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Better Crops International

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Our Cover: Potato production in the highlands of Ecuador.
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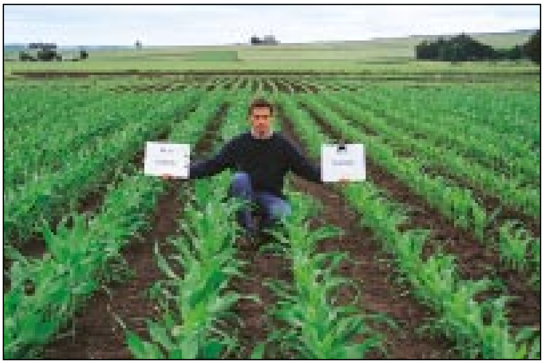
Corn Yield Response to Phosphorus Fertilization in the Southeastern Pampas

By Angel Berardo, Santiago Ehrt, Fernando D. Grattone, and
Fernando O. García

Corn is a major crop in agricultural systems of the southern Pampas of Argentina where soils are low in phosphorus (P) availability. This research suggests a critical soil P level that can help define where profitable responses to P application are obtainable.

The southeastern area of Buenos Aires province in the Argentinean Pampas is characterized by its low soil P availability. Several studies have quantified the effects of P fertilization on the production of pastures (Arosteguy and Gardner, 1978; Berardo and Marino, 1993), as well as grain crops, mainly wheat (Berardo, 1994). Previous research has reported grain yield responses of 1,500 and 500 kg/ha for corn with soil P levels (Bray P-1) of 6 to 7 and 15 to 16 mg/kg, respectively (Darwich, 1984; García et al., 1997). Further information is needed because of the continuous changes in crop management technologies, higher grain yields, and the recent intensification of row crop agriculture. This study evaluated corn yield response to P fertilization in soils of varying Bray P-1 levels generated through previous P application.



On soil with a Bray P-1 level of 8 mg/kg, corn fertilized with P (at left) shows growth response compared to the check treatment at right without P.

Materials and Methods

Research was carried out during the 1997/98 and 1999/00 growing seasons at the Balcarce Experimental Unit of the National Institute of Agricultural Technology (INTA) and the Faculty of Agricultural Sciences (UNMdP). The soil was a typic Argiudoll with an organic matter content of 5.8 percent and pH of 5.9. Treatments were set as a split-plot arrangement in a randomized complete block design with three replications. Main treatments were soil P levels, varying from 5 to 26 mg/kg (Bray P-1). Sub treatments were P fertilization levels (check and 22 kg P/ha). Phosphorus was applied at planting and was banded below the seed as triple superphosphate (0-46-0). Urea was applied at a rate of 120 kg N/ha at planting to avoid N shortages. Corn, cv. Dekalb

Table 1. Soil water availability (SWA) at planting up to a depth of 1 m, monthly precipitation (MP), irrigation (I), and total available water (TAW: SWA+MP+I) during the 1997/98 and 1999/00 growing seasons.

Month	SWA	MP + (I)						TAW
		October	November	December	January	February	March	
	mm							
Dryland 97/98	68	88	109	86	124	50	24	569
Dryland 99/00	74	66	50	66	122	224	34	636
Irrigated 99/00	74	66	50	66+(135)	122+(60)	224	34	831

639, was planted in the first week of October at a density of 70,000 seeds/ha in both seasons. Experiments were conducted under dryland conditions in 1997/98, and under dryland conditions with supplementary irrigation in 1999/00. Soil water availability to a depth of 1 m was determined at planting. Precipitation during the growing period is shown in **Table 1**.

Results and Discussion

Dryland corn yields and yield responses to P fertilization were higher in 1997/98 than in 1999/00 because of higher precipitation during critical crop stages (pre-tasseling to silking) and lower temperatures during early vegetative stages. Supplementary irrigation resulted in significantly higher yields in 1999/00. Check grain yields increased with soil P levels in both years. The following linear regressions between check yields and soil P (Ps) levels were determined:

1997/98 - Dryland Yield=6,521+74 Ps $r^2=0.43$
1999/00 - Dryland Yield=5,450+88 Ps $r^2=0.70$
1999/00 - Irrigated Yield=7,614+195 Ps $r^2=0.82$

Corn yield increased by 74 to 88 kg/ha per unit of Ps under dryland conditions. The response was 2.2 to 2.6 times greater with supplementary irrigation. Yield response to P fertilization was dependent on Ps levels and varied between 700 and 1,300 kg/ha in 1997/98 and 100 to 1,100 kg/ha and 450 to 2,400 kg/ha for dryland and irrigated treatments in 1999/00, respectively. Corn yield response to P fertilization decreased linearly as Ps levels increased according to the following regressions:

1997/98 - Dryland Yield response=1,311-31 Ps $r^2=0.47$
1999/00 - Dryland Yield response=1,594-77 Ps $r^2=0.98$
1999/00 - Irrigated Yield response=3,347-151 Ps $r^2=0.97$

Regressions for expected yield responses in all three experiments allow estimation of critical Ps levels (**Table 2**). Data are also included from 26 experimental field sites conducted between 1991 and 1997 in the southeastern region (García et al., 1997). The desired yield response could be decided as a function of grain and fertilizer prices. Considering Argentina prices of US$1.50/kg P and US$0.065/kg corn (as of October 2000, all discounts for commercialization included), an application of 22 kg P/ha, the rate used in these experiments, cost approximately 510 kg corn/ha. Thus, averaging results from all experimental data, P fertilization produced a profitable margin in soils testing less than 17 mg/kg Bray P-1.

Table 2. Estimated soil P critical levels for different corn yield responses found in three most recent experiments as well as in previously conducted research (García et al., 1997).

Yield response	1997/98	1999/00	1999/00	Garcia et al. (1997)	Average
	Dryland	Dryland	Irrigated		
kg/ha	Estimated soil P critical levels, mg/kg				
300	33	17	20	26	24
400	30	16	20	22	22
500	26	14	19	17	19
600	23	13	18	13	17
700	20	12	18	8	15

Conclusions

Corn yield and yield response to P fertilization were highly related to soil P and water availability during the growing season. Data from this study along with previous research indicate corn P fertilization can result in profitable margins in soils testing less than 17 mg/kg Bray P-1. **BCI**

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Effects of Phosphorus, Potassium, Sulfur, and Magnesium on Sugar Cane Yield and Quality in Yunnan

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

Nutrient depletion of sugar cane soils in Yunnan has limited the area's yield potential and profitability. This balanced fertilization study examines the impact of applied nutrients and provides recommendations that more closely match crop requirement.

Balanced fertilization studies in Yunnan are showing the importance of K application as part of a complete system for sugar cane yield and quality.

As a potassium (K)-loving plant, sugar cane removes large quantities of the nutrient from the soil every year. In the past, Yunnan's farmers applied only nitrogen (N) and phosphorus (P) fertilizer to the crop. Thus, the K required for production came from the soil, with K depletion resulting. The large demand for soil K exceeded amounts supplied by organic or inorganic fertilizers for quite some time. Thus, production decreased in Yunnan.

Increasing sugar cane yield and sugar content through the efficient use of fertilizer requires an understanding of the magnitude of the imbalance between plant nutrient supply and crop demand. To this end, the Soil and Fertilizer Institute of the Yunnan Academy of Agricultural Sciences studied balanced fertilizer application in a PPI/PPIC-sponsored project.

Material and Methods

Field experiments were conducted on ratooned sugar cane at three locations (Baoshan, Wenshan and Mile) representing soil conditions of the three main sugar cane growing areas in Yunnan. Plant nutrient application was based on soil test results. Plant nutrient sources were urea, diammonium phosphate (DAP), muriate of potash (MOP), potassium-magnesium sulfate (SKMg), gypsum ($CaSO_4$), and magnesium chloride ($MgCl_2$). Fertilizer application rates for the eight treatments are presented in **Table 1**. All sulfur (S) and Mg fertilizers were applied as basal applications. Phosphorus was applied in two splits (70 percent at basal dressing and 30 percent at seedling stage). Nitrogen and K were applied in five splits at basal dressing, seedling, tillering, elongating, and peak elongating stages.

Table 1. Effect of balanced fertilization on sugar cane yield and profit, Yunnan province.

	Treatment, kg/ha					Baoshan			Wenshan			Mile		
Treat-ment	N	P_2O_5	K_2O	S	Mg	Yield, t/ha	Rel[2] yield, %	Net profit[3], Yuan/ha	Yield, t/ha	Rel[2] yield, %	Net profit[3], Yuan/ha	Yield, t/ha	Rel[2] yield, %	Net profit[3], Yuan/ha
1	350	203	0	60	60	108	68.2	36,000	82.2	65.8	27,200	80.4	82.8	19,700
2	350	203	225	60	60	149	94.5	56,300	115.0	91.8	40,200	85.3	87.8	23,400
3	350	203	375	60	60	158	100.0	61,800	125.0	100.0	47,800	97.1	100.0	28,200
4	350	203	525	60	60	167	106.0	68,100	120.0	96.8	47,100	101.0	104.0	28,900
5	350	135	375	60	60	133	84.5	50,900	95.0	76.0	34,700	85.8	88.4	24,200
6	350	203	375	0	60	156	98.7	60,400	116.0	92.7	42,800	93.6	96.4	26,300
7	350	203	375	60	0	138	87.2	53,900	110.0	88.2	42,200	88.8	91.5	24,700
8	350	203	375	90	60	162	103.0	63,600	131.0	104.0	51,000	96.8	99.7	27,400
F value[1]	Treatment					2.8*			8.9**			6.4**		
	Replication					NS			NS			NS		

[1] NS = Not significantly different; * = Significantly different at the 0.05 level; ** = Significantly different at the 0.01 level.

[2] Relative yield compares each treatment against treatment 3, which was set at 100%.

[3] Value: Sugar =3.2 Yuan/kg; SKMg =1.6 Yuan/kg; $MgCl_2$ =1.6 Yuan/kg; DAP =2.0 Yuan/kg; Urea =2.5 Yuan/kg; Gypsum =1.2 Yuan/kg; KCl = 2.0 Yuan/kg.

Treatment plot areas were 30 m^2, with four replications. A randomized complete block design was used. Sugar cane varieties and plant populations followed local practices.

Results

Effect of Balanced Fertilization on Yield of Sugar Cane

Data indicate significant treatment effect on yield with balanced fertilizer use at all three locations in Yunnan (**Table 1**). Yield increased as applied fertilizer amounts increased. Phosphorus, K, S, and Mg had positive effects on yield. The effect on increasing yield was impressive when P, K and Mg were added with N applied at the high fixed rate of 350 kg/ha.

Potassium application resulted in significant increases ($P = 0.05$) in yield at all three sites. Some improvements in yield with P and Mg application were significant ($P = 0.10$). The effect of S was neither large nor statistically different from plots with no applied S at all three sites.

The effect of K diminished with increased application above 375 kg K_2O/ha only at the Wenshan site, indicating need for further study with higher rates at the other locations. The experiment at Wenshan showed a yield increase with rates between 225 to 375 kg K_2O/ha. At Baoshan and Mile, 525 kg K_2O/ha still increased sugar cane yield. This additional K rate was not profitable at Wenshan or Mile. However, at Baoshan, it was considerably more profitable, indicating even higher rates of K_2O need testing in that region. It should be noted the effect of K on sugar cane is not significant without S and Mg.

The P application (203 kg P_2O_5/ha), higher than normally used by farmers (105 to 135 kg/ha), produced a much greater and more

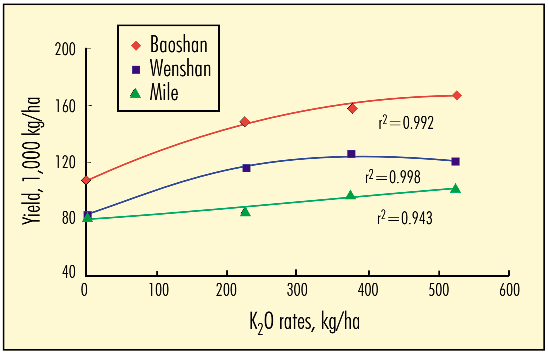

Figure 1. The effect of applied K on sugar cane yield at the three locations.

profitable yield increase at all three locations. Yield increases and profits with the higher rate of P_2O_5 for Baoshan, Wenshan and Mile were 25 t/ha and 10,900 Yuan/ha, 30 t/ha and 13,100 Yuan/ha, and 11.3 t/ha and 4,030 Yuan/ha, respectively.

The addition of 60 kg S/ha did not have a statistically significant effect at any site.

However, addition of 60 kg Mg/ha had a marked effect at all three locations. Yield increases and profits for Baoshan, Wenshan and Mile were 20.0 t/ha and 7,900 Yuan/ha, 15.0 t/ha and 5,600 Yuan/ha, and 8.3 t/ha and 3,500 Yuan/ha, respectively. Results clearly demonstrate the benefits of applying Mg to sugar cane in these three counties in Yunnan.

The main interest of this study was to evaluate K responses in sugar cane. Different regression curves were developed for the three trials (**Figure 1**). The relationship between K_2O and sugar cane yield for the three locations gave a positive correlation, with very high coefficients reaching significant levels. The response curves are rising at the three locations, but there is only a transition point on the curve for Wenshan, indicating need to test higher K application rates at Baoshan and Mile.

Effects of P, K, S and Mg on Sugar Content

Data in **Table 2** show the relationship among plant nutrient application, percent sugar content, and total sugar production per hectare at the three study sites.

Percent sugar content was most affected by applied K when other plant nutrients were adequate, increasing 2.0, 1.8 and 1.7 percent at Baoshan, Wenshan and Mile, respectively, when the highest sugar content with K_2O application was compared to no K application.

Table 2. Effect of K rates on sugar content and sugar yield with balanced fertilization, Yunnan province.

Treatment, kg/ha				Baoshan		Wenshan		Mile	
P_2O_5	K_2O	S	Mg	Sugar content, %	Sugar yield, t/ha	Sugar content, %	Sugar yield, t/ha	Sugar content, %	Sugar yield, t/ha
203	0	60	60	11.9	12.8	13.0	10.7	15.6	12.6
203	225	60	60	12.9	18.0	13.2	15.1	16.8	14.3
203	375	60	60	13.4	21.1	14.3	17.8	17.3	16.8
203	525	60	60	13.9	23.2	14.8	17.8	17.2	17.3
135	375	60	60	13.2	17.7	14.1	14.0	17.2	14.8
203	375	0	60	13.3	20.7	14.0	16.2	17.0	15.9
203	375	60	0	13.3	18.3	14.2	15.7	17.0	15.1
203	375	90	60	13.4	21.8	14.5	18.9	17.1	16.6

Total yield of sugar per hectare is calculated by multiplying sugar cane yield by percent sugar content (**Table 2**). The trend in sugar production was similar to sugar cane yield, where K stood out as the most influential plant nutrient. But

P, S and Mg all had some positive influence, mainly due to their influence on sugar cane yield. Variety can also be a significant factor affecting sugar content.

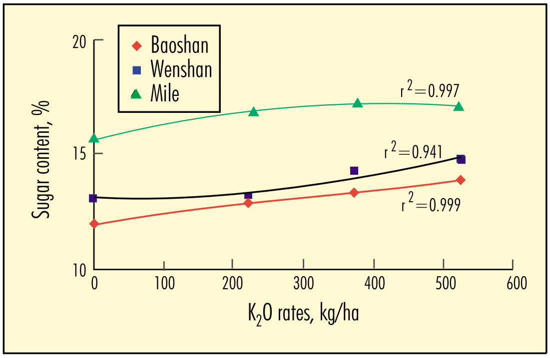

Figure 2. The effect of applied K on sugar content at the three locations.

Correlation studies were conducted between percent sugar content and the different rates of K fertilizer (**Figure 2**). Data indicated the effect of applied K on sugar content was significant. The correlations were r^2=0.997 at Mile, 0.941 at Wenshan, and 0.999 at Baoshan. Again, no downturn appeared from the effect of K at Wenshan and Baoshan, indicating higher doses of K need to be tested at these locations in the future.

Conclusions

Since the wide-scale adoption of balanced fertilization in Yunnan, variable rate fertilizer application and site-specific management provide one of the greatest new challenges and opportunities for improving fertilizer use efficiency for higher, more profitable crop yields. The assumption with balanced fertilization is that it will more closely match productivity, input efficiency, and profitability if compared with traditional farmer application methods. These experiments show that sugar cane yield, sugar content, and total sugar production per hectare can be increased by application of P, K, and Mg. Among these plant nutrients, K has the dominant effect. Both correlation coefficients for K and sugar cane yield and K and sugar content were very high at the three locations. However, at Baoshan and Mile, higher rates of all plant nutrients should be tested since response to the highest rate of K was still positive and may have been even greater had some of the other nutrients not been limiting to yield.

Considering that 60 percent of Yunnan's sugar production area harvests less than 45 t/ha, the trials presented herein demonstrate the potential to increase provincial sugar output by using balanced fertilization in an efficient and profitable manner. Until more precise data are obtained, the optimum rates for high yields and profits are recommended as N 375, P_2O_5 203, K_2O 375, and Mg 60 kg/ha. Results indicate that these rates of plant nutrients will also produce higher sugar content and, therefore, higher total sugar production. However, additional research is needed to refine these recommendations. **BCI**

Hong Lifang is a Ph.D. student in Huazhong Agricultural University, Wuhan. Su Fan, Fu Libo, and Zhao Zongsheng are staff of the Soil and Fertilizer Institute of the Yunnan Academy of Agricultural Sciences, Kunming.

Sweet Potato Response to Potassium

By Lu Jian-wei, Chen Fang , Xu You-sheng, Wan Yun-fan, and Liu Dong-bi

Sweet potato is an important crop for the mountainous regions of Hubei province and accounts for 3 percent of Hubei's total cultivated area. Low soil fertility is presently restricting yields.

Table 1. Nutrient content of different sweet potato soils, Hubei province.

Site	pH (H_2O)	Organic matter %	Available N, ppm	Available P, ppm	Available K, ppm
1	7.2	2.6	120.0	8.1	79.5
2	-	2.2	125.0	15.0	90.0
3	6.0	-	49.0	6.7	140.0
4	5.7	1.7	82.6	20.2	39.0
5	7.3	2.2	109.0	13.4	45.0
6	8.0	0.7	35.0	3.1	55.0

Table 2. Yield and K-use efficiency responses to optimal K applications at nine sites, Hubei province.

Site	Yield, t/ha CK	Yield, t/ha +K	Increment t/ha	Increment %	K use efficiency, kg yield/kg K_2O
1	24.4	27.4	3.0	12.3	13.1
2	26.4	28.9	2.5	9.5	16.7
3	42.2	63.6	21.5	50.7	95.3
4	22.1	26.8	4.7	21.3	20.9
5	45.7	61.8	16.1	35.2	71.3
6	41.4	61.3	19.9	48.1	88.6
7	25.3	34.5	9.2	36.4	60.4
8	31.1	32.7	1.6	5.1	10.5
9	30.3	34.5	4.2	13.9	18.6
Average	32.1	41.3	9.2	28.7	43.9

Sweet potato yield and quality showed strong improvement with K fertilizer application in Hubei studies.

Average yields for sweet potato in Hubei are low...about 15 t/ha...because of low soil fertility (**Table 1**) and unbalanced fertilization. Almost no potassium (K) is traditionally applied except that contained in organic manure. Field trials and balanced fertilization demonstrations were carried out in the major sweet potato production region to better understand the importance of K fertilizer on crop yield and quality.

Effect of Potassium on Sweet Potato Yield

All nine field trials showed that adequate K inputs greatly increased sweet potato yields (**Table 2**). Yields were increased by 1.6 to 21.5 t/ha (average 9.20 t/ha) with responses of 5.1 to 50.7 percent (average 28.7 percent). Yield response per kg K_2O was 10.5 to 95.3 kg (average 43.9 kg). Data also indicated the K benefit was greater in high yielding fields than in low yielding fields. More nitrogen (N) and phosphorus (P) were applied in the high yielding fields, which lead to a larger imbalance between K and N and P.

Table 3. Sweet potato yield response to K rates in different sites, Hubei province.

	Site 1		Site 2		Site 3	
K_2O rate, kg/ha	Yield, t/ha	Relative, %	Yield, t/ha	Relative, %	Yield, t/ha	Relative, %
0	22.5	100	61.0	100	38.0	100
75	—	—	70.0	115	—	—
150	27.4	122	73.0	120	44.3	117
225	26.2	117	78.0	128	46.3	122
300	27.5	122	80.0	131	48.0	126

Table 4. Effect of K rates on sweet potato quality, Hubei province.

	Average weight of single sweet potato		Starch content	
K_2O rate, kg/ha	kg	Relative, %	%	Relative, %
0	0.28	100	60.6	100
75	0.31	111	—	—
150	0.32	114	63.5	105
225	0.35	125	65.2	107
300	0.33	118	64.5	106

Table 5. Effect of K sources on sweet potato yield and quality, Hubei province.

Treatment	Flesh yield t/ha	Flesh yield %	Starch content %	H_2O content %	Starch yield t/ha	Starch yield %
CK	22.1	100	61.3	60.1	5.41	100
KCl	28.4	128	62.0	59.7	7.08	131
K_2SO_4	25.8	116	62.6	59.1	6.59	122
½KCl + ½K_2SO_4	26.8	119	—	—	—	—

*K rate: 225 kg K_2O/ha

Yield and Quality Response to Potash Application Rate

In three selected sites, yields increased with added K up to the highest rate of 300 kg K_2O/ha (**Table 3**). However, the best economic response for site 1 was achieved with 150 kg K_2O/ha; at site 2 with 225 kg K_2O/ha; and, site 3 with 300 kg K_2O/ha (**Figure 1**). Both average tuber weight and starch content, indicators of quality, increased with K rates up to an optimum of 225 kg K_2O/ha (**Table 4**).

Yield and Quality Response to Potassium Sources

Both potassium sulfate (K_2SO_4) and potassium chloride (KCl) had positive yield and quality effects on sweet potato (**Table 5**). However, KCl was more efficient, in terms of yield, than K_2SO_4 applied at the same rate. Starch content of sweet potato tubers tended to be higher with K_2SO_4 than with KCl. However, total starch yield was higher with KCl treatments due to the higher fresh sweet potato yield. The southern mountain area of Hubei has an annual rainfall of more than 1,100 mm. As a result, soil profiles of this region commonly have chloride (Cl) contents below 20 parts per million (ppm).

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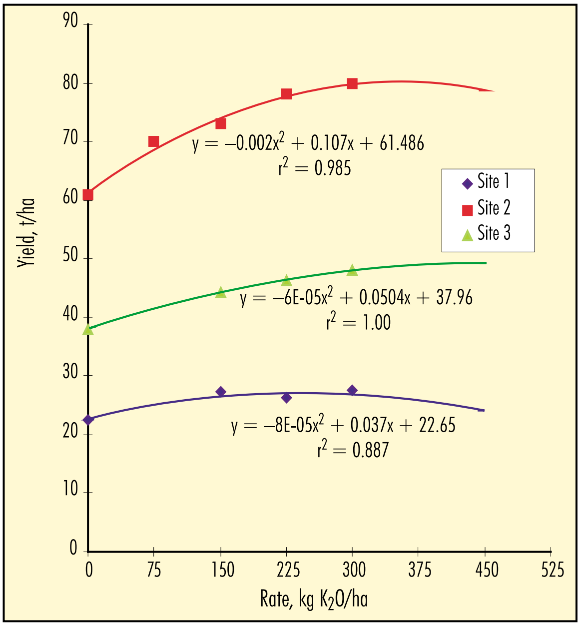
Figure 1. Sweet potato yield response to K rates, Hubei province.



PPI/PPIC Wuhan Office Moves to Wuhan Institute of Botany

The PPI/PPIC office for Eastern China is now located at the Wuhan Institute of Botany.

After three years of excellent cooperation from the Hubei Academy of Agricultural Sciences (HAAS), the PPI/PPIC Wuhan Office has moved to the Wuhan Institute of Botany of the Chinese Academy of Sciences, due to a personal decision of Dr. Fang Chen, PPI/PPIC Deputy Director, Eastern China. PPI/PPIC wishes to thank Dr. Liu Dingfu, President of HAAS, for the support he and his Academy and staff provided to the PPI/PPIC office over the past three years. PPI/PPIC looks forward to continuing close cooperation with the HAAS Soil and Fertilizer Institute on soil and fertilizer-related research and educational activities.

Effective April 2001, the PPI/PPIC Wuhan Office is now located in the Wuhan Institute of Botany, of the Chinese Academy of Sciences, in Wuhan, Hubei province. Dr. Chen will continue with his responsibilities of developing agronomic research and educational programs in the provinces of Anhui, Hubei, Hunan, Jiangsu, and Zhejiang, and the city of Shanghai. The new address is:

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Sweet Potato Response... *(continued from page 11)*

Conclusions

This study indicates that low soil fertility, especially low availability of soil K, in sweet potato production areas in Hubei is presently restricting yields and lowering profits. Sweet potato yield and quality respond strongly to K applications. The optimal K rate in these areas varies from 150 to 300 kg K_2O/ha. Potassium sulfate application resulted in the highest tuber starch content; however, KCl produced greater fresh weight and overall starch yields. It was evident that more K should be used in fields with better soil fertility and higher yield potential. **BCI**

Mr. Lu Jian-wei is Assistant Professor, Mr. Xu You-sheng is retired Professor, Mr. Wan Yun-fan and Mrs.Liu Dong-bi are Researchers, Soil and Fertilizer Institute, Hubei Academy of Agricultural Sciences, Wuhan, China. Dr. Chen Fang is Deputy Director, China Program, PPI/PPIC, Wuhan.

Effect of Sources and Rates of Potassium Application on Potato Yield and Economic Returns

By Shahid Umar and Moinuddin

Leaf potassium (K) content increased significantly with applied K and showed positive correlation with tuber yield and negative correlation with frost score. Yields obtained with muriate of potash (MOP) were comparable to those produced with sulfate of potash (SOP) after balancing sulfur (S) using gypsum.

Potato is the most important food crop in the world after wheat, rice and maize. In India, potato occupies 1.28 million ha producing 22.5 million tonnes, but the average yield (17.6 t/ha) is very low. Apart from other factors, the main cause for poor yield is inadequate and unbalanced use of fertilizers.

Potato is a heavy feeder of K, but application rates in India are low. The crop commonly suffers from K deficiency leading to disease and pest problems, frost damage, poor yield, and reduced quality.

Cultivar sensitivity to K deficiency varies greatly, and the resulting yield loss is equally variable. This study was planned to evaluate the effect of varying rates and K sources on yield, economics, and frost damage in different potato cultivars.

Materials and Methods

The two-year experiment was conducted on a farm field near Masoori in Uttar Pradesh in 1999 and 2000. Soil at the experimental site was Gangetic alluvium with sandy loam texture, pH 7.8, electrical conductivity (EC) 0.40 dS/m, organic carbon (C) 0.40 percent, available phosphorus (P) 6 parts per million (ppm), available K 75 ppm, and available S 4 ppm [0.15 percent calcium chloride ($CaCl_2$) extractable]. The experiment comprised 16 treatments including all combinations of four potato cultivars (Kufri Chandramukhi, Kufri Jyoti, Kufri Bahar, and Kufri Sindhuri), four levels of K (0, 60, 120, and 180 kg K_2O/ha),

Potato crop without (left) and with (right) K application, Uttar Pradesh, India.

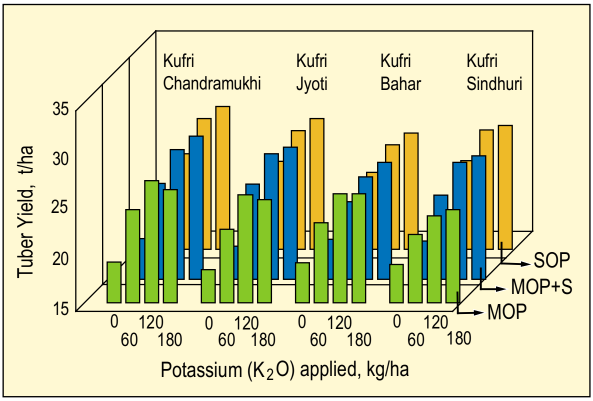

Figure 1. Yield response of potato cultivars to MOP, MOP+S and SOP, Uttar Pradesh, India.

and two K sources, MOP and SOP. Equivalent quantities of S added with SOP were balanced in MOP treatments with gypsum ($CaSO_4$) to avoid bias. Nitrogen (N) and P (as P_2O_5) were supplied at 200 and 100 kg/ha, respectively, using urea and diammonium phosphate (DAP) as sources. Tuber yields were recorded at maturity. As there was occurrence of frost 10 weeks after sowing, observations regarding intensity of frost were scored and, simultaneously, leaf samples were collected and analyzed for K content. Relationships of leaf K content with tuber yield and frost score were calculated. Frost score was also correlated with tuber yield.

Results and Discussion

Potato tuber yield increased significantly with applied K (MOP alone) up to 120 kg K_2O/ha (**Figure 1**). The magnitude of this response differed according to cultivar as the percent increase in tuber yield was highest in Kufri Chandramukhi (43 percent) followed by Kufri Bahar and Kufri Jyoti (41 percent) and Kufri Sindhuri (26 percent).

Application of S (as gypsum) along with MOP enhanced tuber yield significantly, regardless of cultivar. However, the magnitude of response to applied S also differed according to cultivar. Application of 66 kg S/ha produced the largest response with Kufri Sindhuri (3.05 t/ha), followed by Kufri Jyoti (3.0 t/ha) and Kufri Chandramukhi (2.97 t/ha). No S response was found with the Kufri Bahar cultivar. These observations give clear indication of differential susceptibility of cultivars to soil S deficiencies. A similar trend was recorded with SOP with respect to S supply. Sulfur deficiency is an important problem in many states and soils of India as nearly 130 districts are considered to be suffering from varying degrees of S deficiency. Indications are that S deficiencies will become even more important in coming years. In such areas, balanced fertilizer use will have to include S along with NPK application (Anonymous, 2000).

Table 1. Quadratic equations predicting optimum K_2O requirements for different potato cultivars, Uttar Pradesh, India.

Potato cultivar	Quadratic equation	Optimum K_2O rate, kg/ha
	MOP	
Kufri Chandramukhi	$19.05+0.117x-0.0004x^2$	143
Kufri Jyoti	$18.17+0.097x-0.0003x^2$	156
Kufri Bahar	$18.94+0.095x-0.0003x^2$	144
Kufri Sindhuri	$18.84+0.065x-0.0002x^2$	143
	MOP + S	
Kufri Chandramukhi	$19.13+0.109x-0.0003x^2$	173
Kufri Jyoti	$18.38+0.124x-0.0004x^2$	149
Kufri Bahar	$19.04+0.072x-0.0002x^2$	167
Kufri Sindhuri	$18.79+0.097x-0.0003x^2$	153
	SOP	
Kufri Chandramukhi	$19.10+0.110x-0.0003x^2$	162
Kufri Jyoti	$18.36+0.108x-0.0003x^2$	159
Kufri Bahar	$19.00+0.074x-0.0002x^2$	154
Kufri Sindhuri	$18.82+0.105x-0.0003x^2$	155

Optimum K rates were calculated by fitting quadratic response equations with tuber yield. The optimum K rate for Kufri Jyoti was higher (156 kg K_2O/ha) than other cultivars, in which the optimum K rate varied within a narrow range of 143 to 144 kg K_2O/ha (**Table 1**).

Net returns from MOP+S and SOP exceeded US$300/ha (data not shown). Local markets, including MOP, SOP and S (gypsum) prices and product availability will determine which K sources fit individual grower needs.

Leaf K content was highly correlated (r=0.823) with tuber yield and frost score (r=0.981) on K- and S-deficient sites (**Figure 2**). The frost score also exhibited a highly significant correlation with tuber yield (r=0.852). Therefore, K application increased leaf K content, induced frost resistance, and ultimately produced larger tuber yields. It is of interest to mention that between the two K sources, the frost score in the case of MOP was lower (more resistant to frost) than SOP. The high concentration of both K and chloride (Cl) in leaves due to MOP application presumably would have lowered the freezing point of cell sap and thus helped mitigate frost incidence. Our results agree with those of Grewal and Singh (1980) who observed a significantly negative correlation between available soil K and frost damage to potato yield.

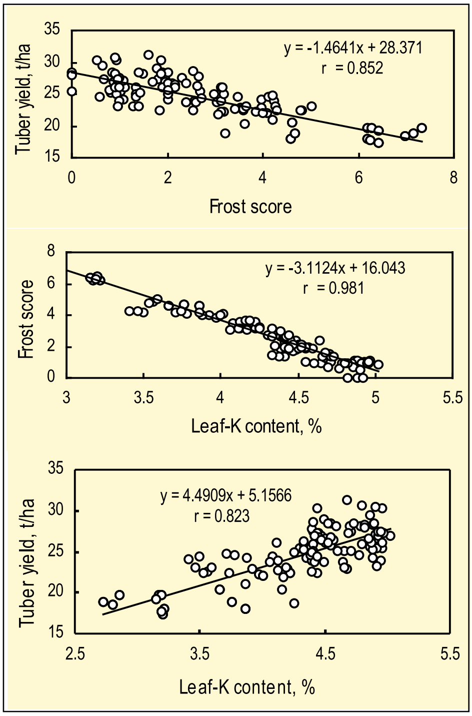

Figure 2. Relationships between leaf K content, tuber yield and frost score of potato, Uttar Pradesh, India.

Conclusion

Such a large increase in tuber yield (26 to 43 percent) with applied K clearly confirms that continuous cropping with insufficient K fertilization in India has impoverished soils of their native K fertility. Increasing susceptibility to frost incidence in the northern plains of India can be avoided by adequate K supply to soils. Thus, proper K applications would be essential and inevitable for obtaining maximum economic yield of potato. **BCI**

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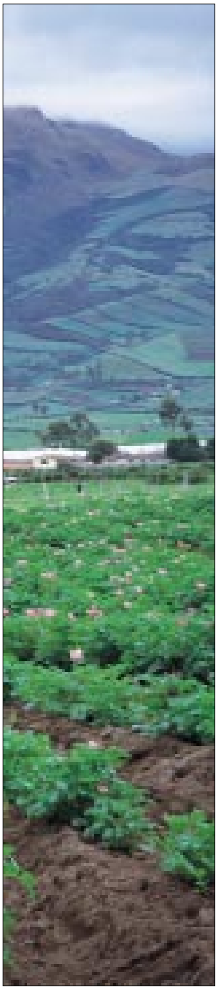
Anonymous. 2000. Nutrient deficiencies in Indian soils. In: Agri-Facts 2000:No.1. PPIC-India Programme, Gurgaon, (Haryana).

Potato Response to Potassium Application in Volcanic Soils

By Juan Córdova and Franklin Valverde

Volcanic soils are commonly mistaken as high potassium (K) soils that provide little opportunity for crop response to K fertilizer. This research, conducted in the highlands of Ecuador, shows K application is capable of increasing total potato yield, improving quality, and reducing the effects of water stress on successive crops.



Volcanic soils, classified as Andisols in the U.S. classification system, cover an extensive area of the highlands of Ecuador, Colombia, Panama, and Costa Rica. These areas support a high population density with growing food needs and which traditionally depend on potato as a staple. Research into potato breeding and crop management has improved the crop's yield potential and increased its K demand. Further research is needed to examine the effect of K on improved varieties grown on volcanic soils in order to challenge the general belief that economic K responses are not common in these areas.

Materials and Methods

Field experiments were established at two different sites in the heart of potato country in the highlands of Ecuador. Tests were conducted for three consecutive cycles of production in site 1 and two production cycles in site 2. Site 1 was classified as Vitrand, a volcanic soil characterized as having coarse volcanic glass and sandy loam texture. Site 2 was classified as Udand, a loamy textured volcanic soil dominated by allophane and imogolite in its clay fraction. Both sites were cultivated with potato, cv. Esperanza, a high yielding cultivar resistant to Phytophthora. Two K rates, 60 and 120 kg K_2O/ha, applied as potassium chloride (KCl), were compared to a check at both sites.

Results and Discussion

Yield response to K application was consistent during the three crop cycles at site 1. The response at site 2 was lower compared to site 1 (**Table 1**). After the final crop, soil K content was 0.19 $cmol_c$/kg in the check plot at site 1 and was 0.36 $cmol_c$/kg at site 2. Soil K status accounted for the difference in response to K application between the two sites.

Critical levels will change with variations in soil type. The coarse texture of the Vitrand soil is a key indicator of low cation exchange capacity (CEC) and a poor ability to retain K for plant uptake, reflected in the low critical level of 0.25 $cmol_c/kg$ at site 1. The finer textured Udand soil had an inherently higher CEC, thus a higher critical K level of 0.59 $cmol_c/kg$.

The generalized critical K level for potato grown on Andisols in Ecuador is 0.38 $cmol_c/kg$. Therefore, fertilizer recommendations based on this general value tend to ignore potential responses in soils with higher critical levels such as Udand soils.

The effect of K on alleviating water stress was clearly demonstrated by this research. Rainfall data indicate both sites had less than normal rainfall in years 1 and 2 (**Table 1**). The effect of drought was reflected in lower yields at both sites when compared with year 3, which had normal amounts of rainfall. The effect of K application on tuber yield was evident at both sites in dry years, but the effect was particularly interesting at site 1 in year 1. Investment in K fertilizer was well rewarded with improved yield during the drought. Of course, drought is difficult to forecast, but these data do show good K nutrition helps protect farmers from drought stress.

The effect of K on tuber quality, measured as tuber size, is presented in **Table 2**. Data indicate higher K rates consistently increased the yield of tubers weighing over 120 g while tubers weighing less than 120 g decreased accordingly. Tuber size is a significant factor at market and translates into price premiums for the farmer.

Table 1. Potato yield response to K application in volcanic soils of Ecuador.

K rates, kg K_2O/ha	Potato yield --- t/ha --- Year 1	Year 2	Year 3	Soil K, $cmol_c$/kg[1] Year 3
Vitrand				
0	18.6	34.2	43.8	0.19
60	27.9	49.3	47.9	0.25
120	39.3	49.7	51.0	0.26
Udand				
0		20.6	49.3	0.36
60		21.7	43.1	0.59
120		25.0	51.3	0.60
Rainfall, mm	779	1,063	1,240	

[1] K extracted with modified Olsen solution

Table 2. Effect of K application on tuber size in potato grown in volcanic soils of Ecuador.

K rates, kg K_2O/ha	Potato yield --- t/ha --- >120 g	<120 g	Total
Vitrand			
0	22.0	21.8	43.8
60	32.5	15.4	47.9
120	33.0	18.0	51.0
Udand			
0	34.0	15.3	49.3
60	38.8	4.3	43.1
120	40.0	11.3	51.3

Conclusion

The preconceived notion that crops grown on volcanic soil do not respond to K application is false, particularly with high K-demanding crops like potato. These data show a generalized critical K level for volcanic soil of Ecuador is not a good reference for K recommendations, and site-specific characteristics need to be considered. Potassium's effect on helping potato cope with water stress was clearly demonstrated in the highlands of Ecuador. **BCI**

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Potato Variety Differences in Nutrient Deficiency Symptoms and Responses to NPK

By S.P. Trehan, S.K. Roy, and R.C. Sharma

Recent work by researchers in India provides understanding of the subtle yet important differences in varietal expression of nutrient deficiency as well as their variable response to applied nutrients. Crop yield and quality implications for common potato varieties grown in India are discussed.

The knowledge of nutrient deficiency symptoms is a prerequisite for balanced plant nutrition. Experience shows that deficiency symptoms can vary with crop cultivar. Some cultivars exhibit strong symptoms under stress while others may not. Deficiency symptoms often resemble symptoms of disease, which commonly results in misinterpretation and confusion. Therefore, as a guide for nutrient management for potato, field and pot experiments were conducted to document and photograph the differences in nitrogen (N), phosphorus (P), and potassium (K) deficiency symptoms in different cultivars grown in India.

Material and Methods

Field and pot experiments were conducted in 1999 and 2000 at the Central Potato Research Station near Jalandhar, Punjab. The field experiment included three potato cultivars (Kufri Jyoti, Kufri Jawahar, and Kufri Sutlej) with varying rates of N, P and K. Deficiency symptoms were recorded in the field at 50, 70 and 80 days after planting. At harvest, the treatment effect on potato tuber number and yield for different grades...large (>75 g), medium (27 to 75 g) and small (<25 g)...was recorded. The pot experiment was conducted on three cultivars (Kufri Chandramukhi, Kufri Badshah, and Kufri Jyoti) with and without P application in a 1:1 soil/quartz sand mix. The pot experiment was terminated at 45 days, then deficiency symptoms were recorded.

Nutrient Deficiency Symptoms

Nitrogen: At 50 days, N deficiency affected overall plant growth, and bare field ridges were clearly visible in all N-deficient plots. Shoots of deficient plants were upright, thin and bore small, pale green and yellowish leaves. Leaves of Kufri Jyoti and Sutlej cultivars were more

Table 1. Influence of N, P and K fertilizer on height, shoot and leaf number per plant at 60 days after planting in different potato cultivars (mean of eight plants), Jalandhar, Punjab.

	Potato cultivars			
Treatment[1]	K. Sutlej	K. Jawahar	K. Jyoti	Mean
	Height per plant , cm			
NPK	75.0	52.4	61.3	62.9
P K	41.0	24.8	28.3	31.4
N K	64.8	48.9	50.6	54.8
N P	63.0	49.8	56.9	56.6
Mean	60.9	44.0	49.3	
	Number of shoots per plant			
NPK	3.8	5.3	4.1	4.4
P K	2.9	3.8	3.4	3.4
N K	3.9	4.4	4.1	4.1
N P	4.0	4.6	4.1	4.2
Mean	3.6	4.5	3.9	
	Number of leaves per plant			
NPK	388	357	298	348
P K	250	185	154	196
N K	404	372	273	350
N P	422	293	340	352
Mean	366	302	266	

CD (LSD) at 5%	Height	No. of shoots	No. of leaves
Cultivar mean	2.8	0.6	34
Treatment mean	3.4	0.6	39
Cultivar x Treatment	5.7	1.1	67

[1] Rates of fertilizers were 240 kg N, 150 kg P_2O_5, and 180 kg K_2O/ha.

yellowish than Kufri Jawahar. Shoot and leaf numbers were lowest in N-deficient plants, and plant height was about half that of plants that received N, P and K (**Table 1**). At 80 days, Kufri Jyoti plants died due to induced senescence, but plants of other cultivars were still green.

Phosphorus: At 50 days, P deficiency created abnormal plant growth. However, the spaces between field ridges were not as visible as was observed in N-deficient plots. The shoots were upright and thin, with small, dark green, lusterless leaves. The leaves of Kufri Jyoti showed upward curling, while other cultivars did not exhibit curling. Plant height was reduced, but the degree of stunting was less than N-deficient plots. Further, the reduction in plant height was smallest in Kufri Jawahar and largest in Kufri Sutlej (**Table 1**). Phosphorus deficiency reduced the number of shoots and leaves in Kufri Jawahar, but not in Kufri Sutlej and Kufri Jyoti. Kufri Jawahar did not exhibit symptoms of leaf curling even up to maturity. However, at 70 days, leaf curling intensified in Kufri Jyoti (**Plate 1**) and also appeared in Kufri Sutlej (**Plate 2**).

Potassium: At 50 days, K deficiency reduced plant height to a degree similar to that observed with P deficiency. However, a more severe reduction in plant height was observed in Kufri Sutlej (**Table 1**). Leaf color was commonly dark green with a bluish tinge. Potassium deficiency reduced the number of shoots and leaves in Kufri Jawahar alone. Leaf area was greatly reduced in Kufri Sutlej and Jyoti. The physical touch of deficient leaves revealed a rough textured surface. At 70 days, leaf color progressed from dark green with bluish tinges to a bronzed color with interveinal chlorosis. Leaf margins also showed scorching (**Plates 1, 2 and 3**). Lower leaf surfaces showed brown spotting, and the foliage often withered and collapsed prematurely in Kufri Jyoti (**Plate 1**).

Plate 1. Nutrient deficiency at 70 days of plant growth of Kufri Jyoti potato.

Tuber Yield and Plant Characteristics

Application of N, P and K increased tuber yield

Table 2. Influence of N, P and K on yield and number of potato tubers in different cultivars, Jalandhar, Punjab.

	Tuber yield, t/ha				Tuber number, thousand/ha			
Treatment[1]	Large[2] (>75g)	Medium[2] (25-75g)	Small[2] (<25g)	Total[3]	Large[2] (>75g)	Medium[2] (25-75g)	Small[2] (<25g)	Total[3]
				K. Sutlej				
NPK	30.6 (71)	11.3 (26)	1.3 (3)	43.2	174 (40)	160 (36)	104 (24)	438
P K	7.8 (40)	11.2 (58)	0.3 (2)	19.3 (45)	59 (19)	204 (65)	52 (16)	315 (72)
N K	26.6 (76)	7.2 (21)	1.1 (3)	34.9 (81)	161 (38)	157 (36)	111 (26)	429 (98)
N P	16.3 (54)	12.9 (43)	0.8 (3)	30.0 (69)	111 (26)	240 (55)	83 (19)	434 (99)
				K. Jawahar				
NPK	21.3 (55)	11.9 (30)	5.7 (15)	38.9	80 (24)	219 (29)	344 (46)	743
P K	2.3 (14)	9.8 (59)	4.4 (27)	16.5 (42)	24 (4)	213 (38)	320 (57)	557 (75)
N K	6.7 (24)	17.0 (61)	4.1 (15)	27.8 (71)	44 (7)	303 (46)	306 (47)	653 (88)
N P	6.6 (19)	24.9 (72)	2.9 (8)	34.4 (88)	47 (6)	478 (57)	318 (38)	843 (113)
				K. Jyoti				
NPK	7.7 (26)	17.9 (60)	4.3 (14)	29.9	57 (8)	323 (47)	306 (45)	686
P K	0.4 (4)	6.1 (66)	2.8 (30)	9.3 (31)	23 (5)	152 (33)	289 (62)	464 (68)
N K	6.1 (25)	15.2 (63)	2.9 (12)	24.2 (81)	44 (9)	261 (53)	184 (38)	489 (71)
N P	4.2 (18)	14.7 (63)	4.4 (19)	23.3 (78)	33 (6)	297 (50)	258 (44)	588 (86)

[1] Rates of fertilizer were 240 kg N, 150 kg P_2O_5, and 180 kg K_2O per hectare
[2] Values within parentheses represent the percent of category total
[3] Values within parentheses represent the percent of NPK treatment

significantly. However the extent of the increase varied with crop variety (**Table 2**). Nitrogen increased tuber yield of Kufri Sutlej, Jawahar and Jyoti by 23.9, 22.4 and 20.6 t/ha, respectively. The corresponding increase due to P and K was 8.3, 11.1 and 5.7 t/ha and 13.2, 4.5 and 6.6 t/ha, respectively. Yield reduction due to N, P and K deficiency was largest in Kufri Jyoti (69 percent), Jawahar (29 percent), and Sutlej (31 percent), respectively. Results also showed Kufri Sutlej and Jyoti were more responsive to N and K while Kufri Jawahar was more responsive to P. This differential responsiveness of potato varieties might be related to differences in plant height. Plant height was highest in Kufri Sutlej and lowest in Kufri Jawahar. Greater plant heights resulted in fewer shoot numbers (Kufri Sutlej and Jyoti) and subsequently resulted in larger N and K responses. In contrast, shorter plants had larger shoot numbers (Kufri Jawahar) and a larger P response.

Plate 2. Nutrient deficiency at 70 days of plant growth of Kufri Sutlej potato.

Tuber Size

The effect of N, P and K on the grade (quality) of tubers also varied among varieties tested (**Table 2**). Nitrogen application increased yield of all Kufri Sutlej and Jawahar tuber grades. In Kufri Jyoti, N increased the yield of large and small sized tubers but decreased the yield of medium sized tubers. Potassium application consistently increased the yield of large sized tubers across varieties, but the effect on yield of medium sized tubers differed with variety. In Kufri Sutlej and Jawahar, K decreased medium sized tuber yield but had the opposite effect with Kufri Jyoti.

Plate 3. Nutrient deficiency at 70 days of plant growth of Kufri Jawahar potato.

Tuber Number

Kufri Jawahar produced the highest number of tubers, followed by Kufri Jyoti and Sutlej (**Table 2**). Nitrogen increased tuber number and this increase was most prominent with Kufri Jyoti followed by Kufri Jawahar and Sutlej. Nitrogen also modified the number of tubers in each grade. In Kufri Sutlej, N increased the number of large and small sized tubers whereas, in Kufri Jawahar and Jyoti, it increased the number of all grades. Phosphorus did not affect tuber numbers in Kufri Sutlej, but the numbers did increase in Kufri Jawahar and Jyoti by 90,000 and 197,000, respectively. In Kufri Jyoti, the increase was more pronounced in medium sized tubers. In Kufri Jawahar, it was more pronounced in large sized tubers. Potassium had little effect on total number of tubers in Kufri Sutlej but did decrease tuber numbers in Kufri Jawahar. Potassium decreased the number of medium sized tubers in Kufri Sutlej and Kufri Jawahar proving large sized tubers contributed most to the yield increase in these two varieties. On the other hand, K increased the number of all grades in Kufri Jyoti.

Conclusions

Differences in nutrient deficiency symptoms of potato varieties must be kept in mind while assessing their respective nutrient needs. Nitrogen deficiency in potato consisted of yellowing of leaves and stunted growth. Phosphorus deficiency symptoms varied with cultivar. Kufri Jawahar did not exhibit P deficiency symptoms on its leaves, but had less leaves and shoots. Kufri Jyoti and Sutlej showed upward curling of leaves. Kufri Badshah and Chandramukhi also exhibited leaf curling as well as reduced numbers of shoots and leaves. Potassium deficiency was more acute in Kufri Jyoti and developed as a dark green coloration on leaves. With time, a bluish tinge progressed to bronzing and scorching. Absence of N, P and K reduced tuber yield by 55 to 69, 19 to 29, and 12 to 31 percent, respectively. Kufri Jawahar was most responsive to P, whereas Kufri Sutlej and Jyoti were more responsive to both N and K. **BCI**

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Phosphorus Balance in the Argentinean Pampas

By Fernando O. García

Increased crop production and limited phosphorus (P) fertilizer use have diminished soil P levels and created negative soil P balances in the Argentinean Pampas. Maximum economic yields require adequate soil P supply. Research has quantified the decline in soil available P under low P replenishment management and is highlighting the benefits of adequate fertilization programs.

Soil tests in the Pampas region of Argentina, the main grain producing area of the country, show continual declines in soil P levels (**Figure 1**). This decrease is attributed to increased crop production and limited use of P fertilizers. Low P replenishment has not been overcome by the observed increase in fertilizer consumption during the 1990s (**Figure 2**).

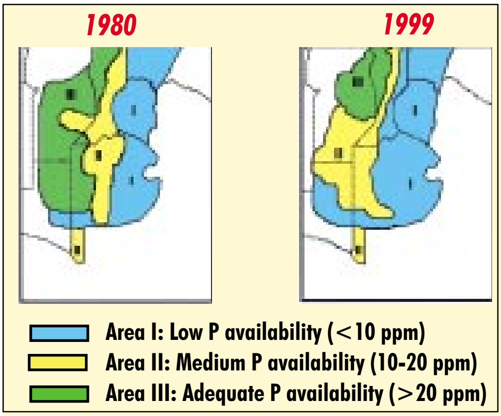

Figure 1. Soil P availability in the Pampas of Argentina for 1980 and 1999…parts per million (ppm). Source: N. Darwich (1983) and N. Darwich (personal communication, 2000).

An estimate of P removal by harvested grain for the four main grain crops of the Pampas (soybeans, corn, wheat and sunflower) is compared with actual P consumption in **Figure 3**. Phosphorus consumption represented 43 to 56 percent of the P removal by grain for the last three years. Levels of fertilizer use by these crops would need to be approximately 1.2 million tonnes of diammonium phosphate (DAP) to reach a zero balance (i.e., 100 percent replenishment).

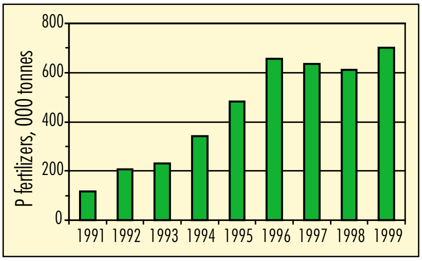

Figure 2. Apparent consumption of phosphate fertilizers in Argentina during the period 1991-1999. Source: SENASA-SAGPyA. (National Service of Agricultural Health – Secretary of Agriculture, Livestock, Fisheries, and Food).

At the farm level, P balance between grain removal and fertilizer application varies, depending on the technical level of the farmer, the crop, and primarily, the price of grain. **Table 1** shows P balances for typical three-year rotations of northern

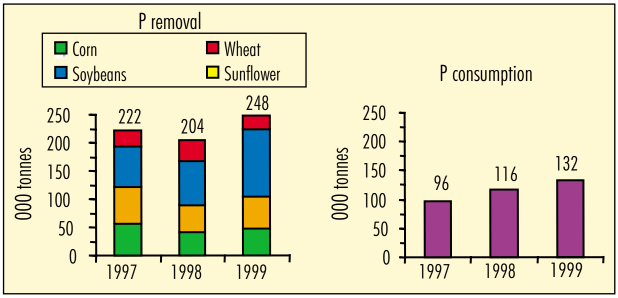

Figure 3. Estimated P removal in grain and apparent P consumption in the four main grain crops of the Pampas in 1997, 1998 and 1999. Extracted from data of SENASA-SAGPyA and Project INTA Fertilizar.

Buenos Aires-southern Santa Fe and southern Buenos Aires. The losses of soil P are 36 and 15 kg P/ha for the northern and southern areas, respectively.

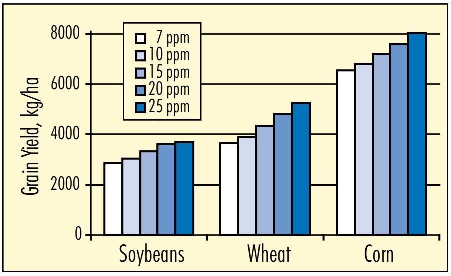

Figure 4. Grain yields of soybeans, wheat and corn at different levels of soil Bray P-1 content at southeastern Buenos Aires (Argentina). Adapted from Berardo et al. (1999), Berardo et al. (2000) and A. Berardo (personal communication, 2000).

Research carried out at Balcarce (Buenos Aires Province, southern Pampas) by Angel Berardo and co-workers shows the effect of decreasing soil P levels on grain yields of corn, soybeans, and wheat (**Figure 4**). Residual P studies in a seven-year continuous wheat sequence estimated an imbalance of negative 9 kg P/ha (difference between P removal in grain and P applied), which resulted in an average annual decrease of 1 ppm soil Bray P-1 (Berardo and Grattone, 1998). Considering this rate of soil P loss, farmers following Situation A in **Table 1** are losing 4 ppm every three years, and farmers following Situation B are losing 1.7 ppm P every three years.

Table 1. Phosphorus balances for two typical three-year rotations of the northern Pampas (A) and the southern Pampas (B).

A. Northern Pampas, Rotation Wheat/Soybeans-Corn-Soybeans

Crop	Yield, t/ha	P uptake, kg P/tonne	P harvest index	P grain removal, kg P/ha	P applied[1], kg P/ha	Difference, kg P/ha
Wheat	2.5	5	0.75	9.4	16	
Soybeans II	2.2	8	0.80	14.1		
Corn	8.0	4	0.75	24.0	16	
Soybeans I	3.2	8	0.80	20.5		
Total				67.9	32	-35.9

B. Southern Pampas, Rotation Wheat-Corn-Soybeans

Crop	Yield, t/ha	P uptake, kg P/tonne	P harvest index	P grain removal, kg P/ha	P applied, kg P/ha	Difference, kg P/ha
Wheat	4.0	5	0.75	15	20	
Corn	8.0	4	0.75	24	20	
Soybeans	2.5	8	0.80	16		
Total				55	40	-15.0

[1] P applied was estimated at 80 kg/ha of DAP for wheat and corn in the northern Pampas and 100 kg/ha of DAP for wheat and corn in the southern Pampas.

This research also showed how decreasing soil P levels (**Figure 5**) resulted in steady declines in wheat yield (**Figure 6**). In comparison to the 22R treatment (annual applications of 22 kg P/ha during seven years of the study), relative grain yields for the 0 (control) and 88 kg P/ha (applied in the first year only) treatments decreased by 2.4 and 5.2 percent per year, respectively.

Summary

Field research and experimentation have shown the agronomic and economic advantages of P fertilization

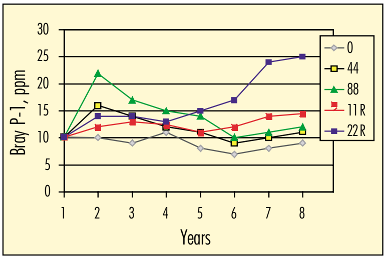

Figure 5. Changes of soil Bray P-1 in five P fertilization treatments in a seven-year sequence of continuous wheat in the southern Pampas. Treatment 0 is the control; 44 and 88 are applications of 44 and 88 kg P/ha in the first year; and 11R and 22R are annual applications of 11 and 22 kg P/ha. Balcarce (Buenos Aires). Adapted from Berardo and Grattone (1998).

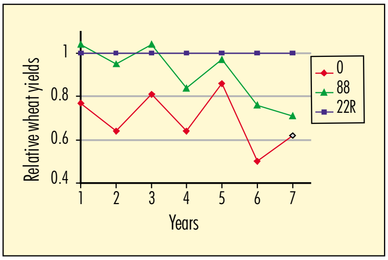

Figure 6. Relative wheat yields of three P fertilization treatments in a seven-year sequence of continuous wheat in the southern Pampas. Treatment 0 is the control; 88 is one application of 88 kg P/ha in the first year; and 22R is an annual application of 22 kg P/ha. Balcarce (Buenos Aires). Adapted from Berardo and Grattone (1998).

Without adequate fertilizer application based on soil testing, soil P levels will drop and yields of wheat and other crops will decrease in the Pampas region of Argentina.

under low soil P supply conditions. Sustainable agriculture relies on the adequate soil biological, physical and chemical characteristics of a fertile and long-term productive soil. Agriculture of the Pampas region will not be an exception to this rule. As agronomists and farmers, we should address this problem with knowledge and information continually developed through years of research and experimentation. However, soil sampling is the first step to improving soil P management. **BCI**

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Boosting Spice Production under Coconut Gardens of Kerala: Yield Maximization of Ginger with Balanced Fertilization

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

Field experiments were undertaken for two years on ginger intercropped under partial shade of coconut. A standardized, most profitable nutrient recommendation is provided for this unique and highly valuable cropping system. Results indicate ginger will respond to higher fertilization levels than are usually recommended.

India is the land of spices, and ginger is one of the important spices grown in the country for export. It is currently cultivated on 70,900 ha, producing 283,000 tonnes of dry ginger, or 3.99 t/ha. World demand is expected to rise by 30 to 40 percent during the coming five years. Present estimates indicate India will need to double production in order to meet growing demands of internal as well as export markets.

Kerala state accounts for more than 50 percent of India's 1.9 million ha under coconut. As such, coconut palm actually utilizes only 25 percent of the land area. Hence, there is ample opportunity for the remaining shaded area of coconut gardens to grow intercrops such as ginger and turmeric, which are shade loving/tolerant and highly profitable. There is a need to develop fertilization and cultural practices that are agronomically sound and economically viable.

Ginger cultivation under coconut gardens is highly profitable when grown with adequate nutrients.

Saraswat (1972) reported the yield benefits in ginger from nitrogen (N), phosphorus (P), and potassium (K) under open field conditions. Kerala Agricultural University (KAU) has also formulated recommendations based on trials conducted in open field conditions (KAU, 1996). However, the nutrient requirement of ginger under artificial shade was found to be higher. Preliminary studies conducted under open and shaded situations at Vellayani, Kerala, indicated a significant difference in nutritional requirement. Thus, the present study was planned to standardize the nutritional requirement of ginger in coconut gardens. Existing state fertilizer recommendations are 75-50-50 kg N-P_2O_5-K_2O/ha.

Field experiments were conducted at Vellayani during 1998-2000. The experimental site was lateritic, sandy clay loam in texture, pH 5.0, low in available N, K, boron (B), and below optimum in available P and sulfur (S). The experiment was conducted in randomized block design with 14 treatments and three replications. Treatments were based on initial soil test values as well as soil requirements based on sorption/ fixation studies. Treatments consisted of selected combinations from four levels of N (50, 100, 150, 200 kg N/ha), P (0, 25, 50, 75 kg P_2O_5/ha) and K (0, 50, 100, 150 kg K_2O/ha). Blanket applications of 15 kg S/ha and 2 kg B/ha were also provided. Experimental treatments were compared with state fertilizer recommendations and a control. Nutrients were supplied from urea, mussoriephos (local rock phosphate), muriate of potash, elemental S, and borax. The full rates of P and micronutrients and half rates of N and K were supplied basally. The remaining N and K were applied 120 days after planting. Recommended cultural practices were adopted uniformly for all treatments (KAU, 1996).

Results

Two years of study indicated incremental rates of N applied with 50 kg P_2O_5 and 100 kg K_2O/ha increased (3.80 t/ha) fresh rhizome yield of ginger (**Table 1**). Similarly, higher yields were found with increased P application together with 150 kg N and 100 kg K_2O/ha. Lastly, varying K application rates together with 150 kg N and 50 kg P_2O_5/ha also provided steady yield gains. Treatments with neither P nor K clearly were visibly affected in terms of yield loss.

Table 1. Selected responses of NPK on fresh rhizome yield of ginger, Kerala, India.

Nutrient	Rate, kg/ha	Fixed rates[1], kg/ha	Fresh rhizome yield, t/ha		
			1998-99	1999-2000	Average
N	50		13.4	13.9	13.7
	100	P_2O_5 (50)	14.6	16.7	15.7
	150	K_2O (100)	15.4	16.6	16.0
	200		16.9	18.1	17.5
P_2O_5	0		13.0	16.5	14.8
	25	N (150)	15.9	17.1	16.5
	50	K_2O (100)	15.4	16.6	16.0
	75		16.5	17.8	17.2
K_2O	0		14.0	16.5	15.3
	50	N (150)	14.8	17.3	16.0
	100	P_2O_5 (50)	15.4	16.6	16.0
	150		17.4	19.3	18.4

[1] Blanket applications to all treatments: 15 kg S/ha, 2 kg B/ha

This study emphasized yields can be increased with up to 150 kg N/ha when P and K are also applied in balanced quantities (**Table 2**). In other words, P_2O_5 and K_2O applications (up to 50 and 100 kg/ha, respectively) improved yield when applied along with N. Over two years, the combined application of 150-50-150-15-2 kg N-P_2O_5-K_2O-S-B/ha produced the highest fresh rhizome yield of 18.4 t/ha, which was 22 percent higher than the average yield (15.1 t/ha) obtained with state fertilizer recommendation.

In terms of economics, after deducting costs of all inputs and other cultural practices, a farmer adopting this production practice could get net returns of 148,000 Rupees per hectare (Rs./ha...US$3,290) compared to 110,000 Rs./ha (US$2,460) with the state fertilizer recommendation (**Table 2**). Of course, this income is over and above the income obtained from coconuts harvested from the same piece of land. This cash infusion would be extremely valuable to farmers. Extension specialists and policy makers should be aware of the economic advantage for large-scale adoption of the practice.

Table 2. Effect of selected application rates on fresh rhizome yield of ginger, Kerala, India.

Treatments	N	P_2O_5	K_2O	S	B	Average fresh rhizome yield, t/ha	Net returns, Rs./ha	Benefit: cost ratio
SR[1]	75	50	50	0	0	15.1	110,000	2.09
T2	100	50	100	15	2	15.7	111,000	2.02
T3	150	50	100	15	2	16.0	116,000	2.06
T7	150	75	100	15	2	17.2	131,000	2.20
T10	150	50	150	15	2	18.4	148,000	2.35

[1] State recommended fertilizer application rates

Conclusions

Based on this study, it can be inferred that ginger, when intercropped in coconut gardens, requires nutrients applied at 150-50-150-15-2 kg N-P_2O_5-K_2O-S-B/ha for maximum economic yield. In view of the fact that this practice is agronomically sound and economically viable, the state fertilizer NPK recommendations need upward revision. This study also emphasizes the importance of S and B in fertilizer schedules. Further studies are needed to determine whether higher yields are achievable by modifying current fertilizer recommendations under open field conditions. **BCI**

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Identifying Fruit Mineral Removal Differences in Four Avocado Cultivars

By Samuel Salazar-García and Ignacio Lazcano-Ferrat

The goal of this research was identification of proper fertilization management strategies for sustained production of high quality fruit for dominant commercial avocado in Mexico by assessing nutrient removal by four major avocado cultivars.

Mexico is an important avocado producer, with close to half of the world's production. Commercial avocado producers are concentrated in the states of Michoacan and Nayarit (Téliz-Ortíz et al., 2000). With an area of more than 95,000 ha and a production of over 800,000 t of fruit per year, the Mexican avocado industry provides a direct source of income to more than 61,000 families. It is estimated that new plantations and technology will increase Mexico's production to over 1 M t/yr by 2005. With an internal market value estimated at over US$1 billion, the avocado industry will play an important role in the regional economy.

For many years, profitability of avocado production was measured in terms of total fruit yield per tree or hectare. However, this parameter has lost importance due to market globalization. Currently, harvest time, size, and fruit quality (external and internal) are considered the main factors for successful avocado marketing. To determine the proper fertilization management that sustains fruit production of the size and quality required, it is necessary to have information on nutrient removal for each commercial avocado variety grown in the region.

Traditionally, little fertilizer has been used, based on the belief that the avocado tree is adapted to medium and low fertility soils. Given the fruit's high oil content (up to 20 percent), high yield avocado production requires an adequate supply of nutrients, especially potassium (K). Owners of old orchards argue that it was common, 30 to 40 years ago, to get 20 t/ha yields without fertilization, but today it is almost impossible because native soil fertility levels have declined significantly.

Average yields for avocado orchards in Mexico now range from 4 to 10 t/ha/yr. In most orchards, fertilization rates range from 0 to 100 kg/ha of nitrogen (N) and from 0 to 115 kg/ha for P_2O_5 and K_2O. Growing evidence indicates scientifically managed orchards may easily produce yields greater than 25 t/ha/yr, minimizing the alternate bearing problem (when trees or orchards bear a high yield...“on” crop year...followed by a low yield...“off” crop year). Despite improvements in orchard management, no local information is available on crop nutrient export in commercial avocado orchards. This study, which assessed mineral nutrient removal by fruit of four major avocado cultivars, will give growers important information regarding improved fertilization and will help create rational nutrition management plans for avocado orchards under rain-fed conditions.

Materials and Methods

Four avocado cultivars, Booth-8, Choquette, Hall, and Hass, were grown in commercial orchards. Booth-8, Choquette and Hall avocado orchards were located at 700 meters above sea level (masl). The Hass avocado orchard was at 950 masl. Soils in all four sites were typical of most avocado orchards and were well suited to each cultivar. Sites were located at Tepic, Nayarit, on sandy loam soils with cation exchange capacity (CEC) values between 5.2 and 9.2 $cmol_c$/kg, pH values from 5.0 to 5.8, 4 to 15 parts per million (ppm) Bray P-1, 222 to 1,000 ppm exchangeable K, 2.9 to 4.0 percent organic matter, and low to mid levels of micronutrients at all sites. All avocado tree management followed traditional fertilization practices used by cooperators without irrigation. Each tree received 6 kg 17-17-17 (N-P_2O_5-K_2O) in two applications, one at the beginning of the rainy season (June to July) and another at mid-growth. No foliar applications of micronutrients were provided despite apparent zinc (Zn) deficiency symptoms, mostly in the Hass orchard. Five physiologically ripe, average size avocado fruit were harvested from each of 20 trees. These were analyzed for mineral nutrient content, various quality traits, and yield components, including epidermis, pulp, seed coat, and cotyledons plus embryo. Each fruit part was weighed fresh and dried. Chemical analyses were performed using standard methods approved by the Mexican Soil Science Society. Nutrient removal was calculated as the amount of each nutrient in dry matter. Calculations based on dry and fresh fruit weight are reported.

Results and Discussion

Fresh fruit weight is a common parameter to estimate yield and profitability of an avocado orchard. However, this does not mean that bigger fruit or an abundant harvest of big fruit will extract more nutrients from the soil. Information on the difference in fruit fresh weight among avocado cultivars is provided in **Figure 1**. Hass avocado (239 g/fruit) could be considered a small fruit compared to Booth-8, Hall and Choquette.

Dry matter content showed a different pattern than fresh fruit weight

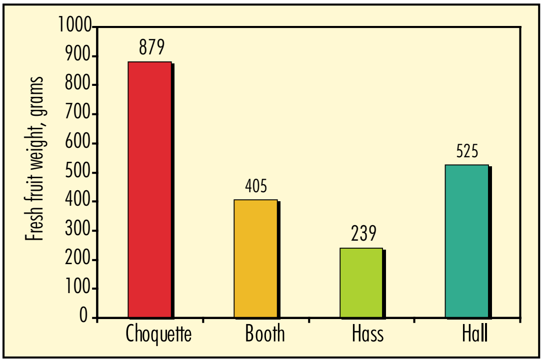


Figure 1. Average fruit fresh weight of four avocado cultivars.

(**Figure 2**). Hass fruit had the highest dry matter content (23.2 percent) compared to other cultivars. This study showed that fruit size was not directly related to total nutrient removal. There were significant nutrient removal differences among cultivars. Nutrient removal was much higher for smaller, higher dry matter content fruit, such as Hass.

Dry matter is composed of carbon and other nutrients accumulated during fruit growth and development. Nutrients are also used in protein and oil synthesis, both found in high amounts in the Hass cultivar fruit. Therefore, it is expected that fruit with high dry matter and oil content will require more nutrients.

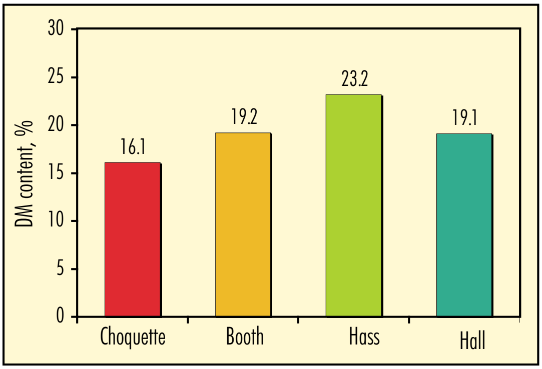
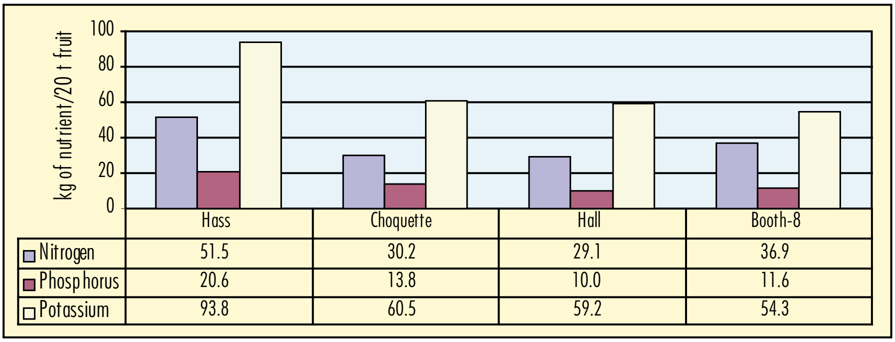


Figure 2. Average percent dry matter content per fruit.

Despite many cases of higher yields in Mexico, energy costs have established the yield potential for Hass avocado at 32.5 t/ha (Wolstenholme, 1986). In this study, calculations of nutrient removal were based on a fresh fruit yield of 20 t/ha. It is important to mention that for Choquette orchards (with 100 trees/ha) yields may go over 60 t/ha. Thus, nutrient removal might be greater when these yield potentials are included. However, no research has been done to determine fruit nutrient content for record yields in this cultivar.

In this study, the amount of N, phosphorus (P) and potassium (K) removed by a crop of Hass avocado was highest (**Figure 3**). A crop of 20 t/ha removed 52, 21 and 94 kg of N, P_2O_5 and K_2O, respectively. Potassium removal by Hass avocado fruit was 70, 77 and 39 percent higher than Choquette, Hall and Booth-8, respectively.

Figure 3. Nitrogen, phosphorus (P_2O_5) and potassium (K_2O) removal in 20 t of avocado fruit.



	Hass	Choquette	Hall	Booth-8
▨ Nitrogen	51.5	30.2	29.1	36.9
▨ Phosphorus	20.6	13.8	10.0	11.6
☐ Potassium	93.8	60.5	59.2	54.3

Export of magnesium (Mg), sulfur (S), Zn, boron (B), and molybdenum (Mo) by fruit was highest with Hass avocado (**Table 1**). Nutrient removal by Choquette, Booth-8 and Hall avocados were similar; however, Hall showed a lower removal for several nutrients when compared to either Choquette or Booth-8 (**Table 1**).

Table 1. Nutrient removal according to fresh fruit production of several avocado cultivars grown without irrigation in Nayarit, Mexico.

	Nutrient removal							
	Grams per 100 kg of fresh fruit				kg per 20 t of fresh fruit			
Nutrient	Hass	Choquette	Hall	Booth-8	Hass	Choquette	Hall	Booth-8
N	257.0	151.0	145.0	185.0	51.5	30.1	29.1	36.9
P_2O_5	103.0	69.2	49.9	58.2	20.6	13.0	10.0	11.6
K_2O	469.0	302.0	296.0	271.0	93.8	60.5	59.2	54.3
Ca[1]	8.4	8.7	6.5	10.4	1.7	1.7	1.3	2.1
Mg	29.5	16.3	16.5	22.3	5.9	3.3	3.3	4.5
S	34.5	19.2	18.4	22.6	6.9	3.8	3.7	4.5
Cl[1]	12.0	7.3	0.2	7.4	2.4	1.5	0.04	1.5
Fe[1]	0.6	1.0	0.4	0.7	0.12	0.2	0.08	0.14
Cu[1]	0.2	0.1	0.2	0.2	0.04	0.02	0.04	0.04
Mn[1]	0.1	0.1	0.01	0.07	0.02	0.02	0.002	0.014
Zn	0.4	0.3	0.3	0.2	0.08	0.06	0.06	0.04
B	0.4	0.2	0.2	0.3	0.08	0.04	0.04	0.06
Mo	0.02	0.01	0.01	0.01	0.004	0.002	0.002	0.002
Na[1]	1.0	0.6	0.8	1.0	0.2	0.12	0.16	0.2
Al[1]	0.3	0.3	0.2	0.4	0.06	0.06	0.04	0.08

[1] Ca=calcium; Cl=chloride; Fe=iron; Cu=copper; Mn=manganese; Na=sodium; Al=aluminum.

Conclusions

These results show that it is reasonable to expect significant differences in nutrient removal among avocado cultivars. Growers should pay attention to each cultivar's yield potential and its fruit's total nutrient removal, by insuring sufficient N and K to achieve optimal growth and quality. Soil P, Mg and S should be in the sufficient range prior to planting, micronutrient status should be monitored, and foliar applications made if necessary.

Balanced fertilization programs that are cultivar-specific are essential for improving fruit yield and quality. A rational avocado fertilization program must include analyses of fruit nutrient content along with soil and leaf nutrient content to better estimate fertilizer application requirements. **BCI**

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Agricultural Research and Education – a *Noble* and *Practical* Endeavour

Looking at the PPI/PPIC logo, one can begin to understand our purpose: to encourage, focus and support phosphorus (P) and potassium (K) research, and to facilitate, through education, the use, integration and application of science-based evidence into knowledge and new technologies farmers can use.

I recently spoke to a university faculty and graduate student audience on the subject: *Why are we in Agricultural Research and Education?* Considering all those cooperators and colleagues I have had the good fortune to work with over many years, my deliberations revealed some very interesting traits about us; characteristics which I think help to define us and our careers, as well as our profession.

Agriculture's researchers and educators are psychologically instilled with a *noble* spirit. Our disciplines address one of mankind's fundamental needs – food and fiber, and we take this challenge seriously. Agriculture is the foundation on which societies are built. U.S. President Franklin Delano Roosevelt, when viewing the devastation of drought in the 1930s…America's dust bowl era…spoke to this point when he said: "The Nation that destroys its soil, destroys itself." Because our work benefits the lives of others, we ennoble ourselves as well as our effort.

The *practical* nature of agricultural researchers and educators emerges from that noble spirit. By determining how to produce food and fiber efficiently—that is, understanding the soils we plant to crops; the requirements of plants and how to feed and protect them; and the use of scarce inputs (water, fertilizers, etc.)—we produce food in a cost-efficient manner. That is how this basic industry generates wealth.

Noble effort is required to understand how to exploit, while at the same time to protect the soil, water, air, and genetics, as well as the intellectual capital we individually and collectively possess, to create the wealth that builds nations.

The last noble and practical act we commit is to freely pass knowledge and capability on to others. We teach and train, and in doing so, we enable others to improve their standard of living because they now have a greater understanding of how to effectively harness inputs for efficient food and fiber production.

On behalf of PPI/PPIC, I want to thank all our cooperating and collaborating colleagues in agricultural research and education for your ***noble, practical and good*** character.

Dr. Mark D. Stauffer
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and President, PPIC

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