (Mg), sulfur (S) and zinc (Zn) become limiting when the soil is cultivated for several years. Consequently, sustained agriculture in the region is based on sound liming and fertilizer programs.

A field experiment was conducted during two rainy seasons to evaluate the effect of P and K rates on soybean yield and nutrition.

Materials and Methods

The site was located on a farm at Palo Seco, Guarico state, Venezuela. The test soil was an Oxisol, typical of the savanna soils of the Eastern Llanos of Venezuela. Physical and chemical characteristics of the soil are presented in **Table 1**.

A randomized block design with three replications was used in the field. Variables were: 0, 5, 10, 20, 30, 40, 50, 60, and 70 kg P/ha as triple

Table 1. Soil characterization at Palo Seco, Guarico state, Venezuela.

Sand	Silt	Clay	Texture	pH	Organic matter	P	K	Ca
%					%	ppm	cmol(+)/kg	
51	29	20	Loam	4.5	1.3	22	0.10	0.05

superphosphate (TSP), and 0, 9, 18, 36, 54, 72, 90, 108, and 135 kg K/ha as potassium chloride (KCl). All P plots received a fixed rate of 108 kg K/ha, and all K plots received a fixed rate of 60 kg P/ha. A basic application of 1,000 kg lime/ha (300 kg Ca/ha) was incorporated in all plots along with 220 kg magnesium sulfate ($MgSO_4$)/ha...40 kg Mg/ha. All the fertilizers were broadcast and plowed under before planting. In both years, soybean seeds (cultivar FP-3) were inoculated at planting with *Bradyrhizobium japonicum*. Nitrogen was also applied at 30 kg/ha during planting to insure adequate N supply while nodules developed and became active.

The uppermost trifoliate leaves were sampled at the R2 plant reproductive stage to evaluate P and K nutritional status of the plant for comparison with the published sufficiency levels in the literature. Harvest was carried out 115 days after planting. Grain yield at 12 percent moisture was recorded.

Results and Discussion

Grain yield responses to P treatments for two years are presented in **Table 2**. A yield response to P is clear in both years, and the best yields were obtained with 70 kg P/ha. Grain yield response to K application is given in **Table 3**. The best grain yields were obtained with 108 kg K/ha in the two years studied.

Foliar P and K concentrations at the R2 plant reproductive stage are presented in **Tables 2** and **3**, respectively. As expected, when P was not applied, foliar P concentrations were at deficient levels in both years. The highest foliar P concentration was reached at 60 kg P/ha in 1997 and 20 kg P/ha in 1998. This difference was likely related to a better rainfall distribution in 1997 and excess moisture in 1998.

In 1997, foliar K concentrations were deficient in the two lowest K treatments while application of 18 kg K/ha produced values within the sufficiency range as reported in published literature. In 1998, all the treatments produced a foliar K concentration within the sufficiency range. Highest

Table 2. Soybean grain yields and foliar P concentration responses to P application rates in field experiments at Palo Seco, Guarico state, Venezuela.

P rates[1]	Soybean yield		P foliar concentration[2]	
	kg/ha		%	
	1997	1998	1997	1998
0	615	700	0.23	0.28
5	814	890	0.26	0.35
10	826	960	0.44	0.35
20	925	1,338	0.44	0.57
30	1,188	1,667	0.46	0.51
40	1,585	2,433	0.46	0.40
50	2,443	2,731	0.44	0.35
60	2,598	2,814	0.50	0.35
70	2,713	2,938	0.50	0.38

[1] All treatments received a blanket application of 108 kg K/ha

[2] Uppermost trifoliate leaves at the R2 plant reproductive stage

Table 3. Soybean grain yields and foliar K concentration responses to K application rates in field experiments at Palo Seco, Guarico state, Venezuela.

K rates[1]	Soybean yield		K foliar concentration[2]	
kg/ha			%	
	1997	1998	1997	1998
0	914	1,180	1.51	2.27
9	973	1,280	1.58	2.87
18	1,092	1,299	2.34	2.64
36	1,188	1,320	2.36	2.54
54	1,559	2,236	2.66	2.64
72	2,294	2,725	2.62	2.62
90	2,246	2,773	2.71	2.70
108	2,544	3,164	2.25	2.65
135	2,520	2,815	2.21	2.61

[1] All treatments received a blanket application of 60 kg P/ha

[2] Uppermost trifoliate leaves at the R2 plant reproductive stage

concentrations were reached with 90 kg K/ha in both years.

These results suggest that the sufficiency ranges presented in the literature are probably not appropriate for tropical conditions and particularly for the soybean varieties used in Venezuela. Grain yield results obtained in this experiment did not correlate well with foliar nutrient concentrations. Therefore, further research is needed to define the critical levels for soybean grown in Venezuelan environments.

This study also emphasized the importance of seed inoculation with *Bradyrhizobium japonicum* to promote fixation of atmospheric N. Since the majority of these soils do not have a history of soybean cultivation, a small amount of N at planting is also needed to assure adequate supply of N. Future efforts will be needed to commercially produce this inoculant in Venezuela to satisfy the demand of soybean area expansion.

Conclusions

Soybean yields showed a positive response to P and K fertilization in the savanna soils of Venezuela. The treatment combination of 60 kg P/ha and 108 kg K/ha produced the best grain yield of 3,164 kg/ha in 1998. High yielding treatments also produced leaf P and K concentrations within known sufficiency ranges.

Established critical levels for leaf P and K in soybean did not relate well with yields obtained in the two study years. These results suggest that the sufficiency range used to establish the plant nutritional status is probably not appropriate for the tropical conditions and varieties used in Venezuela. Therefore, it will be necessary to conduct additional research in order to define new critical levels for soybean grown in the country.

Data documented with these experiments clearly demonstrate that nutrient and fertilizer management is an important factor to be considered for soybean production in the acid, low fertility soils of the Venezuelan savannas. Careful soil management can sustain high soybean yields to satisfy the needs of Venezuelan poultry and swine production. **BCI**

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Research Notes

India: Optimal Phosphorus Management Strategies for Wheat-Rice Cropping on a Loamy Sand

Researchers evaluated phosphorus (P) management strategies for a wheat-rice rotation, comparing seven P fertilizer treatments for wheat and rice, respectively. Results of the 1990 to 1997 study were as follows:

- Grain yields and seasonal P accumulation were highest with highest P fertilizer rates and remained stable in treatments with P applied to wheat.
- Phosphorus fertilization of rice increased P accumulation by rice, but did not consistently increase yields (because flooding decreased soil P sorption and increased P diffusion, resulting in a higher P supply to rice relative to wheat).
- Phosphorus adsorbed by ion-exchange resin capsules placed in situ was five times greater under rice than under wheat.

Researchers concluded that when both grain and straw were removed from fields, annual application of 32 kg P/ha to wheat, along with 15 kg P/ha to rice, was optimal for achieving short-term economic and long-term agronomic goals. They also pointed out that their results require further study at other sites, at higher rice yield levels and for different straw management. **BCI**

Source: Yadvinder-Singh, A. Dobermann, Bijay-Singh, K.F. Bronson, and C.S. Khind. 2000. Soil Sci. Soc. Am. J. 64: 1413-1422.

Boosting Spice Production under Coconut Gardens of Kerala: Maximizing Yield of Turmeric with Balanced Fertilization

By M. Meerabai, B.K. Jayachandran, K.R. Asha, and V. Geetha

A two-year field study was conducted on turmeric intercropped under partial shade of coconut. Results indicated that turmeric responded to higher nitrogen (N) and potassium (K) fertilizer application. Proper nutrition produced higher yield and net profit compared to turmeric supplied with state fertilizer recommendations.

Turmeric is a spice used extensively by all classes of people in India and is one of India's most ancient and traditional export commodities. The healing property of turmeric has long been acknowledged by practitioners of traditional medicine. Scientists working in the U.S. and Britain have found evidence supporting claims that turmeric acts as an anti-cancer agent (Anonymous, 1994). Alleppey turmeric from Kerala is highly profitable as an internationally accepted variety (Thampi, 1997). The turmeric industry is emerging stronger year after year with increased production capabilities and product range. India continues to be the largest producer (659,000 tonnes) from an area of 147,000 ha and earns about 461 million rupees (Rs.) annually (George, 1997).

The agro-climatic conditions in Kerala state are favorable for successful turmeric cultivation. Thus Kerala can play a predominant role in turmeric production by improving productivity through balanced fertilizer use. However, area expansion as an individual crop is limited due to scarcity of cultivable land in Kerala.

Coconut is a widely spaced (i.e., 7.6 m x 7.6 m) crop with minimal root density in the top 30 cm of soil. Also, lateral spread of most tree roots is confined within a two meter radius of the tree base. Turmeric is shallow rooted with 95 percent of its roots confined to the top 30 cm of soil. This combination of root distribution makes turmeric and coconut a compatible, agronomically sound, and economically viable cropping system.

A cultivar's genetic potential and environmental setting usually control crop yield. However, crop nutrition plays an important role by allowing full exploitation of a cultivar's genetic potential. Quite often it also plays a crucial role in overcoming biotic and abiotic stresses. Earlier experiments conducted on open field conditions indicated significant improvements in rhizome yield of turmeric with increased N levels up to 120 kg N/ha (Singh *et. al.,* 1992). Similarly, Thamburaj (1991) reported a favorable effect on yield with increased K up to 90 kg K_2O/ha. Kerala Agricultural University (KAU, 1996) recommends 30-30-60 kg N-P_2O_5-K_2O/ha for turmeric grown in open field conditions, but these recommendations are not suitable for turmeric grown in shaded areas of coconut gardens.

Materials and Methods

The field study was undertaken at Vellayani, Kerala during 1998-2000. The experimental site was lateritic, sandy clay loam in texture, pH 4.4, low in available N, K, boron (B), and zinc (Zn). Other nutrients were near optimum. The experiment was conducted in a randomized block design with 14 treatments each and replicated three times. Treatments were determined by initial soil test values and soil requirements based on sorption/fixation studies. They consisted of selected combinations of four levels of N (30, 60, 90, 120 kg N/ha), two levels of P (0, 30 kg P_2O_5/ha), and four levels of K (60, 120, 180, 240 kg K_2O/ha). Blanket applications of 10 kg Zn/ha and 2 kg B/ha were also provided. These treatments were compared with the state fertilizer recommendations and a control. Nutrients were supplied in the form of urea, mussoriephos (rock phosphate), muriate of potash, elemental sulfur (S), and borax. Zinc oxide (ZnO) was the Zn source. All the P and micronutrients and half the N and K were supplied basally. The remaining N and K were given one month after planting. The remaining recommended cultural practices were applied uniformly for all treatments (KAU, 1996).

Results

Averaged over two years, graded N rates applied with 120 kg K_2O/ha raised turmeric yields from 16.2 to 19.8 t/ha (**Table 1**). Similarly, incremental rates of K applied along with 90 kg N/ha increased fresh rhizome yields from 16.5 to 19.3 t/ha. Sufficient soil P prevented a significant response to P application. Application of 120-120-2-10 kg N-K_2O-B-Zn/ha resulted in the highest average rhizome yield of 19.8 t/ha over two years. These rates could be considered necessary for a maximum economic yield (MEY). This MEY recommendation produced a 25 percent higher yield compared to the current state fertilizer recommendation (**Table 2**).

Table 1. Selected responses of N and K on fresh rhizome yield of turmeric, Kerala, India.

Nutrient	Rate, kg/ha	Fixed rates[1], kg/ha	Fresh rhizome yield, t/ha 1998-99	1999-2000	Average
N	30		17.6	14.7	16.2
	60	K_2O (120)	19.4	14.9	17.1
	90		20.5	16.1	18.3
	120		23.0	16.6	19.8
K_2O	60		18.4	14.6	16.5
	120	N (90)	20.5	16.1	18.3
	180		21.2	16.5	18.8
	240		21.4	17.1	19.3

[1] Blanket rates applied to all treatments: 2 kg B/ha, 10 kg Zn/ha.

Table 2. Effect of selected nutrient rates on fresh rhizome yield of turmeric, Kerala, India.

Treatments N	 K_2O	Average fresh rhizome yield, t/ha	Net returns, Rs/ha	Benefit: cost ratio
State recommendation[1]		15.8	92,824	2.15
90	60	16.5	93,013	2.05
90	120	18.3	112,565	2.26
120	120	19.8	128,788	2.44

[1] 30-30-60 kg N-P_2O_5-K_2O/ha; all treatments received 2 kg B/ha and 10 kg Zn/ha except for the state recommendation.

Despite the higher rates of nutrients prescribed by the MEY recommendation, the MEY system produced net returns equivalent to US$2,862/ha and a benefit:cost ratio of 2.44. This income is in addition to income from coconut harvest from the same land. The MEY recommendation provided farmers additional profit equivalent to US$799 on every hectare of coconut garden turmeric production when compared to current state fertilizer recommendations. As a high value, export-oriented crop, this economic comparison should be of interest to farmers, extension workers, and policy-makers.

Conclusion

This study indicates the present state fertilizer recommendation for turmeric is insufficient when turmeric is intercropped in coconut gardens. Higher yields for turmeric grown under such conditions can be achieved with higher doses of N and K applied in a balanced manner. Application of 120 kg N and 120 kg K_2O/ha, along with micronutrients such as B (2 kg B/ha) and Zn (10 kg Zn/ha), produced MEY. Inclusion of P would be necessary in soils testing low and medium in available P. This practice was found to be agronomically sound and economically beneficial. Results of these studies also suggest that higher yields could be achieved using higher fertilizer application rates under open field conditions. Further research with higher levels of N and K is needed to find a true MEY. **BCI**

M. Meerabai and B.K. Jayachandran are Associate Professors and K.R. Asha and V. Geetha are Research Associates in the College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram, Kerala.

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Effect of Magnesium Fertilizer on Sustaining Upland Agricultural Development in Guangxi Province

By Tan Hongwei, Du Chenglin, and Zhou Liuqiang

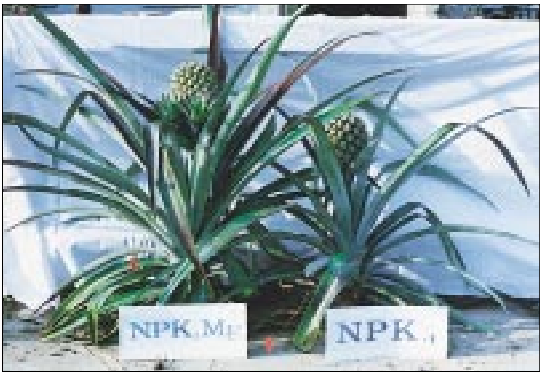
The rainfed upland soils of Guangxi province in south China are subject to high rainfall and heat, as well as an intense climate that has effectively made most agricultural soils nutrient poor. When fertilized, these soils can support a wide variety of high value crops. It is apparent, however, that the future profitability of the region depends on balanced fertilization. This article describes how insufficient soil magnesium (Mg) is limiting crop yield, quality, and use efficiency of nitrogen (N), phosphorus (P) and potassium (K).

Plant available Mg in the main upland soils of Guangxi province is quite variable (10.9 to 370.6 mg exchangeable Mg/kg), but soils commonly used for crop production...such as lateritic red earth, latosols and silicosols...often test less than 70 mg exchangeable Mg/kg.

This study found a negative correlation between soil exchangeable Mg levels and applied Mg. That is, at high levels of soil Mg, application of Mg fertilizer reduced yields. This is expressed in the following

Table 1. Influence of Mg fertilizer application on cash crop yields, kg/ha.

		Treatment					
Crops		NP	NPMg	NPK1	NPK1Mg	NPK2	NPK2Mg
Cassava	Yield	8,400	9,516	19,270	21,207	23,697	27,788
	Yield incr.		1,116		1,937		4,091
	%		13.3		10.1		17.3
Kenaf	Yield	—	—	1,940	2,366	2,619	3,012
	Yield incr.	—	—		426		393
	%	—	—		22.0		15.0
Sugarcane	Yield	60,937	64,875	82,610	99,426	85,483	93,176
	Yield incr.		3,937		16,815		7,693
	%		6.5		20.3		9.0
Watermelon	Yield	24,724	34,695	41,991	44,584	44,284	46,371
	Yield incr.		9,971		2,593		2,087
	%		40.3		6.2		4.7
Pineapple	Yield	35,563	37,969	44,906	49,063	45,163	52,219
	Yield incr.		2,406		4,156		7,056
	%		6.8		9.3		15.6



Improved pineapple growth due to balanced fertilization is shown at Guangxi.

equation: $Y=10.95e^{-0.30x+\ln x}$, where Y=yield, e=constant (2.7183), and x=content of exchangeable Mg.

The average yield response to Mg fertilizer in cash crops, oil crops, grain crops, and vegetables was 4.7 to 40.3; 1.5 to 39.1; 4.6 to 11.4; and 1.7 to 25.5 percent, respectively, (**Tables 1** to **4**). It is important to note that most crops had large yield responses to K fertilizer as well, but addition of Mg to the NPK treatments resulted in further yield gains.

Application of Mg fertilizer not only increased yield, but also had a positive effect on quality. Sugar content in sugarcane increased 0.9 percent, fiber intensity of kenaf increased, and soluble sugar content in watermelon increased 0.90 to 1.79 percent.

All the crops absorbed more N and P when Mg was applied, while K uptake was increased only in some cases. Generally, Mg application reduced both K and calcium (Ca) uptake. It is important these facts be considered in a fertilizer recommendation that includes Mg so that proper balances are kept for healthy plant growth and to maintain soil fertility.

Table 2. Influence of Mg fertilizer application on oil crop yields, kg/ha.

		Treatment			
Crops		**NPK1**	**NPK1Mg**	**NPK2**	**NPK2Mg**
Peanut	Yield	3,083	3,934	4,526	4,592
	Yield incr.		851		66.0
	%		27.6		1.5
Soybean	Yield	1,380	1,920	2,134	2,299
	Yield incr.		540		165
	%		39.1		7.7

Table 3. Influence of Mg fertilizer application on grain and tuber crop yields, kg/ha.

		Treatment			
Crops		**NPK1**	**NPK1Mg**	**NPK2**	**NPK2Mg**
Corn	Yield	3,833	4,036	4,716	5,117
	Yield incr.		203		401
	%		5.3		8.5
Sweet potato	Yield	11,261	11,914	12,688	14,139
	Yield incr.		652		1,451
	%		5.8		11.4
Rice	Yield	4,890	5,115		
	Yield incr.		225	—	—
	%		4.6		

Balancing Magnesium in the Uplands of Guangxi Province

Only a small amount of Mg (2.04 kg/ha per year) is supplied to the region's rainfed upland crops through precipitation. Additionally, the stability of Mg-containing soil minerals is poor. Since the area endures high temperatures and heavy rainfall, sources of soil Mg are subject to rapid weathering and leaching resulting in large Mg losses. This negative balance was further amplified with the introduction of improved crop varieties that were both higher yielding and Mg-loving. For instance, cassava may take up more than 19 and sugarcane 130 or more kg MgO/ha/yr (**Table 5**). Higher NPK fertilizer use producing higher yields has also resulted in greater crop removal of Mg from these soils.

Table 4. Influence of Mg fertilizer application on vegetable crop yields, kg/ha.

		Treatment					
Crops		**NP**	**NPMg**	**NPK1**	**NPK1Mg**	**NPK2**	**NPK2Mg**
Tomato	Yield			63,150	67,380		
	Yield incr.	—	—		4,230	—	—
	%				6.7		
Eggplant	Yield			43,500	45,570		
	Yield incr.	—	—		2,070	—	—
	%				4.8		
Cabbage	Yield	38,042	47,745	41,127	42,845	47,370	48,195
	Yield incr.		9,703		1,718		825
	%		25.5		4.2		1.7
Chinese cabbage	Yield			63,094	65,625		
	Yield incr.	—	—		2,531	—	—
	%				4.0		

Table 5. Balance of soil Mg with fertilizer application, kg/ha.

Crops	**Treatment**	**Application rate**	**Uptake**	**Input/output balance**
		kg MgO/ha		
Sugarcane	NPK1	0	102.0	-102.0
	NPK1Mg	63.0	117.5	-54.5
	NPK2	0	130.0	-130.0
	NPK2Mg	63.0	137.0	-74.0
Cassava	NPK1	0	19.4	-19.4
	NPK1Mg	40.5	19.9	+20.6

It is apparent that the problem of soil Mg deficiency has not been solved in the uplands of Guangxi province. As a result, sustained high yielding crop production cannot be achieved. Magnesium deficiency also reduces the effectiveness of other applied plant nutrients. Thus, the positive effects on yield and farmer income from balanced NPK fertilizer use cannot be brought into full play. Guangxi's development of its agricultural uplands requires attention to Mg fertilizer application. Otherwise, farmers will continue to struggle with poor NPK fertilizer use efficiency, low yields, poor crop quality, and lower profits. **BCI**

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Soybean Responses to Potassium Fertilization in a Low Fertility Oxisol

By C.M. Borkert and T. Yamada

Research on potassium (K) nutrition for soybean is providing guidelines for correcting nutrient deficiencies in low fertility soils of Brazil.

Aerial view of the experiment in low fertility soils, Brazil.

After nitrogen (N), K is the second most absorbed nutrient by soybean. A soybean crop takes up about 81 kg of N and 54 kg of soil K for every 1,000 kg (tonne) of harvested grain, which results in an annual export of 51 kg of N and 14.4 kg of K per tonne of grain (**Table 1**).

Sustained high yielding soybeans are fundamentally achieved by maintaining the best conditions for plant growth and for biological N fixation due to its overwhelming role in soybean production. This means that the soil's nutrient supplying power must be capable of meeting the nutrient demands of both the crop and the rhizobia. Besides K, other nutrients such as sulfur (S) and micronutrients are often deficient. Attention to balanced fertilization ensures the best response to all nutrients applied.

A study on soybean responses to K was conducted over a five-year period by researchers of the Brazilian Agricultural Research Corporation (EMBRAPA) National Soybean Research Center. The experiment was carried out on a dystrophic oxisol (latossolo roxo distrófico) with low overall fertility and a very low level of exchangeable soil K, 0.05 cmol$_c$/dm^3. The treatments were 0, 40, 80, 120, 160, and 200 kg K_2O/ha applied annually.

Table 1. Nutrients absorbed by the growing crop and exported in 1,000 kg of soybeans.

Nutrients	Absorbed	Exported	Exported/absorbed
	kg nutrients/1000 kg soybeans		%
N	81.5	51.0	62.5
P	8.1	6.4	79.0
K	54.5	14.4	26.4
Ca	27.2	2.5	9.2
Mg	9.3	2.5	26.8
S	4.6	2.4	52.2

Source: Flannery (1986, 1989).

Responses to Potassium

Response to K fertilization occurred when exchangeable soil K was below 40 mg K/kg of soil. It was also observed that K application rates greater than 80 kg of K_2O/ha were required to produce top yields and correct the soil K level after five years of experimentation (**Figure 1**).

This study has allowed researchers to define a range of sufficiency for

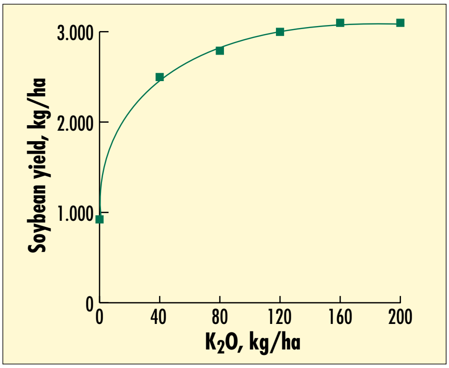

Figure 1. Soybean response to K fertilization in a low fertility oxisol (Borkert et al., 1993a).

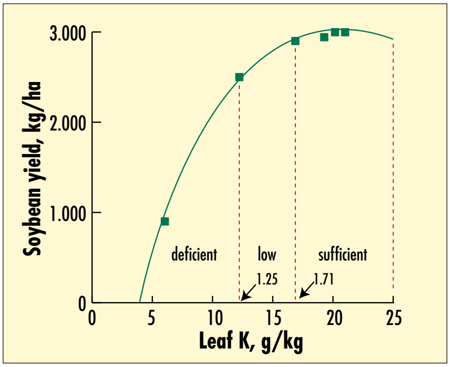

Figure 2. Relationship between leaf K and soybean yield (Borkert et al., 1993b).

leaf K concentration. These results agree with the overall ranges and categories given in previous literature (**Figure 2**).

The effect of K fertilization on seed quality was also evident as seed K concentration increased with higher K rates (**Figure 3**). The recommended threshold for superior seed quality of soybean corresponds to a K content of 12 g K/kg seed, which was achieved by applying more than 80 kg K_2O/ha.

The dystrophic oxisol studied was characterized by low fertility that included a significant K deficiency on soybean. This K deficiency occurs on 85 percent of the soils in 200 million hectares of Brazilian cerrado. High responses to K fertilization were evident when exchangeable K was below 40 mg K/kg of soil. In addition to increasing yield, a large improvement in seed quality was also observed with adequate K fertilization. **BCI**

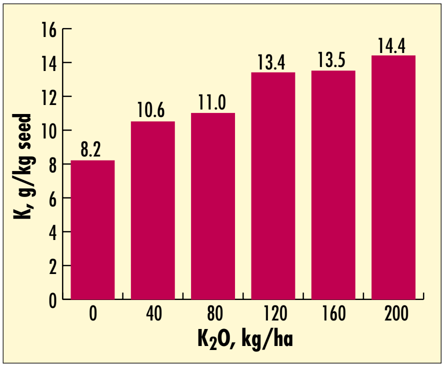

Figure 3. Relationship between K fertilization and K content in soybean seed.

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

By Hong Lifang, Su Fan, Zhao Zongsheng, and Fu Libo

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

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

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.

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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Effect of Various Sulfur Sources on Yield and Soil Sulfur Balance in a Rice-Rice Cropping Pattern in Guangxi Province

By Tan Hongwei, Xie Rulin, Zhou Liuqiang, and Lu Jinping

Guangxi is a major agricultural province in China, located in the southern sub-tropical region. Years of high temperature, heavy rainfall, and cultivation have resulted in soils with low cation exchange capacity (CEC), low organic matter, and low levels of plant available phosphorus (P), potassium (K) and sulfur (S). Recent cultural practices with a rice-rice cropping pattern have increased nutrient demand in this area and brought attention to proper S balances in these soils.

Guangxi's major lowland cropping system is early rice followed by late rice. In the past, Guangxi had low rice yields. Soil S supply was not considered important because past practices of recycling organic matter and extensive use of single superphosphate (SSP) had provided most S needs. That situation changed as farmers began striving for higher rice yields to satisfy the needs of a growing population.

Success was achieved with more nitrogen (N), P and K fertilizer and higher plant populations. However, an increasing amount of organic matter began to be diverted to commercial uses such as fodder or fuel. Also, farmers reduced S inputs by becoming more reliant on calcium magnesium phosphate (CaMgP) as the source for supplying P. It is apparent that any increase in yield also increased S uptake by rice (**Table 1**). Thus, Guangxi's prevailing conditions of climate, soil, fertilizer use, and cropping intensity combined to create a serious S imbalance.

Table 1. Total rice production and S uptake, Guangxi, 1978-1995, 1,000 tonnes.

Year	Crop	Total yield	S uptake
1978	Rice	9,110	11.0
1980	Rice	10,070	12.2
1985	Rice	9,860	11.9
1990	Rice	12,390	15.0
1995	Rice	13,080	15.8

The two locations chosen for this study were Qaogong in Laibin county and Loshi in Wuming county. Sulfur sources tested in the field were ammonium sulfate (AS), SSP, elemental S (ES) and gypsum (GYP). Sulfur was applied at 30 kg S/ha in early rice. The following late rice crop did not receive additional S. Treatment plot size was 33 m^2 with each treatment replicated three times. Plant population was 375,000 plants/ha. Rain and irrigation water samples were collected and analyzed for sulfate-S (SO_4-S) content.

Reported results are averages of these two locations.

Application of various S sources to an early rice-late rice cropping system increased yield of both crops significantly in Guangxi province.

Results indicate that all S sources had a positive effect on early rice yield (**Table 2**). Yield increases ranged from 9 to 10 percent higher than plots receiving no S. The residual effect of S increased late rice yield from 7 to 8 percent. The effect of S on total yield of the rice-rice cropping pattern was significant and ranged from 8.3 to 9.2 percent. There were no significant differences in yield responses among the four S sources.

The S rice needs for normal growth can originate from inorganic or organic forms in soil, atmospheric deposition, or fertilizer. Sulfur deficiency will occur if these inputs are not in balance with crop uptake. Analysis of water from rain combined with rainfall data indicates 47.6 kg SO_4-S/ha are deposited annually. Due to soil absorption and losses associated with water flow, it is estimated that only about 50 percent of the SO_4-S deposited by rainfall is used by the crop, which converts to 23.8 kg SO_4-S/ha/yr. In Guangxi, it was calculated that about 12.2 kg SO_4-S/ha was added to the rice crops per year through irrigation water. This estimate of S received from water supplies by the two rice crops, compared against plant uptake data when 30 kg S/ha is added as fertilizer, suggests positive S balances (**Table 3**).

Table 2. Effect of various S sources on rice yield (kg/ha), Guangxi.

		S source				
Crops		**CK**	**AS**	**SSP**	**ES**	**GYP**
Early rice yield, kg/ha	Average	6,103	6,661	6,675	6,735	6,726
	> CK	–	558*	572**	632**	623**
	Rel. yield, %	100	109	109	110	110
Late rice yield, kg/ha	Average	5,337	5,747	5,721	5,760	5,715
	> CK	–	410**	384**	423**	378**
	Rel yield, %	100	108	107	108	107
Total yield, kg/ha	Average	11,441	12,408	12,397	12,495	12,442
	> CK	_	967**	956**	1,054**	1,001**
	Rel. yield, %	100	108	108	109	109

*,**Significantly different from CK (zero S) at 0.2 and 0.05 levels, respectively.

Table 3. Sulfur balance (kg/ha) in an early rice-late rice cropping pattern, Guangxi.

Item treatment	**CK**	**AS**	**SSP**	**ES**	**GYP**
Sulfur from rain, irrigation, and fertilizer	36.0	66.0	66.0	66.0	66.0
Rice sulfur uptake	38.6	44.4	43.1	45.8	44.2
Sulfur balance	-2.6	21.6	22.9	20.2	21.8

Application of various S sources to an early rice-late rice cropping pattern increased yield of both crops significantly. There was no real difference among the S sources as far as their effect on yield. When 30 kg S/ha was applied to this lowland cropping pattern in Guangxi, a positive S balance remained in the soil. Without added S there was a negative S balance, depletion of soil reserves, and lower yields. Use of S-containing fertilizers would seem a good strategy for high yield rice production in these areas of Guangxi province. **BCI**

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Factors Controlling Potassium Fertility in Hill Country Pastures

By R. Tillman and S. Officer

The steeply undulating pastures of New Zealand hill country have historically been unresponsive to potassium (K) fertilizers. However, decades of nutrient removal and transfer by stock have suggested that K deficiencies may be developing. The onset of K deficiency is difficult to detect in hill country pastures because of the inherent variability in K status across the landscape and within landscape units due to transfer of K by animals. Recent studies in the North Island identified the main factors controlling K fertility in hill country pastures. The work may create opportunities for managing K fertility in hill country using precision application technology.

In New Zealand, it is generally considered that mixed pasture forages should have a K concentration of approximately 2.5 percent for maximum production. This means that in extensive hill country pastures producing approximately 8 tonnes dry matter (DM)/ha/yr, annual plant uptake of K can amount to 200 kg K/ha. Given this high annual requirement for K, understanding the dynamics of K cycling in grazed pasture systems becomes very important.

Surveys were undertaken on two hill country sites in the North Island to determine the relationship between soil K status and slope, aspect, pasture regrowth, spring soil moisture content, and mineralogy. They confirm that three main factors control K fertility of hill country pastures – animal redistribution, micro-relief, and erosional processes.

Animal Redistribution

Although pasture plants require large amounts of K to achieve maximum production, grazing animals such as sheep and cattle require only small quantities to flourish. Most (more than 90 percent) of the K they ingest is excreted, mainly in urine.

On flat land, the spatial distribution of dung and urine is generally random, although areas around gateways, water troughs, and trees or hedges tend to receive a higher return. Therefore, over a period of several years, all areas of the paddock are likely to benefit from the addition of a large quantity of excreted K.

In hilly land, the distribution of dung and urine is not random. Although animals forage for food over the whole area, they rest and sleep on well-defined flatter areas known as camp sites. These are often

Table 1. Soil test results and pasture regrowth within three slope zones in two hill country pastures.

	Ground slope class, degrees					
	20 to 50		10 to 20		0 to 10	
	Mean	C.V.	Mean	C.V.	Mean	C.V.
Exchangeable K, mg/g	0.14	44%	0.37	78%	0.51	59%
Pasture regrowth, kg DM/ha	880	40%	1430	37%	1480	27%
Number of results	31		11		17	

in sheltered spots in the lee side of ridges. There is, therefore, a systematic transfer of K from the sloping areas of the paddock to the flatter areas (**Table 1**).

Relief

Hilly land, by its very nature, has areas of differing slope and aspect. The rugged landscape in which one of the surveys from this study was conducted is illustrated in the photo. Areas facing the sun are warmer than areas on the shady side of the hill. Rainfall tends to run off steep spurs and ridges and collect in hollows and flatter areas. These contrasts in relief and microclimate can result in three- and four-fold differences in the amount of pasture grown in different areas of the paddock. This will have major implications for the amount of K taken up by the pasture plants and the amount transferred away by grazing animals.

Grazing stock favor flatter ground in hilly pastures, particularly the ridge-tops.

These differences in soil water status, temperature, and plant growth also affect the chemistry of K within the soil. Young soils of sedimentary origin are generally well supplied with available K. As time goes on, the soils become more weathered, and the reserves of available K become depleted through grazing or other crop removal and through leaching. The varied terrain in hill country means that all of these processes are occurring at different rates in different parts of the landscape. Thus, the soil K status can be expected to vary in a complex way. For example, this study showed that non-exchangeable K content had a strong positive relationship with mica content. But it was also related to aspect and spring soil moisture, suggesting that the microrelief was able to influence the weathering of clay minerals due to temperature and moisture effects.

Erosion Processes

The final complicating factor in New Zealand hill country relates to the age of the soil and soil renewal through erosion. As noted earlier, young, undeveloped soils on sedimentary parent materials tend to have large reserves of available K. As soils on flat land weather and are cropped year after year, these reserves become depleted, and K fertilizers are required to enable farming to be sustainable. On steep slopes, however, erosive processes constantly remove the topmost layers of soil and expose the less weathered parent material beneath. This is a disadvantage for nutrients like nitrogen (N) that are stored mainly in the organic matter in the topsoil. But for K that originates in the soil minerals, this constant exposure of fresh, unweathered material can maintain soil reserves at a high level. Once again, the extent of these erosion processes and the soil K status will vary markedly across the landscape.

As a result of all these interacting processes, many hill country pastures contain areas that are deficient in K and will respond to added fertilizer, but also contain areas that have ample reserves of soil K and are unlikely to respond to fertilizer K. This variability in soil K levels across the landscape may mask a developing deficiency for many years. What is needed is an understanding of the processes that are affecting the distribution of K within the farming system, so that areas of the landscape that are likely to be most deficient can be identified. It is in these areas that soil samples should be collected and trials conducted to assess the degree of response to K fertilizer addition.

This study has concluded that developing K deficiency will first be apparent in steep areas of the field where the micro-relief results in collection of moisture. In these sites, plant uptake is enhanced, weathering of micaceous minerals is more rapid, and grazing will transfer K away from steep slopes towards the flatter ridge tops. To manage such a complex system successfully, it is necessary to recognize the whole spectrum of K availability that exists in the landscape – and not resort to a single value such as an average. This concept is now well established in the "precision farming" technologies associated with cropping on flat land, but is new to the management of extensive hill country pastures.

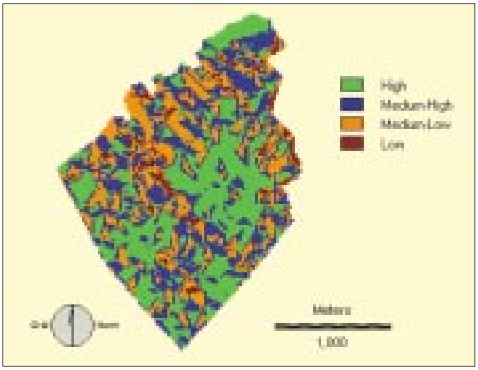

Figure 1. Fertilizer requirements vary with north- or south-facing slopes, steepness, and other factors.

The first step in formulating a fertilizer program is to consider the limits imposed by the application technology. Most fertilizer application in hill country is from the air. This limits the precision of application. However, the soil pattern and the nature of the topography may still allow different fertilizers – or different rates of the same fertilizer – to be applied to different areas. An example might be differentiating between north- and south-facing aspects or slope categories (**Figure 1**). If one aspect or slope category is likely to respond to K fertilizer and the other is not likely to respond, then the ability to differentially apply fertilizers will greatly improve the economics of fertilizer use.

(continued on page 31)

Measuring and Managing Variability in Potassium Fertility for Hill Country Pastures

By R. Tillman and S. Officer

The complex suite of factors controlling potassium (K) fertility of New Zealand hill country pastures results in a large variation in soil K content across both large- and small-scale topography. At the same time, the deposition of high K urine and dung patches by grazing animals increases the range in soil K levels likely to be detected and can have a large influence on the measured K content of bulked samples from multiple sampling sites. The potential exists to underestimate the K status of hill country paddocks using conventional sampling techniques. A survey undertaken on North Island hill country pastures identified typical distributions of soil K measurements and suggested more appropriate sampling strategies.

Approximately 40 percent of New Zealand's land surface is characterized by the steep, non-arable hills below 1,000 m altitude, popularly called hill country. As reported in the related article preceeding, several factors interact in a complex way to produce a wide variation in K fertility across the landscape, resulting in a mosaic of high K fertility and potentially K responsive areas. Under these conditions, the ability of current soil sampling procedures to identify developing K deficiencies is questionable, and alternative methods of measuring the K fertility status of hill country pastures are needed.

A survey was undertaken on a 10 ha hill country site in the North Island to determine the variability in soil K status with distance and the frequency distribution of soil K measurements from individual sampling sites.

Characterizing the spatial distribution of a variable involves taking many measurements at known distances apart and constructing a picture of the rates of change in the variable with distance. This survey was based on an approximate 50 m grid with each square sampled using a 25 m long sampling string anchored on one end to the center of the square. Six samples were taken along the string placed in a random direction, so that the distances between points were equal to 0.25 m, 1.0 m, 2.5 m, 10 m, and 25 m. At each sampling point, note was made of several descriptive landscape categories: the predominant pasture species, aspect, medium scale, and small-scale topography. Soil

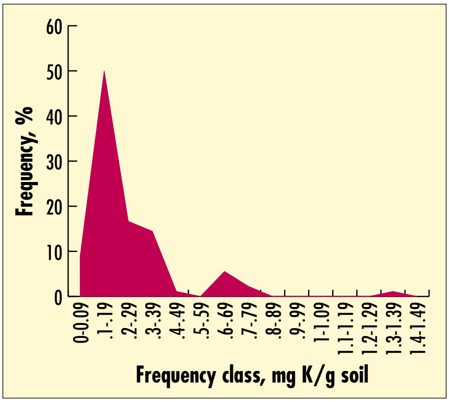

Figure 1. Distribution of soil test K measured from a hill country site is heavily skewed. The arithmetic mean (which would be approximated by bulking the samples) is much higher that the median value, giving a false indication of the K status of the site.

samples were taken from each point and analyzed for exchangeable K (Quick Test K - two minute ammonium extraction).

Distribution

A wide range in soil exchangeable K content (from 0.07 to 1.34 mg K/g) was found in the 90 samples taken from the site. The frequency distribution of soil K measurements was skewed (assymetrical), with the bulk of samples lower than the arithmetic mean and a long tail of much higher values (**Figure 1**). This is compared with the median value, which more closely represented the bulk of the samples.

The distribution of exchangeable K values in this survey was similar to two further surveys conducted 18 months later on this pasture and another hill country site. This suggested that the distribution of exchangeable K was not affected by seasonal changes and is probably representative of the variability found in many hill country pastures.

Distance Dependent Variability

At the smallest sampling distance of 0.25 m, no changes occurred in any of the descriptive landscape categories (**Figure 2**). At distances of 1.0 m, only the small-scale topography changed, with about half of the sampling sites now positioned on a different small-scale topographical formation. Comparing points 2.5 m apart showed that by now pasture species were also changing with distances, and by 10 m distance, all the descriptive categories had at least some degree of change.

The amount of variation in exchangeable K was so great that no significant relationship between distance and frequency of change could be identified. Even at the smallest sampling distance of 0.25 m, the variability of soil K tests was considerable. It seemed that soil K variability was not primarily influenced by any one of the landscape characteristics described and that all of the variability in soil K may already have been present at 0.25 m. This is a very small scale, but corresponds with the approximate size of a urine patch.

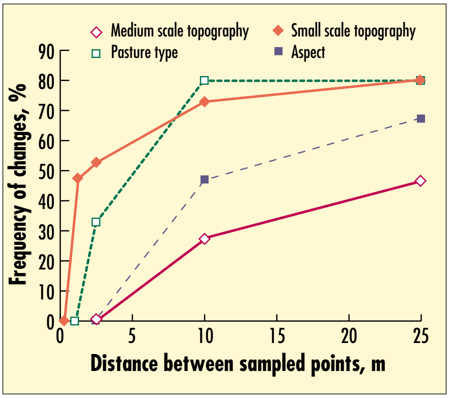

Figure 2. At the smallest sampling distance of 0.25 m, no changes occurred in any of the descriptive landscape categories.

Discussion

Current sampling procedures rely on the assumption that the distribution of soil K status across a paddock is approximately normal (i.e., the mean = median) and that a sufficient number of samples will result in a representative sample and soil test result. However, bulking samples from soils with such wide-ranging and skewed distributions of

K content may introduce significant sampling errors.

There are several reasons for the inappropriateness of bulked samples in hill country. Even if a bulked sampling test result does happen to accurately reflect the arithmetic mean of the soil population, the relevance of a single number as an adequate representation of such a wide-ranging population remains highly debatable. Collecting individual samples and analyzing them separately to find a median and range may be a more appropriate way of describing these distributions.

It is also noteworthy that if the main effect of grazing is an increasing incidence of very high K sites, then the average values of bulked samples will be disproportionately increased. This could create the incorrect impression of increased K fertility under grazed pasture, when in fact the bulk of the soil area is being depleted of K.

The high degree of variability within very small distances also sheds doubt over the effectiveness of avoiding known affected areas such as camp sites where animals rest, and bulking samples from smaller, apparently even areas. In addition, it poses problems for the conduct of small-plot field trials, with it being almost impossible to delineate plots with a low degree of variability. This may suggest that a change to large scale, landscape area experimental approaches would not suffer the penalty of increased within-plot variation, an advantage if a move to precision aerial application techniques in experimentation is likely. **BCI**

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Factors Controlling Potassium...

(continued from page 28)

Soil testing and trials to assess likely plant growth responses clearly have to be conducted at a scale that makes best use of the opportunities afforded by the spreading technologies. In the future, use of global positioning system (GPS) technology in planes is likely to improve markedly the precision of spreading, and this will place additional demands on soil testing and fertilizer recommendation schemes. **BCI**

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"If I increase my yields…?"

As traditional farming practices must give way to progressive high yielding technologies, so must the way farmers…and their societies…view the economics of increasing agricultural productivity. Twice in the past few weeks I was challenged by senior government officials in two different countries, in two separate conversations, regarding my contention that higher farm yields are needed to increase incomes for farmers…and that balanced, adequate fertilizer use is a necessary component. The responding view by both individuals was singular in nature – that increasing yields when prices are as low as they are now does nothing more than undercut the price farmers are paid.

Although analysis of this issue is crucial to a farmer's decision making, it is imperative that the right questions be asked. Questions such as: If growing higher yields is the wrong thing to do, does lowering yields increase income? If the commodity price rises, how many consumers are excluded from buying? Farmers and their society have a very intimate association, one that is almost symbiotic in nature, whereby the health of one is dependent on the health of the other. In developing countries particularly, when agriculture thrives, so does society. And the converse situation is equally true.

As straightforward and to the point as I can be about answering the question, *"If I increase my yields…?"*, economic studies based on sound agronomic data show that improved productivity (yield per hectare of land) results from increased efficiencies – of both free and purchased inputs – and that is beneficial in every analysis of the facts. And, although we want 'good' prices for our products, we also recognize that more people consume more when food prices are low.

To the majority of the world's population, agriculture is their life…their livelihood both physically and economically. As agriculture becomes more productive and more efficient, it breathes life into itself and the society it supports.

Is this being too optimistic? Probably, since government intervention is too often the short-term solution to commodity pricing and farmer income problems. Unfortunately, subsidies usually reduce farm efficiencies and minimize farmers' options when it comes to making sound agronomic and economic decisions. Worse yet, they further entrench farmers into inefficient traditional practices. Should farmers increase their yields? Definitely yes, using all the skills and technology available so it is done effectively and efficiently.

Dr. Mark D. Stauffer
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International Programs, PPI
and President, PPIC

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