Vol. 13, Issue 2,
November 1999

Better Crops International

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Our Cover: Floating market in Thailand.
Photo source: Uniphoto Pictor.

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BCI is intended primarily for agricultural leaders and scientists working in agronomy and related sciences outside North America. Subscription price is (U.S.) $5.00 (five dollars) per year (free on request to qualified individuals).

The Government of Saskatchewan helps make this publication possible through its resource tax funding. We thank the Government for its support of this important educational project.

Release of Native and Non-Exchangeable Soil Potassium and Adsorption in Selected Soils of North China

By Cheng Mingfang, Jin Ji-yun, and Huang Shaowen

Research indicates that soils of northern China can have considerably different potassium (K) release rates and K adsorption capacities. This study shows a general increase in the release rate of non-exchangeable K (NE-K) and a decrease in fertilizer K adsorption as one moves from east to west in northern China.

It was once believed most soils in northern China had abundant supplies of available K (native soil K) for crop production. In recent years, with development of new crop cultivars and improved crop management practices, crop yields increased considerably, and native soil K has become severely depleted. Evidence of yield responses to K in northern China continues to accumulate. However, the exact kinetics of native soil K and NE-K release and soil adsorption of fertilizer K are still unclear.

Materials and Methods

Twenty-five soil samples were collected from northern China, including many locally classified soil types such as gray desert soil, anthropogenic alluvial soil, cinnamon soil, chestnut soil, fluvo-aquic soil, brown earth, meadow soil, black soil, and chernozemic soil. The kinetics of native soil K release were determined by extracting with 0.375 mol/L calcium chloride ($CaCl_2$) solution, NE-K release with 0.1 mol/L hydrochloric acid (HCl) solution, and K adsorption with 40 mg/L K solution using the miscible displacement technique. Temperature and flow rate during the experiment were set at 25° C and 1 ml/min, respectively. The K concentration in solution was analyzed by an atomic absorption spectrophotometer.

Cheng Mingfang and Huang Shaowen examining K depletion pot experiments in greenhouse.

Soil K depletion was conducted in pot experiments with successive planting of corn for eight to 10 harvests. Plant uptake of K was determined after each harvest.

Minimum and Maximum Values for Soil K Release and K Adsorption

For the 25 test soils, the amount of native soil K released ranged from 71 to 279 mg/kg while the amount of NE-K ranged from 39 to 672 mg/kg. The maximum release rate of native soil K varied from 2.6 to 21.4 mg/kg/min. Over a 10-hour extraction period, the average release rate of NE-K ranged from 0.07 to 1.1 mg/kg/min. The total amount of K fertilizer adsorbed by these soils varied from 139 to 2,550 mg/kg.

Regional Differences in Soil K Release and K Adsorption

Results (**Table 1)** indicate soils from northwestern China (Xinjiang, Qinghai, Gansu, Ningxia, and Shaanxi provinces) have higher release rates for both native soil K and NE-K and, therefore, higher K supplying power than soils from north central (Beijing, Hebei, Henan, Shandong, Tianjin, and Shanxi provinces) or northeastern China (Heilongjiang, Jilin, and Liaoning provinces). Differences in K release and adsorption were smaller between soils from north central and northeastern China. However, the measured parameters indicate average long-term K supplying power of north central soils is higher than northeastern soils.

The degree of K fertilizer adsorption in northern China increased in a west to east direction (**Table 1**). The respective average K adsorption capacities for seven northwestern, 10 north central, and eight northeastern soils were 608, 1,276, and 1,818 mg/kg. This trend is the reverse of regional differences in soil-K release and the resulting K supplying power.

It should be pointed out that the distribution of soils in northern China is inherently complex. As an example, loessial soils located in the northwestern province of Shaanxi are known to have lower K release rates and higher K adsorption capacities. In addition, chernozemic soils located in north central and northeastern China (Heilongjiang province) have higher K release rates and lower K adsorption capacities.

Table 1. Parameters of native soil K and NE-K release and adsorption to applied K.

Region	Total native K released, mg/kg	Maximum native K release rate, mg/kg/min	Total NE-K released, mg/kg	Average NE-K release rate, mg/kg/min	Total K adsorbed, mg/kg	Average K adsorption rate, mg/kg/min
Northwest (n=7)	171	9.4	314	0.52	608	1.46
North central (n=10)	144	5.1	87	0.14	1,276	2.07
Northeast (n=8)	164	4.8	60	0.10	1,818	2.75

In K depletion pot experiments, K uptake by corn was closely correlated with soil K release rates (**Figure 1**). Correlation coefficients between the maximum native soil K release rate and K uptake during the first planting and total plantings were 0.66 and 0.54, respectively. In turn, correlation coefficients between the average release rate of NE-K and K uptake during the first planting and total plantings were 0.78 and 0.78, respectively. These correlation coefficients were significant at the one percent significance level, which confirms the importance of native soil K and NE-K release rates in influencing the K supplying power for soils of northern China.

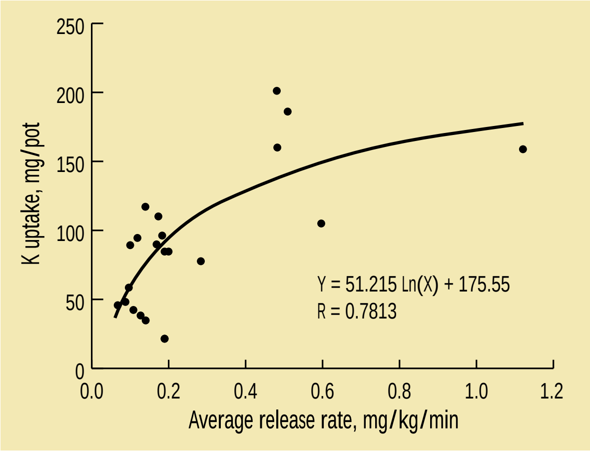

Figure 1. Correlation between non-exchangeable K release rate and K uptake in the first planting of K depletion pot experiments.

Conclusion

Release rate of soil K, especially NE-K, is one of the most important factors governing soil K supplying power. Results of this research are consistent with those of field trials in recent years. Reports of crop responses to K in northeastern and north central China are much more common than in northwestern regions. Reported responses in northwestern China are mainly in specific regions such as those with sandy soils or in high K demanding crops such as cotton, vegetables, and fruits. It is apparent that China's limited supply of K could be better distributed in the K deficient soils of northeastern and north central China. Smaller K quantities are required in northwestern China. Potash supplies are needed for high value crops, high K demanding crops, and localized K deficient soils. For all soils of northern China presently rich in native K, a monitoring system should be established to observe changes in K supplying power. This can be achieved through determination of readily available K, slowly available K, and NE-K release rate. **BCI**

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Acknowledgment — This research was supported by PPIC and National Natural Sciences Foundation of China.

Identifying Fertilization Needs for Soybean in Argentina

By F.H. Gutiérrez-Boem, J.D. Scheiner, and R.S. Lavado

This research shows that phosphorus (P) and sulfur (S) fertilizers can increase soybean yields in a region where few farmers fertilize this crop. However, current information is insufficient to develop a fertilizer recommendation program.

Soybean is a relatively new crop in Argentina. In 1970, only 37,000 ha were produced in the country. Since then, the area planted has grown steadily, reaching 7.8 million ha in 1998. The main production region is the Pampas, where the predominant soils are Typic Argiudolls and Hapludolls.

Traditionally, fertilizer use has been very low due to high fertilizer:grain price ratios (two to three times higher than in U.S.) and the popular belief that soils of the Pampas have unlimited fertility. During the last two decades, increasing cropland at the expense of pastures and low levels of fertilization has led to nutrient depletion of Argentine soils. Farmers have shown an increasing concern about soil fertility and the potential for economic crop response to balanced fertilization. Consequently, fertilizer use has increased five-fold since 1991, greatest increases being in wheat and corn.

Soybean is currently the most important grain crop in Argentina, but few Argentine farmers fertilize their soybeans. They are reluctant to adopt this practice because of a lack of information about the crop's response to fertilization. Therefore, studies to assess the effects of nitrogen (N), P and S fertilization are considered quite timely.

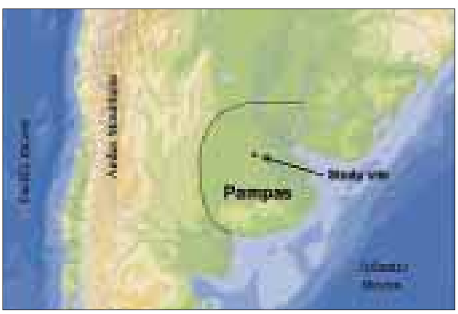

Figure 1. The Pampas region has great potential for intensive crop production.

Three field experiments were conducted during the 1998-1999 season, at the center of the Pampean Region (**Figure 1**). Sites were located at Junin on a sandy loam soil with 5 parts per million (ppm) Bray P-1 and 14 ppm sulfate-S (SO_4-S), at Viamonte on a loam soil with 12 ppm P and 18 ppm SO_4-S, and at Obligado on a loam soil with 22 ppm P.

There was no yield response to the use of starter N (18 kg N/ha) on any soil. Starter N increased aboveground biomass by 14 percent, leaf area by 13 percent, and radiation interception by 10 percent at Viamonte at flowering, but this enhancement of early growth by N addition did not translate into higher grain yields. Differences in radiation interception

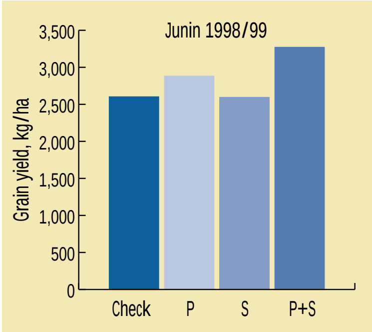

Figure 2. Soybean grain yield as influenced by the addition of P (20 kg/ha) and S (10 kg/ha) at Junin.

disappeared two weeks after flowering, suggesting that the effect of N was most evident during vegetative growth, a period not too important for yield formation in soybean.

Another alternative for N management is late-season application. Here, the objective is to retard N translocation from leaves to seeds and, consequently, leaf senescence. As N fixation decreases during seed filling, it was hypothesized that late-season fertilization would not affect symbiotic fixation, but would still provide a source of N to match seed demand. To test this hypothesis, 50 and 100 kg N/ha were applied as urea at pod formation (R3) or beginning of seed filling (R5) at Obligado. Neither rate nor application time had any effect on yield. Seed yields approached 2,600 kg/ha. Other researchers have reported positive response to late-season N fertilization in higher yielding environments. It seems that N fixation provided enough N for our level of yields.

Figures 2 and **3** show results of a factorial combination of P (as triple superphosphate) and S (as calcium sulfate) at Junin and Viamonte. Both fertilizers were applied at planting. Phosphorus was banded to the side and below the seed. Sulfur was applied as a broadcast application.

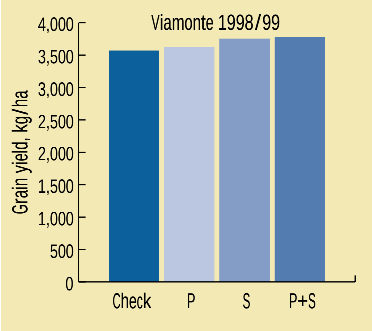

Figure 3. Soybean grain yield as influenced by the addition of P (20 kg/ha) and S (10 kg/ha) at Viamonte.

Phosphorus fertilization increased yields by 300 kg/ha, or 11 percent above the check at Junin, where soil P level was 5 ppm (**Figure 2**). However, at Viamonte where soil P was 12 ppm, there was no response to P (**Figure 3**). Other researchers working in the region have reported that the probability of a yield response to applied P increased when soil test P was below 9 ppm.

Sulfur fertilization increased yields at both locations. At Viamonte, adding S increased yield by 200 kg/ha, or 5 percent above the check (**Figure 3**). At Junin, where soybeans responded positively to applied P, a combination of S+P yielded 670 kg/ha more than the non-fertilized check (**Figure 2**), a 25 percent yield increase. More than half of that yield gain could be attributed to S addition (difference between P and P+S treatments). It seems that yield response to S fertilization took place only when P requirements were satisfied either by the soil (Viamonte) or by the fertilizer (Junin).

These results show that it is reasonable to expect significant yield increases due to P or S fertilization in a region where farmers have not traditionally used these nutrients. They also demonstrate the additive effect of balanced fertilization. Further experimentation is needed to develop appropriate recommendation programs. BCI

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Phosphorus and Potassium Interactions in Acid Soils of the Eastern Plains of Colombia

By Luis A. León

Researchers are investigating the response of several maize varieties to phosphorus (P) and potassium (K) on an acid soil in the Eastern Plains of Colombia.

Most of the acid soils of the Eastern Plains of Colombia and the tropical lowlands of Brazil, Ecuador, Peru, Bolivia, and Venezuela are high in exchangeable aluminum (Al). Aluminum saturation is often higher than 80 percent in these soils. High amounts of calcite or dolomite limestone are required to reduce the Al saturation to less than 20 percent.

Phosphorus and K availabilities in these soils are generally very low. High rates of P and K are needed to obtain good maize yields, but in the case of the poorly developed Eastern Plains this could be logistically very expensive. If the farmers of the lowland tropics can use varieties resistant to acid soil, they could use less amendments, making P and K fertilizers comparable to those required when using varieties not resistant to acid soil.

The International Maize and Wheat Improvement Center (CIMMYT) has been studying the tolerance of maize to acidic soil conditions. However, it's unlikely that all maize varieties tolerant of soil acidity respond equally to P and K fertilization.

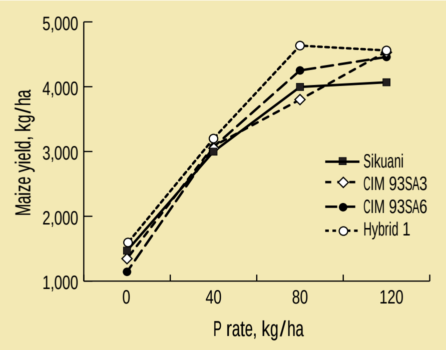

Figure 1. Yield response of four maize genotypes to different P rates (averaged over K rates) on an acid soil, Carimagua, Colombia.

Materials and Methods

A field study was conducted in Carimagua in 1995 to evaluate the response of three maize varieties (ICA Sikuani V 110, CIMCALI 93 SA3, and SIMCALI 93 SA6) and one hybrid (H1) to four rates of P and K (0, 40, 80, and 120 kg/ha). The study was located on an Oxisol with pH 4.7, 1.8 parts per million (ppm) Bray P-II, 0.04 meq/100g exchangeable K, and 87 percent Al saturation. Aluminum saturation was reduced to 55 percent using 1,034 kg/ha of dolomite limestone that was broadcast and incorporated 30 days before planting. Two applications of 60 kg N/ha were applied to all the plots. The experimental design consisted of a split plot with three replications. Phosphorus rates were considered main plots, K rates sub-plots, and varieties sub-sub-plots.

Results and Discussion

The hybrid tended to produce higher yields than the other maize varieties, although yield differences were not significant.

Response to P application was excellent in all four genotypes (**Figure 1**). Yields increased linearly with increasing P and reached an optimum at the 80 kg/ha rate in three of the four genotypes. The one exception, CIM 93SA3, continued to respond up to the 120 kg P/ha rate, but even at that rate it did not produce more than the hybrid at the 80 kg/ha rate. The optimum P rate for corn production on this acid soil appeared to be 80 kg/ha.

The varieties were not as responsive to applied K as they were to P. However, yield increases did occur at the 40 kg/ha rate in all four varieties and up to 80 kg/ha for CIM 93SA6 and the hybrid (**Figure 2**).

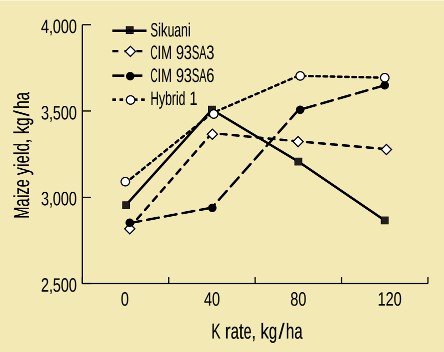

Figure 2. Yield response of four maize genotypes to different K rates (averaged over P rates) on an acid soil, Carimagua, Colombia.

No responses to K were obtained when P was not applied, but increasing rates of P produced a good response to K application (**Figure 3**). The highest yields occurred at 120 kg P/ha and 80 kg K/ha. Low native P contents in this type of soil limit root growth and exploration and, therefore, restrict the uptake of other nutrients, particularly K.

Soil analysis following harvest showed P fertilization increased residual soil test P levels, but K application had less effect on exchangeable K (**Table 1**). Maize has a much higher demand for K than P. At the application rates in this study, little K was left over from the crop to build soil test K levels.

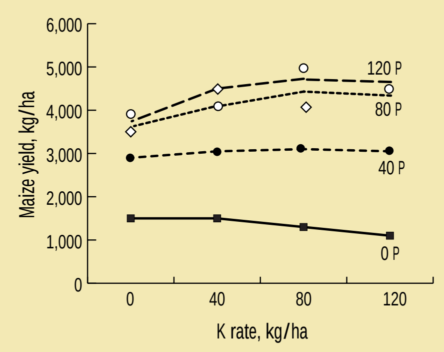

Figure 3. Phosphorus and K interaction in maize grown on an Oxisol, Carimagua, Colombia.

Conclusion

Our research has shown that maize grown on the acid Oxisols of Colombia is responsive to P and K fertilization. High rates of P and K (80 to 120 kg/ha) are required for optimal production. We also found a strong interaction between P and K. Maize was most responsive to applied K when P was not limiting. At the rates used in this study, sufficient P was applied to optimize yields and

Table 1. Soil test P and K after harvest in response to P and K application on an acid soil, Carimagua, Colombia.

P or K rates, kg/ha	Bray P-II[1], ppm	Exchangeable K[1], ppm
0	2.7	0.04
40	7.2	0.06
80	13.1	0.09
120	19.4	0.11

[1]Soil test P and K after harvest, initial soil P test = 1.8 ppm; initial soil K test = 0.04 meq/100g.

build soil test levels, but higher rates of K would be needed to increase soil K fertility. **BCI**

The author is a private consultant, formerly with International Fertilizer Development Council (IFDC) and CIMMYT, located at Apartado 234, Palmira, Colombia.

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Research Notes

India: Effect of Potassium on Yield and Quality of Potato

This three-year study was conducted on 10 farmer fields in the Meerut region. The effects of sulfate of potash (SOP) on tuber yield, chip making quality, and post harvest storage were studied. Potato responded significantly to K fertilization. The following results characterize the study.

- Potassium (K_2O) application rate of 150 kg/ha produced the highest tuber yields in each of the three years.
- Percent dry matter improved with K application up to 150 kg K_2O/ha.
- Chip quality was significantly improved in the last two years of the study in response to the application of 225 kg K_2O/ha.
- Sugar content decreased with K application.
- Potassium did not affect tuber loss two weeks after harvest, but an application rate of 150 kg K_2O/ha did reduce loss four weeks after harvest, resulting in a higher return when tubers were stored for longer periods.
- Split applications in the first year of the study did not offer any advantage. **BCI**

Source: Fertiliser News, *Vol. 43 (11), p. 43-46, November 1998.*

Beneficial Effects of Potassium Application on Upland Soils of Hunan Province

By Zheng Shengxian

Upland soils are an important land resource for sustaining China's rural economy. However, in the upland soils of Hunan, potassium (K) deficiency is a limiting factor in the production of high yielding, good quality crops. Currently, two-thirds of Hunan's 768,826 ha of cultivated upland is considered deficient (critical level < 70 mg/kg) in available K.

Between 1989 and 1993, 204 field experiments were conducted in Hunan province to evaluate the benefit of K application in upland soils. Overall, K fertilization resulted in significant improvement in crop yield and quality while positively affecting crop resistance to disease and stress.

Yield

Results of field trials conducted in more than 80 counties showed K had a positive effect on the yield of cereal, fiber, oil, fruit, vegetable, and medical crops (**Table 1**). The degree to which crops responded to K varied. However, at equal application rates, a higher economic benefit for K was found with cotton, ramie, citrus, chili, tobacco, and medical crops than the other upland crops. Since supply of K fertilizers in Hunan is limited, initial emphasis for its use should be placed on crops with the highest potential economic return.

Professor Zheng Shengxian examining a high yield corn demonstration field plot.

Quality

Essential improvements in crop quality were observed by balancing nitrogen (N) and phosphorus (P) with adequate K. Experiments demonstrated improvements in length, strength, and fineness of fiber in cotton and ramie; in the contents of oil, protein, and essential amino acid in corn and barley; oil and essential aliphatic acids in rapeseed; oil and protein in soybean and peanut; sucrose and reducing sugar in sugarcane; and sugar, soluble solids, and vitamin C in citrus (**Table 2**). Higher levels of essential amino acids in corn are beneficial to both humans and other animals. Good fiber quality in cotton and ramie is important for China to compete in the world textile industry. Overall, the production of high quality crops is essential for farmers and the nation, as both need to increase profits and compete in world markets.

Disease Resistance

Potassium also showed a beneficial influence on improving disease resistance in Hunan's upland crops. It helped reduce anthracnose, root rot, and red leaf stem wilt infections on cotton (**Table 3**). Additional research has shown that potassium chloride (KCl) may have a significant effect in reducing the severity of diseases in corn, soybean and ramie. In Hunan, farmers often state: "KCl fertilizer acts just like a pesticide; once K is added, the disease is removed."

Stress Tolerance

It was evident from an extended drought period in northwest Hunan that K can help reduce lodging of corn in dry years. In June and July of a recent production year, the area received only 20 mm of rainfall, compared with over 150 mm in a normal year. Five experiments with corn in Cili county demonstrated that K application significantly reduced corn lodging and contributed to higher yields (**Table 4**). On average, K application increased corn yield by 135 percent, compared with the no K treatment (data not shown). The magnitude of yield response was much greater than response in normal years.

Table 2. Effect of K fertilizer application on the quality of some upland crops in Hunan province.

Crop	Item analyzed	Without K	With K	Quality change, %
Corn	Protein, %	9.5	10.3	8.4
	Oil, %	4.0	4.4	10.0
	Essential acids, %	3.4	3.8	11.8
Barley	Protein, %	16.3	16.2	-0.6
	Essential acids, %	4.9	5.1	4.1
Cotton	Ginning output, %	40.0	41.7	4.2
	Fiber length, mm	28.4	30.5	7.4
Ramie	Strength, kg/g	32.6	37.3	14.4
	Rind thickness, mm	1.3	2.0	53.8
Rapeseed	Oil, %	36.9	37.8	2.4
	Essential aliphatic acid, %	24.2	25.5	5.4
	Protein, %	21.8	20.4	-6.4
Soybean	Fat, %	18.4	20.9	13.6
	Protein, %	40.2	42.4	5.5
Peanut	Fat, %	49.0	52.0	6.1
	Essential amino acids, %	8.7	9.4	8.0
Sugarcane	Sucrose, %	10.0	11.8	18.0
	Reducing sugar, %	2.1	1.5	-28.6
Citrus	Total sugar, %	9.5	10.1	6.3
	Vitamin C, mg/100g	24.8	26.9	8.5
	Soluble solids, %	9.0	11.5	27.8

Table 1. Effect of K application on yield of main upland crops (1989-1993) in Hunan province.

Crop	Number of experiments	Yield, t/ha Without K	Yield, t/ha With K	Yield increase, %
Corn	26	5.15	6.60	28.2
Barley	14	1.59	2.16	35.8
Cotton	28	0.95	1.13	18.9
Ramie	15	2.59	3.04	17.4
Rapeseed	29	0.99	1.32	33.3
Soybean	24	1.53	1.80	17.6
Peanut	25	1.97	2.49	26.4
Citrus	4	25.38	28.51	12.3
Watermelon	12	30.06	40.32	34.1
Day lily	4	1.21	1.32	9.1
Chili	15	15.56	18.49	18.8
Sugarcane	16	83.20	96.63	16.1
Tobacco	11	1.44	1.78	23.6
Lily	17	2.84	3.37	18.7

Table 3. Chi-square test results of the effect of K application on the index of three cotton diseases.

Treatment, kg $N-P_2O_5-K_2O$/ha	Anthrac-nose	Root rot	Red leaf stem wilt
195-75-0	—	—	—
195-75-75	4.83*	3.21[NS]	12.3**
195-75-150	5.20*	9.43**	18.9**
195-75-225	5.89*	10.38	30.6**

[NS], *, ** = non-significant, significant at 5%, and significant at 1%, respectively.

Table 4. Effect of K on reducing premature plant death and lodging in corn during 1989 drought, Hunan.

Treatment, kg $N-P_2O_5-K_2O$/ha	Lodging, %	Premature death, %
200-90-0	73.0	51.7
240-90-270	1.3	13.2

Conclusion

Potassium fertilizer has proven to be extremely important for crop growth on Hunan's K-deficient upland soils. This has been manifested in higher crop yields, improved crop quality, and increased farmer profit when K fertilizer was applied compared to no K application, but with N and P fertilizer applied at optimal rates.

For the majority of crops grown on these soils, an application of 150 kg K_2O/ha was considered to be a minimum to achieve high crop yield and quality, while higher rates often proved better for the high K demanding crops. **BCI**

The author is Professor, Soil and Fertilizer Institute, Hunan Academy of Agricultural Sciences, Changsha, China.

Research Notes

India: Response of Some Rabi Pulses to Boron, Zinc and Sulfate Application in Farmer Fields

Series of field trials were conducted on calcareous soils in the northern part of Bihar. A high percentage of these soils exhibit sulfur (S), boron (B) and zinc (Zn) deficiencies. Test crops were chickpea, lentil and broadbean. Boron application at 2 kg/ha and Zn application at 5 kg/ha on chickpea produced grain yield responses of 750 (60 percent yield increase) and 400 (28 percent yield increase) kg/ha, respectively. Boron application rate of 1 kg/ha increased lentil yields by 300 kg/ha, or 24 percent. Broadbean yield response to S applied at a rate of 40 kg/ha was 700 kg/ha, a 32 percent increase. In addition to yield responses, plant uptake of all three nutrients was increased by fertilization. **BCI**

Source: Fertiliser News, *Vol. 43 (11), p. 37, 39-40, November 1998.*

Long-term Changes in Soil Fertility and Fertilizer Efficiency under Different Fertilizer Practices

By Zheng Tie-jun

This 12-year study was conducted under the direction of the Soil and Fertilizer Institute, Chinese Academy of Agricultural Sciences (CAAS). Its objective was to monitor long-term changes in soil fertility, fertilizer use efficiency, crop yield, and grain quality under various fertilizer management schemes. The study was conducted in Harbin on black soil, the most important soil type in Heilongjiang province, covering approximately five million ha.

Experimental Procedures

This long-term trial was initiated in 1980 at the Soil and Fertilizer Institute of the Heilongjiang Academy of Agricultural Sciences. Mean annual temperature for the area is 3.5º C, mean annual precipitation is 535 mm, and the frost-free period is about 135 days. From samples collected in 1979, soil pH was 7.2 and organic matter was 2.7 percent. Total nitrogen (N), phosphorus (P), and potassium (K) contents were 0.15 percent, 0.17 percent, and 2.5 percent, respectively. Available N, P and K contents were 151, 51 and 200 mg/kg, respectively.

Data in this paper span four cycles of a three-year wheat-soybean-corn crop rotation. Inorganic fertilizer was applied at 150-75-75 kg N-P_2O_5-K_2O/ha for wheat and corn and 75-150-75 kg/ha for soybean. Farmyard manure (FYM) was applied at a rate of 18.6 t/ha with every corn crop. All fertilizers were applied in the fall after harvest. Plots were 168 m^2 in size and were not replicated.

Long-term Changes in Crop Yield

Zero Fertilization – In the plot receiving no fertilizer, the cumulative yields of wheat, soybean and corn consistently declined over 12 years (**Table 1**). The average change in the cumulative yield (ΔY) between the three-year cycles was -8.1 percent, or -880 kg/ha. Wheat yields continually declined through the second, third, and fourth crop cycle, dropping 1,260 kg/ha from 1980 to 1989. Soybean and corn yields fluctuated, but both crops showed a negative trend. The second cycle soybean yield showed a slight increase over the first cycle, but this was followed by lower yield levels in the third and fourth cycles. Corn production was highly variable and followed an alternating yield pattern throughout the study.

Applying Manure – The plot receiving only FYM also showed a tendency for lower yields over time (**Table 2**). The cumulative yield for wheat, soybean and corn was highest in the second cycle. However, this was followed by lower cumulative yield levels in the third and fourth cycles. The ΔY between the three-year cycles was -0.4 percent, or -110 kg/ha. Wheat production showed an initial increase in the second cycle, followed by two successive cycles of declining yield. Soybean yields followed an alternating yield pattern throughout the study. Corn production was lowest in the second and third crop cycles, but was highest in the fourth crop cycle.

Table 1. Crop yields as affected by no fertilizer application.

Crop cycles	Wheat (Yield, kg/ha)	Soybean	Corn	Cumulative yield, kg/ha
1980	2,535			
1981 (I)		2,070		
1982			6,990	11,595
1983	2,385			
1984 (II)		2,265		
1985			5,850	10,500
1986	1,830			
1987 (III)		1,365		
1988			7,170	10,365
1989	1,275			
1990 (IV)		1,935		
1991			5,745	8,955
Overall production, kg/ha				41,415
Average yield change (ΔY)				-8.1%

Table 2. Crop yields as affected by FYM application.

Crop cycle	Wheat (Yield, kg/ha)	Soybean	Corn	Cumulative yield, kg/ha
I	2,745	2,010	7,350	12,105
II	3,495	2,055	6,885	12,435
III	2,445	1,290	6,900	10,635
IV	1,635	1,890	8,250	11,775
Overall production, kg/ha				46,950
Average yield change (ΔY)				-0.4%

Applying Commercial Fertilizer – Evidence for sustained yield improvement was found with all four treatments supplying N (**Table 3**). The NPK, NP, and NK treatments provided the highest overall production totals and positive ΔY values of 1.4, 3.6, and 3.4 percent, respectively. Reliance on N alone also sustained a positive ΔY of 3.3 percent. However, this practice produced a grain production level only slightly above the level achieved with FYM alone. Reliance on mineral P and K, alone or in combination, resulted in declining yields over time. The ΔY values for the P, K, and PK treatments were -5.5, -4.0, and -1.8 percent, respectively.

Table 3. Crop yields as affected by mineral fertilizer application.

Treatment	Cumulative yield per crop cycle, kg/ha: I	II	III	IV	Total production, kg/ha	(ΔY), %
N	11,280	12,285	11,775	12,390	47,730	3.3
P	12,060	11,295	11,190	10,155	44,700	-5.5
K	11,490	11,340	10,965	10,140	43,935	-4.0
NP	11,955	11,655	12,180	13,245	49,035	3.6
NK	11,910	12,960	11,250	12,900	49,020	3.4
PK	11,685	13,275	11,445	10,845	47,250	-1.8
NPK	12,705	12,255	11,220	13,020	49,200	1.4

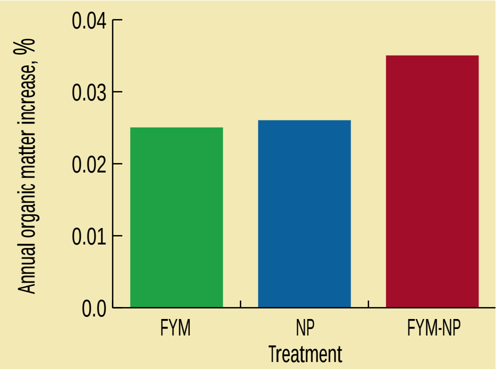

Figure 1. Increases in soil organic matter content in a black soil over 12 years, Heilongjiang province.

Combining FYM with Inorganic Fertilizer – Compared to inorganic fertilizer treatments (**Table 3**), FYM raised the yield levels for FYM-P, FYM-K, FYM-PK, and FYM-NP (**Table 4**). The FYM-NP combination resulted in the study's highest overall production and a positive ΔY of 4.8 percent. The beneficial effects of combining FYM with P, K and PK treatments are evident. These treatments are obviously taking advantage of N being added to the system from the FYM. However, respective ΔY values of -5.2, -1.9 and 0.6 percent still question the sustainability of these treatments. The FYM-N treatment had a high yield in the final crop cycle, resulting in a ΔY of 5.4 percent, but it failed to improve overall grain production relative to inorganic N alone. No yield benefit was apparent with the combination of FYM with NPK despite a positive ΔY of 2.1 percent.

Long-term Changes in Soil Properties

Soil Organic Matter – Soils receiving no fertilizer or FYM showed no consistent changes in organic matter (0 to 20 cm depth) as they fluctuated within the range of 2.37 to 2.79 percent. Application of FYM once in every cycle increased organic matter content by 0.29 percent in 12 years (**Figure 1**). The NP fertilizer treatment was equally as effective and increased soil organic matter content by 0.30 percent in 12 years. In comparison, the FYM-NP combination increased soil organic matter content by 0.42 percent in 12 years.

Soil Nitrogen – Over 12 years, soils that did not receive any nutrients showed no significant changes in N content (0 to 20 cm depth). Application of N fertilizer alone resulted in an average soil N accumulation of 0.03 percent in 12 years. The balanced treatment of NPK increased soil N by 0.046 percent in 12 years. Results suggested little difference in hydrolyzed N (0 to 20 cm depth) among treatments, but did show a slight tendency for higher values in treatments containing inorganic N (data not shown).

Table 4. Effect of combining FYM and mineral fertilizers on crop yield.

Treatment	Cumulative yield, kg/ha I	II	III	IV	Overall production, kg/ha	(ΔY), %
FYM-N	11,685	11,940	10,710	13,305	47,640	5.4
FYM-P	12,765	12,105	11,595	10,860	47,325	-5.2
FYM-K	11,850	12,060	10,545	11,070	45,525	-1.9
FYM-NP	12,420	12,390	12,465	14,220	51,495	4.8
FYM-NK	12,195	12,045	10,890	13,200	48,330	3.4
FYM-PK	12,105	12,915	11,340	12,165	48,525	0.6
FYM-NPK	12,780	12,120	10,710	13,200	48,810	2.1

Soil Phosphorus – Soils that did not receive fertilizer or FYM showed an average decrease in available P equal to 0.17 percent annually. The 12-year duration of this study suggests a strong potential for the spread of P deficiency and lower crop production. Reliance on FYM alone resulted in a rapid decline of available P equal to 3.5 mg/kg annually. Application of NK also appeared to accelerate soil P depletion as the final P level for the treatment was lower than the unfertilized treatments (**Figure 2**). These results show how soil P mining accelerates with application of other plant nutrients when no P is applied. This is a good case for using balanced fertilization. Long-term inclusion of P fertilizer (FYM-NP) successfully raised available soil P above the level measured at the study's inception. Continued fertilizer additions would eventually lead to the establishment of an adequate soil P level and a switch to a soil P maintenance strategy.

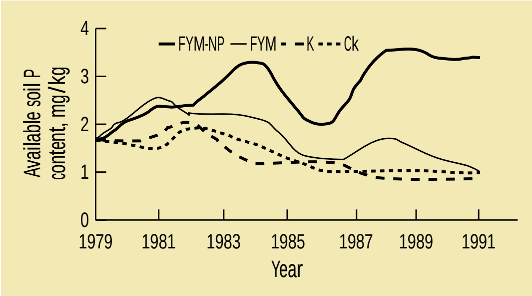

Figure 2. Changes in available P content in a black soil over 12 years, Heilongjiang province.

Soil Potassium – After 12 years, no significant effect on total soil K (0 to 20 cm depth) was observed in any treatment. This is a result of adequate natural soil K levels. All fertilizer treatments maintained soil K between 200 to 300 mg/kg. However, observations indicate soil not receiving fertilizer was slightly below this range. It should be noted that without continuous application of K, soil K will eventually drop below the critical level and cause reduced yields. Thus, monitoring the K status is important, especially as higher crop yields are obtained.

Conclusion

Continuous crop production over 12 years without the addition of either FYM or mineral fertilizer resulted in an average yield reduction of 8.1 percent. Reliance on FYM resulted in a lower rate of yield reduction of 0.4 percent. Such practices are detrimental to China's strategy for food security. The solution lies in the proper utilization of mineral fertilizers. Imbalanced fertilizer use resulted in lower crop production and plant nutrient losses capable of creating severe deficiencies and drastic yield reductions. In this study, N was the most yield-limiting macronutrient, followed by P. However, continued cropping without K fertilizer or FYM application could create another yield-limiting situation. A more intensive soil testing strategy is needed to monitor the soil fertility of Chinese soils. Such a strategy would ensure that all plant nutrients are built up and maintained at adequate levels. **BCI**

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Part A

Potassium for Yield and Quality of Mulberry Leaf in Relation to Silkworm Cocoon Production

By M.A. Shankar and S.A. Sriharsha

Potassium (K) is a key element in the nutrition of mulberry (*Morus indica* L.), the sole plant used in silkworm (*Bombyx mori* L.) cocoon production. The mulberry production area of India covers 0.281 million ha and has an average foliage productivity of 25 to 30 t/ha/yr. Top quality mulberry leaves with high K content stimulate the growth and pupal development of silkworms and increase both egg and silk production. The present investigation was conducted to optimise the K level and application method for increased yield and quality of mulberry leaves.

Experiments were conducted at four farmer field locations in the state of Karnataka with the M_5 mulberry variety. Potassium treatments consisted of four K levels applied at 120, 160, 200, and 240 kg/K_2O/ha/yr as potassium chloride (KCl) in six splits plus one percent foliar KCl spray. The control treatment included only 120 kg K_2O/ha applied in two splits. All treatments had basal doses of nitrogen (N) and phosphorus (P), applied at 280-120 kg N-P_2O_5/ha/yr. Nitrogen was split six times over the growing season while P was split over two applications.

Both mulberry leaf yield and quality parameters, *viz*., K and chlorophyll contents in leaves, were significantly influenced by successive levels of applied K (**Table 1**). Total leaf yield per hectare was high-

Table 1. Mulberry leaf yield and quality as influenced by graded levels of applied K.

kg K_2O/ha in soil + 1 % foliar spray	Total leaf yield in different locations, kg/ha/yr MRS	KDB	KNH	MH	K content, % MRS	Total chlorophyll, mg/g fresh weight MRS
120[1]	29,040	35,718	32,932	35,547	1.90	2.06
160[1]	31,881	38,221	37,252	39,352	2.95	2.30
200[1]	33,027	42,997	37,827	40,743	2.31	2.32
240[1]	33,449	41,684	38,130	42,004	2.38	2.32
120[2]	22,694	37,714	33,274	38,235	2.04	2.02
F. test	*	*	*	*	*	*
S.Em ±	–	–	–	–	0.03	0.03
C.D. at 5%	2,066	823	426	760	0.10	0.09

MRS – Main Research Station, KDB – Kadabagere, KNH – Kannahalli, MH – Marasanahalli
[1]Six splits, [2]two splits (control)

est with the application of 240 kg K_2O/ha/yr. Leaf K content was also highest at 2.38 percent with the application of 240 kg K_2O/ha/yr. Chlorophyll content was highest at 2.32 mg/g with the application rate of 200 or 240 kg K_2O/ha/yr.

A healthy stand of mulberry crop grown with balanced K fertilization, ready for cutting.

Mature worm weight, single cocoon weight, shell weight, shell percentage, and filament length also increased significantly with graded levels of applied K, and highest values were obtained by applying 240 kg K_2O/ha/yr (**Table 2**).

Table 2. Post cocoon parameters as influenced by feeding silkworm with mulberry leaves fertilized with graded levels of K.

kg K_2O/ha in soil + 1 % foliar spray	Mature worm (10) wt., g	Single cocoon wt., g	Shell wt., g	Shell percentage %	Filament length, m	Filament denier
120[1]	24.8	1.36	0.211	23.2	794	1.93
160[1]	26.1	1.46	0.227	23.2	846	1.93
200[1]	26.7	1.45	0.228	23.4	845	1.93
240[1]	27.1	1.46	0.233	23.6	861	1.93
120[2]	25.7	1.42	0.220	23.2	813	1.93
F. test	*	*	*	*	*	NS
S.Em ±	0.17	0.009	0.002	0.12	4.09	0.003
C.D. at 5%	0.54	0.030	0.005	0.36	12.60	–

[1]Six splits, [2]two splits (control) NS - Not significant

These results clearly reveal the usefulness of K in mulberry leaf and silkworm production. The current K recommendation for the areas tested is 120 kg K_2O/ha/yr applied in two splits. Higher leaf yield and quality and, in turn, silkworm growth and cocoon production are accomplished with double (240 kg K_2O/ha/yr) the present recommendation, applied as six splits in combination with one percent KCl foliar spray. However, the net return per rupee invested was highest with 200 kg K_2O/ha/yr. The maximum net return per rupee at the four respective test locations was 1.60, 1.78, 1.57, and 1.98. **BCI**

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Part B

Effect of Applied Nitrogen and Potassium on Mulberry Leaf Yield and Quality in Relation to Silkworm Cocoon Characters

By M.A. Shankar and B.T. Rangaswamy

Mulberry (*Morus indica* L.) leaf quality plays an important role in the nutrition of silkworm (*Bombyx mori* L.) and, in turn, cocoon and silk production. Leaf quality is dependent on the quantity, timing, method, and nutrient balance of fertilizer applications.

Earlier research indicates mulberry responds to nitrogen (N) since it is a constituent of plant proteins, nucleic acids, and vitamins. Potassium (K) plays an important role in plant biochemical functions, development, and yield of foliage and leaf quality improvement. It was also found to have a stimulating effect on growth of silkworm and silk production (see article on page 18 by M.A. Shankar and S.A. Sriharsha). The present investigation was conducted to find the suitable combined dose of N and K for mulberry variety M_5. The objective was to harvest good quality leaves in order to provide for better silkworm growth and cocoon production.

Experiments were conducted at four farmer field locations in the state of Karnataka with the M_5 mulberry variety. All treatments had a single basal dose of phosphorus (P) applied at 120 kg P_2O_5/ha. Four treatments consisted of selected combinations of two levels of N at 300 and 400 kg N/ha and three levels of K at 120,160 and 200 kg K_2O/ha,

Table 1. Mulberry leaf yield and quality as influenced by application of N and K at different levels.

Treatment N - K_2O kg/ha/yr	Total leaf yield in different locations, kg/ha/yr MRS	KCP	KDB	SGH	K content, % MRS	Chlorophyll content, mg/g fresh weight MRS
300-120[1]	29,878	31,761	29,794	26,296	2.05	2.152
400-120[1]	35,535	33,995	35,414	31,510	2.17	2.527
400-160[1]	36,091	36,380	36,199	32,467	2.39	2.420
400-200[1]	37,071	37,379	37,185	33,005	2.42	2.620
300-120[2]	31,072	31,519	29,487	26,092	2.05	2.171
F. test	*	*	*	*	*	*
C.D. at 5%	1,066	1,420	1,434	1,881	0.19	0.21

Blanket application of P at 120 kg P_2O_5 per hectare
[1]N and K applied in five equal splits, [2]N applied in five splits and K applied in two splits
MRS – Main Research Station, KCP – Kenchanapura, KDB – Kadabagere, SGH – Seegehalli

split five times per year. These treatments were compared to the traditional practice of applying 300-120 kg $N-K_2O$/ha, split five times per year for N and two times per year for K.

Split application of K along with N increases yield and improves quality of mulberry leaf.

Application of N and K significantly influenced the leaf yield, quality, and cocoon characters of the PM x NB_4D_2 silkworm race. Incorporation of N and K at 400-200 kg $N-K_2O$/ha/yr in five splits resulted in a higher leaf yield per hectare. Total chlorophyll and moisture contents of leaf tissue also increased and added to overall leaf quality (**Table 1**). Quality parameters of the silkworm such as single cocoon weight and single filament length were also improved with the additional dose of N and K fertilizer (**Table 2**).

Table 2. Silkworm growth and cocoon characters as influenced by application of N and K at different levels.

Treatment $N-K_2O$ kg/ha/yr	Mature worm (1) wt., g	Single cocoon wt., g	Shell wt., g	Single filament length, m	Filament denier
300-120[1]	3.36	1.48	0.238	793	1.94
400-120[1]	3.64	1.63	0.256	867	1.94
400-160[1]	3.65	1.64	0.259	866	1.95
400-200[1]	3.69	1.64	0.277	888	1.95
300-120[2]	3.28	1.50	0.248	781	1.93
F. test	NS	*	*	*	NS
C.D. at 5%	–	0.08	0.048	31.28	–

Blanket application of P at 120 kg P_2O_5 per hectare.
[1]N and K applied in five equal splits, [2]N applied in five splits and K applied in two splits,
NS – Not significant

This research shows that higher doses of N and K are beneficial to mulberry production. Based on the soil type and agro-climatic conditions of the test sites, the application of 400-200 kg $N-K_2O$ ha/yr in five splits resulted in the highest yielding and best quality mulberry plants. The dependence of the silkworm on mulberry highlights the importance of balanced fertilization practices on silkworm health and the subsequent quality of silk spun. This study emphasizes the need for adequate N and K fertilization in order to maintain economic viability in mulberry production centers. BCI

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Cashew Nuts in North Queensland Respond to Phosphorus and Sulfur Fertilizers

By Noel J. Grundon

Cashew nuts prefer a seasonally wet/dry, tropical climate and represent a new horticultural opportunity in northern Australia. North Queensland, the Northern Territory, and northern Western Australia have large areas with soils suitable for cashew. CSIRO Land and Water has initiated research at Dimbulah, North Queensland, to investigate the fertilizer requirements of the crop.

The research programme focused on (a) providing site-specific recommendations of the optimum fertilizer nutrient rates for sustainable economic yields of cashew nuts, and (b) minimising long-term damage to the soil and water resources of the area from high inputs of fertilizer nutrients. Preliminary glasshouse nutrient omission studies identified deficiencies of nitrogen (N), phosphorus (P), and sulfur (S) in cashew seedlings, while observations of nutritional disorders on field-grown trees indicated that potassium (K) may be inadequate for mature trees in the field.

Fertilizer field trials were initiated using five rates of P, K, and S, commencing with four-year-old grafted cashew trees planted at a density of 200 trees/ha (i.e., 8 m row spacing; 6 m spacing within rows). Trees were irrigated when required during their flowering and fruiting season of May to December, which coincided with the seasonally dry period. With the exception of the nutrient being tested, all trees received adequate levels of all nutrients as surface dressings within the dripline of the tree. All P fertilizer was applied in March, towards the

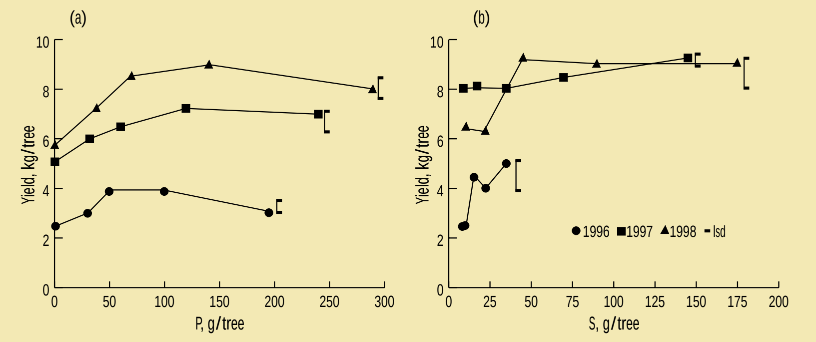

Figure 1. Effects of P (a) and S (b) fertilizers on yield of saleable cashew nut-in-shell at Dimbulah, North Queensland.

Table 1. Selected soil properties of top-soil (0 to 30 cm; sandy loam) and sub-soil (80 to 100 cm; clay loam) from under trees receiving farmer's normal low inputs of fertilizers at Dimbulah, North Queensland.

Depth, cm	pH[a]	EC[a], mS/cm	Org. C, %	N[b], %	Exchangeable cations, cmol(+)/kg Na	K	Ca	Mg	SO_4-S[c]	P[d]	Cu[e] mg/kg	Mn[e]	Zn[e]
0-30	6.1	0.01	0.24	0.004	0.01	0.09	1.11	0.25	1.1	3	0.1	16.5	0.4
100-150	6.5	0.01	0.07	0.001	0.01	0.11	0.87	0.74	2.0	3	0.2	4.0	1.2

[a]1:5 soil:water; [b]total Kjeldahl N; [c]calcium phosphate-extractable; [d]bicarbonate-extractable; [e]DTPA-extractable

end of the wet season, while the remaining fertilizers were applied as three equal splits in March, June and September. The field experiment was conducted over three years, beginning in 1996, and fertilizer rates were increased each year to accommodate increased tree growth with increased maturity.

The impact of high fertilizer input on the soil resources was examined both by sampling the soil profile before fertilizer application and after fertilizer had been applied for two years. To provide a comparison, soil samples were also collected from virgin open forest adjacent to the cashew plantation and from under trees receiving the farmer's normal fertilizer regime.

Response to P, K and S Fertilizers in the Field – Applications of P (up to 288 g/tree/year) and S (up to 176 g/tree/year), significantly (probability level = 5 percent) increased yield of saleable cashew nut-in-shell (cashew nuts sold on the world market with kernel weights greater than the minimum of 0.91 g/kernel). Application of K, up to 3000 g/tree/year, did not increase yield. As the trees became more mature, the optimal rate of P and S for maximum yield increased each year, from about 90 g/tree/year to 150 g/tree/year in the case of P and from about 35 g/tree/year to 50 g/tree/year in the case of S (**Figure 1**).

Economics of Fertilizer Use – Cashews are traditionally grown with no or very low fertilizer input. In Australia, fertilizer use is normally restricted to soil dressings of N and K with occasional foliar sprays of zinc (Zn) costing about 20 cents to 25 cents/tree/year. Excluding fertilizer costs, total variable costs for a 200 ha cashew plantation at Dimbulah have been estimated to be $5.05/tree/year.

The economics of fertilizer use were examined by calculating gross margins. Economic inputs included a farm-gate price of $1.63/kg nut-in-shell and respective yields from trees receiving the farmer's normal fertilizer regime or the trial's higher-than-normal P and S fertilizer rates. The gross margins obtained from the farmer's normal fertilizer regime were calculated to total $7.20/tree for the three years of the field study, or an average gross margin of $2.40/tree/year. In the experimental trees, the highest gross margins for 1996, 1997 and 1998 were obtained with 96, 120, and 144 g P/tree/year, and 34, 144 and 44 g S/tree/year, respectively. Averaged over the three years of this study, the gross margins per year were $3.71/tree/year for the P fertilization and $5.98/tree/year for the S fertilization. Thus, higher-than-normal fertilizer rates have a clear economic advantage over the farmer's normal rates of between $1.31 and $3.58/tree/year. These rates of return could lead to increased incomes of between $260 and $720/ha/year at a plant density of 200 trees/ha.

Impact of Normal and Higher-than-Normal Fertilizer Rates on Soil Resources – The soil chemical properties in the virgin open forest adjacent to the cashew plantation and the soil profile under the cashew trees receiving the farmer's normal low input rates of fertilizers (**Table 1**) were very similar and showed that low inputs of fertilizers over a 10-year period had little effect on the soil resources of the production area.

When the higher-than-normal rates of fertilizers were applied in 1996 and again in 1997, and the soil was sampled in March 1998, there were marked changes in soil pH, soil electrical conductivity, exchangeable cations, and bicarbonate-extractable P. In the surface horizons, soil pH increased by 1.4 units to 7.5 because dolomite was used as the source of calcium (Ca) and magnesium (Mg). Of greater concern was a 1.2 unit decrease in soil pH to 5.3 at depths below 100 cm. Leaching of soluble fertilizer salts under the influence of heavy tropical rains and irrigation was indicated by large increases in exchangeable sodium (Na) [0.15 cmol (+)/kg] and exchangeable K [0.57 cmol (+)/kg] and a three-fold increase in electrical conductivity (0.03 mS/cm) in the 100 to 150 cm horizon. Levels of exchangeable Ca and Mg and DTPA-extractable copper (Cu), manganese (Mn), and Zn had not increased at depth, but their levels were slightly higher in the top-soil (0 to 30 cm), suggesting that fertilizer residues containing these nutrients were accumulating in surface horizons. There were similar but more marked accumulations of P from fertilizer residues in surface horizons. Levels in the 0 to 15 cm horizon had risen from 3 mg/kg in 1996 to 33 mg/kg in 1998.

Conclusions

Initial findings of this research indicate that higher-than-normal inputs of fertilizers increase cashew nut yields and were clearly economically sustainable in cashew plantations in North Queensland. However, the findings need to be verified in different locations and over a longer time frame under actual commercial grower practice.

Of concern in the longer term is the sustainability of the soil resources of the production areas. There is a need to continue to monitor the impact of higher inputs of fertilizers, especially in terms of increased soil acidity and electrical conductivity in the sub-soil and the accumulation of large residues of P in surface horizons. **BCI**

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Nitrogen Fertilization and Plant Nutrient Status Monitoring – the Basis for High Yields and Quality of Broccoli in Potassium-Rich Vertisols of Central Mexico

By J.Z. Castellanos, I. Lazcano, A. Sosa Baldibia, V. Badillo, and S. Villalobos

Central Mexico grows more than 27,000 ha of broccoli and with up to two growing seasons per year provides most of Mexico's broccoli for export to Canada, Japan, and the U.S.

High yielding, high quality broccoli production requires careful nutrient management, but current information is lacking for today's new varieties and drip irrigation production systems. No information is available on nutrient availability in the Vertisols of Central Mexico. In response to a lack of current information, researchers studied the effect of nitrogen (N) fertilization on yield, nutrient accumulation, and demand by broccoli over the growing season in this region. The study also determined normal plant levels of N, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in broccoli during the growing season.

Broccoli requires careful attention to nutrient management for top yields and quality.

Three field experiments were conducted in central Mexico from 1996 through 1998 on clay loam to clay soils near Celaya, Gto. These soils contained 2.0 to 2.2 percent organic matter, 11 to 20 parts per million (ppm) soil test P, and 600 to 900 ppm soil test K with a pH of 7.4 to 7.6

In 1996 to 1997, varying rates of N (0 to 400 kg/ha) were applied at three times during the growing season: 20 percent at planting, 40 percent 30 days after planting, and 40 percent 45 days after planting. Recommended amounts of P_2O_5 (80 kg/ha) and K_2O (300 kg/ha) were applied at planting. During the third year, N and K were injected into the drip irrigation system as determined by the demand curve, but P was applied at planting. Treatments with plus and minus P and K were also included with a level of N considered optimum for crop yield.

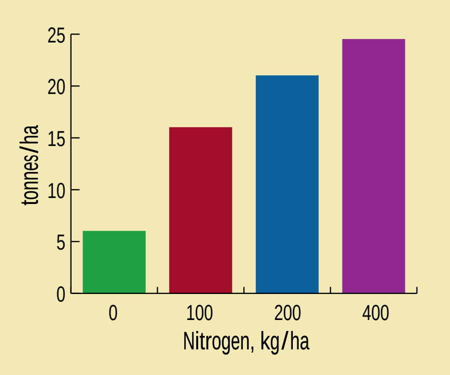

Figure 1. Marketable yield of broccoli under fertigation during 1998 in response to N treatments.

Results for marketable yield for 1998 are shown in **Figure 1**. There was a significant response to N above the level of 290 kg/ha. Maximum yield of 24.5 tonnes/ha was obtained with the treatment of 400 kg/ha of N. Similar trends were observed during 1996 and 1997. In other studies, the maximum reported yields ranged from 10 to 15 tonnes/ha (Rincon *et al.*, 1997; Doerge and Thompson, 1997). The above authors reported an optimum N level of 250 kg/ha to attain a yield of 9.5 tonnes/ha. In our study, the optimum N rate was much higher as was yield, probably the result of more favorable growing conditions and high Ca- and K-rich soils. There was no response to applied P or K, since soil tests were high (Olsen-P ranged from 11 to 20 ppm, and exchangeable K was greater than 600 ppm).

Plants were analyzed at several growth stages to develop sufficiency levels for N and normal nutrient concentrations for P, K, Ca, and Mg. Results for the most recent fully expanded leaves are shown in **Table 1**. Total N ranged from 5.5 to 6.5 percent from the early growth stages until first bud, but was reduced to 5.5 to 6 percent at heading and to 4 to 5 percent during the pre-harvest stage. Lower sufficiency values at heading have been reported by others (Reuter and Robinson, 1986; Jones *et al.*, 1991). Concentrations of P, K, Ca, and Mg also declined as plants matured, but by time of heading the values were within the range commonly reported in the literature.

Normal levels for nitrate-N (NO_3-N), phosphate-P (PO_4-P), and K in the midrib are presented in **Table 2**. Values for NO_3-N are similar to those reported by Doerge and Thompson (1997) and by Gardner and Roth (1989). Normal ranges for PO_4-P were slightly reduced at the end of the growing season, but the values for K were reduced by half from the beginning of the season to pre-harvest.

Table 1. Sufficiency levels for total N, NO_3-N, and normal levels for P, K and Mg in the most recently fully expanded leaf in broccoli (data average ranges of three years).

Growth stage	Total N	NO_3-N	P	K	Ca	Mg
	%					
4-6 leaves	5.5 - 6.5	0.80 - 1.10	0.50 - 0.80	3.50 - 6.50	2.00 - 3.50	0.40 - 0.50
10-12 leaves	5.5 - 6.5	0.60 - 0.80	0.50 - 0.80	3.50 - 6.50	2.00 - 3.50	0.25 - 0.50
First buds	5.5 - 6.5	0.35 - 0.60	0.45 - 0.80	3.00 - 5.00	1.00 - 3.50	0.20 - 0.45
Heading	5.5 - 6.0	0.30 - 0.50	0.45 - 0.80	3.00 - 4.50	1.00 - 2.50	0.20 - 0.30
Pre-harvest	4.0 - 5.0	0.25 - 0.40	0.45 - 0.70	3.00 - 3.50	1.00 - 2.50	0.18 - 0.25

Table 2. Sufficiency levels for NO_3-N and normal levels for PO_4-P and K in the dry midrib of the most recently fully expanded leaf in broccoli.

Growth stage	NO_3-N	PO_4-P	K
		%	
4-6 leaves	1.50 - 2.00	0.45 - 0.55	6.50 - 9.20
10-12 leaves	0.80 - 1.80	0.35 - 0.50	6.50 - 9.00
First buds	0.55 - 1.30	0.30 - 0.50	3.50 - 5.50
Heading	0.50 - 0.80	0.30 - 0.45	3.00 - 5.00
Pre-harvest	0.25 - 0.40	0.30 - 0.40	2.80 - 4.00

Table 3. Sufficiency levels for NO_3-N and normal levels for PO_4-P and K in the petiole press sap of the most recently fully expanded leaf in broccoli.

Growth stage	NO_3-N	PO_4-P	K
		mg/L	
4-6 leaves	1,500 - 2,000	130 - 200	4,000 - 6,500
10-12 leaves	1,000 - 1,900	120 - 200	3,000 - 6,000
First buds	800 - 1,500	100 - 120	2,500 - 5,500
Heading	700 - 1,000	100 - 120	2,500 - 4,000
Pre-harvest	300 - 600	80 - 120	2,200 - 4,000

Values are also presented for press sap of the midrib in **Table 3**. Nitrate-N values are slightly higher at the beginning of the season than those proposed by Kubota et al. (1997), but similar from mid to the end of the season. Literature reports showing normal levels for P and K are very limited and the data in **Table 3** are only for general guidance. The lack of crop response to these nutrients does not allow accurate determination of critical values in these experiments.

Most literature references report only nutrient concentrations at heading or in mature plants. This does not allow correction of deficiencies during the growing season. Data from early growth stages should prove useful in diagnosis of nutrient deficiency problems in time to allow correction during the growing season. **BCI**

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The First of our Human Rights

I can feed myself and my family. – *M.D. Stauffer*

Much has been said and written on the subject of *human rights*. There are a number of rights but none as important, or basic, to improving mankind's condition as this first human right. Travelling to various places around the world and seeing the food problem many of our Earth's inhabitants endure, the inescapable conclusion one reaches is that the most desperate among us are also the most disadvantaged. As such, they are generally without a voice...and the hungry in the world, like all other disadvantaged people, have little chance to correct the 'wrong' and make it 'right'. This unfortunate situation forces society to create a code of human rights. Food is life...and life is the priority.

The readers of this publication are sensitive to, and diligent in their effort to correct, the plight of hungry people throughout the world. By committing our efforts to this most basic of human rights, whereby everyone can say, *I can feed myself and my family*, we begin a whole and essential process of enabling and empowering the individual. Once food security is provided, people and their societies develop in significant and meaningful ways. Farmers prosper and cities thrive. That is why it is important for us to see beyond the science, the research, the education, to the real outcome of our labor.

Often, I think there is an unspoken question or concern by researchers, particularly in the developing countries of the world. It is this: Am I making a difference? You are. The current economic situation in many parts of the world is depressed and may seem to be overpowering our progress, although the benefit of rising yields...or the potential for raising yields...is being discovered. Once revealed to key policy makers and influential leaders, this wrong will become a right in reality, so all can say *I can feed myself and my family*. That is the underlying objective of this publication...helping people feed the world in ways that are economic and environmentally protective...helping others understand the needs and opportunity.

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Better Crops International,
published by the
Potash & Phosphate Institute/
Potash & Phosphate Institute of Canada

Printed on recyclable
paper with soy ink.