SOIL TESTING TO IMPROVE PHOSPHORUS MANAGEMENT ON INTENSIVE VEGETABLE FARMS IN HAWAII

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ABSTRACT

According to a recent survey of soil samples sent to the Agricultural Diagnostic Service Center (ADSC) at the University of Hawaii between October 2002 and September 2003, a majority of the samples showed soil test P (STP) levels in the high or excessive categories. Despite high soil test P, many farmers in Hawaii continue to apply P fertilizers. We began a project to evaluate soil P status on a range of vegetable farms throughout the state, to determine crop response to P fertilizers on soils testing high in P, and to evaluate current soil P critical levels used by the ADSC. Soil samples were collected from 14 vegetable farms on Hawaii, Maui and Oahu Islands and analyzed for P concentration. We installed five on-farm field trials to compare crop response to different fertilizer treatments and two trials to measure crop response to increasing quantities of P. Soil P concentrations at all fourteen locations were in the high to excessive categories. In all but one of the five field trials, adding P fertilizers did not increase crop yield compared to treatments receiving N+K and N alone. The P fertilizer response trials showed that the current P critical levels used by the ADSC are too low for vegetable crops and need to be revised. Finally, we showed that farmers can make significant reductions in fertilizer costs by not applying P to soils that have accumulated a large reservoir of residual P.

INTRODUCTION

Continual long-term application of fertilizers to areas under intensive agriculture has resulted in the accumulation of soil P at often excessively high concentrations. Information gathered from soil testing laboratories in the eastern United States in 1989 showed that a majority of the submitted soil samples had STP levels that were in the high or excessive categories (Sharpley, 1995). According to a recent survey of soil samples sent to the Agricultural Diagnostic Service Center (ADSC) at the University of Hawaii between October 2002 and September 2003, a majority of the samples also showed STP levels in the high or excessive categories. Fertilizer recommendations based upon these soil test results would leave out additional P applications because residual soil P would be able to sustain adequate crop growth (Olusegun and Christensen, 1990). Applying P fertilizers to soils that already show P concentrations above the agronomic optimum has three measurable disadvantages. First, accumulation of soil P above optimum concentrations is an inefficient use of a non-renewable resource (phosphate). Second, P fertilizer applications to soils that test high in P do not increase crop yields and reduce farm profitability especially since fertilizer costs have increased dramatically in the recent past. And, third, soils with high P concentrations threaten the quality of surface water and coastal environments (Pautler and Sims, 2000).

Farmers in Hawaii, however, generally disregard fertilizer recommendations based upon soil test information and apply fertilizer blends that are often high in P. For example, extension agents in Hawaii report that fertilizer blends like 10-30-10 and 10-20-20 are commonly used on vegetable farms throughout the islands. Information gathered from farm visits showed that farmers ignored soil test recommendations for a number of reasons. Many farmers claimed that their crops responded to P fertilizers even when theirs soils showed high P concentrations. Others hesitated to follow recommendations based upon soil tests because they were not convinced that the soil test represented "available" P. Most of the farmers questioned whether the soil P numbers used by the ADSC to represent sufficiency were relevant to their specific soils and crops. The objectives of this project were to 1) evaluate soil P status on a range of vegetable farms throughout the state, 2) determine crop response to P fertilizers on soils testing high in P, and 3) evaluate current soil P critical levels used by the ADSC.

MATERIALS AND METHODS

We collected surface soil samples (0-15 cm) from fourteen intensive vegetable farms on Oahu (5), Maui (5), and Hawaii Islands (4) to assess soil P status. The soils from these locations represented a broad range of soil mineralogy and were representative of soil types associated with vegetable production throughout the state (Table 1). The soils were analyzed for pH,

Table 1. Location including island and district and soil taxonomic designation of soil sampling sites.

Location	Farm #	Soil Type
Hawaii		
Waimea	1-4	Medial, amorphic, isothermic, humic haplustand
Maui		
Kula	5, 6	Medial, amorphic, isothermic, humic haplustand
Omaopio, Pulehu	7-9	Fine, kaolinitic, isohyperthermic, ustic haplocambids
Oahu		
Waimanalo, Kahuku	10-12	Very-fine, mixed, superactive, isohyperthermic pachic haplustolls
Ewa	13	Fine, halloysitic, isohyperthermic typic haplotorrerts
Waianae	14	Fine, smectitic, isohyperthermic, typic chromustert

extractable cations, and extractable P (modified truog and olsen methods) according to the methods used by the ADSC (Hue et al., 2000). We identified five farmers (1 Hawaii, 4 Maui) who were willing to install on-farm field trials to evaluate crop response to different fertilizer treatments. The treatments included the farmer practice (FP, control), the farmer practice without P (N+K), N alone at the same rate as in the farmer practice, and N plus P at a reduced application rate (Table 2). Treatments were replicated three times at each location. We collected soil samples from all experimental plots at the outset of the experiment and at harvest to evaluate nutrient status. For leafy crops, leaf samples were collected six weeks after transplanting to measure tissue P concentration (hue et al., 2000). At harvest, we obtained fresh weight in the field and then four to six samples were selected randomly from each plot and brought back to the laboratory for dry weight determination and P concentration to estimate P uptake. We installed two P fertilizer trials in Waimea on head cabbage and romaine lettuce to characterize crop response to increasing quantities of P. The head cabbage experiment was conducted with a cooperating farmer (Farm 3) and included four P levels (0, 44, 88, 176 lb P acre^{-1}) replicated six times. The romaine lettuce experiment was conducted at the University of Hawaii Lalamilo Experiment Station in Waimea and included five P levels (0, 20, 40, 80, 160 lb P acre^{-1})

replicated four times. At both sites P was applied pre-plant as 0-45-0, N (46-0-0) was applied at 200 lb $acre^{-1}$ (half pre-plant and half four weeks after transplanting), and K (0-0-62) at 100 lb $acre^{-1}$ pre-plant. Soil and plant data were collected according to the procedures outline above except that soil P was determined by both the modified truog and olsen methods (Hue et al., 2000).

Table 2. Fertilizer treatments and the amount of P and N applied at each of the experimental sites.

Farm	Treatments	P Rate FP	P Rate N+P	N Rate	Crop
		lb $acre^{-1}$			
2	FP, N+P, N	222	63	252	Cabbage
5	FP, N	68	NA	246	Cabbage
7	FP, N+P, N	304	63	270	Cabbage
8	FP, N+P, N	66	40	60	Bean
9	FP, N+K, N	88	22	125	Onion

RESULTS AND DISCUSSION

Soil P Status

Average soil P concentrations at the twelve vegetable farms with acid soils ranged from 133 to 3531 ppm (modified truog) and the two farms with neutral to alkaline soils had soil P levels (olsen P) of 40 and 46 ppm (Table 3). At all fourteen sampling locations soil P was consistently in the high to excessive categories for the two soil test methods. Soil P levels were generally uniformly high in the sampled fields showing relatively low spatial variability with the exception

Table 3. Mean surface soil pH, extractable P (modified truogg and cation concentrations from surface soil samples collected from intensive vegetable farms on Hawaii (1-4), Maui (5-9), and Oahu (10-14).

Farm	N	pH	P	P Sufficiency Range	Ca	K	Mg
			ppm		ppm		
1	24	6.4	3531(190)	50-85	6220	2431	476
2	15	6.1	1361(22)	50-85	5074	2179	238
3	47	6.0	285(4.6)	50-85	4108	683	171
4	26	5.9	387(10)	50-85	2516	1261	409
5	15	5.4	1767(95)	50-85	4801	2019	281
6	17	6.0	133(3.4)	50-85	3591	455	414
7	31	6.6	775(48)	25-50	3735	1065	583
8	27	5.8	611(19)	25-50	2015	1130	239
9	35	6.7	1104(86)	25-50	4660	1083	775
10				25-50			
11	20	5.9	552(36)	25-50	2496	190	360
12	30	6.7	255(7.5)	25-50	4123	773	1541
13	35	7.1	40(1.6)†	10-15	1666	549	830
14	18	8.2	46(2.1)†	10-15	7924	2083	1727

†Olsen extractable P

of farm 7 on Maui where there was a clear P gradient from an average of 775 ppm P in the eastern half of the field to an average of 314 ppm in the western half of the field. No yield response to added P fertilizers would be expected at all fourteen locations, and at some of the locations (1, 2, 5, and 9) soil P levels were alarmingly high. Despite the high P levels in all of these soils, all the farmers continue to P fertilizers prior to each cropping cycle. In many cases, that represents three to four fertilizer applications per year.

Minus P Experiments

Five on-farm field trials were established to determine whether soils with a high soil P test showed yield response to P fertilizer additions. There was no significant difference in fresh head cabbage yield between the farmer practice and the N alone treatments on the Andisols with high initial P at farm 2 (Hawaii) and farm 5 (Maui) (Fig. 1). At farm 2, starter P applications (N+P treatment) also had no significant effect on cabbage yield. On the Aridisol at farm 7 (Maui), the experiment was duplicated - one experiment in the western portion of the field (less P) and the other in the eastern section (more P). We observed a differential yield response in the two experiments reflecting the effect of initial soil P concentration. In the section where mean initial soil P concentration was 775 ppm (Farm 7a) there was no significant yield decline when only urea was applied compared to the farmer's blended fertilizer containing P. In contrast, we measured a significant decline in cabbage yield in the N alone treatment compared with the farmer practice in the western section of the field where initial soil P averaged 314 ppm (farm 7b); fresh head cabbage yield was 46,000 lbs $acre^{-1}$ with the farmer's practice and it declined to 39,500 lbs $acre^{-1}$ in the urea alone treatment. These results showed that cabbage yields did not respond to P fertilizer additions when soil P

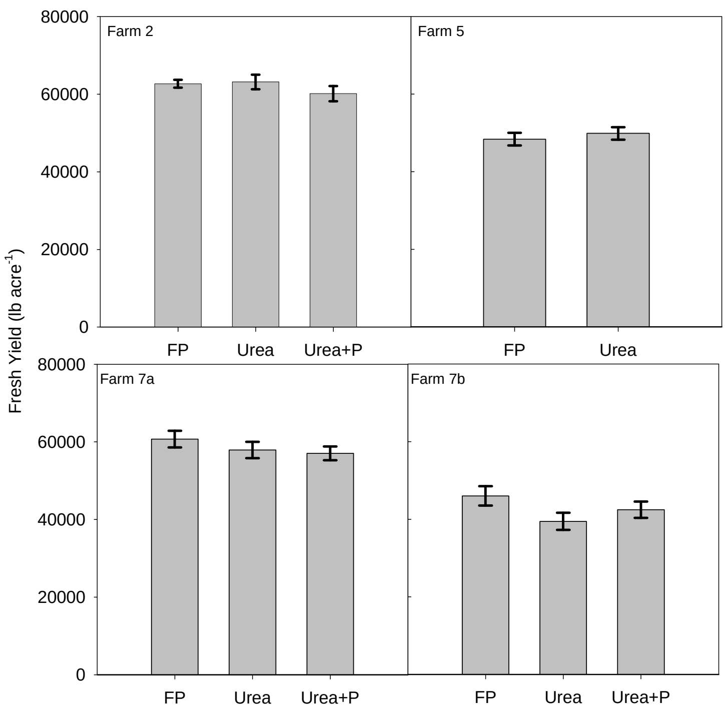

Figure 1. Head cabbage yield response to different fertilizer treatments on Andisols on Hawaii and Maui (farms 2 & 5) and an Aridisol on Maui (farm 7).

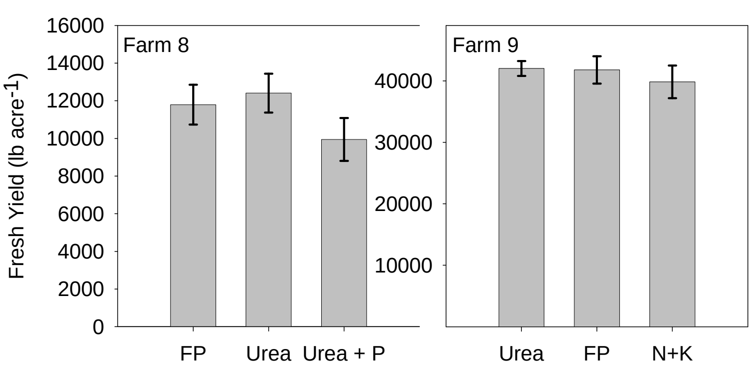

Figure 2. Bush bean (Farm 8) and onion (Farm 9) yield response to different fertilizer treatments on an Aridisol on Maui.

concentration was above 700 ppm, but did respond to P fertilization when soil P levels were near 300 ppm.

At farm 8, bush bean yield showed no response to fertilizer treatments when initial soil P was 611 ppm. The plots receiving only urea fertilizer produced similar bean yields compared to the plots receiving P fertilizers (Fig. 3). On the same soil type on neighboring farm 9, onion yields showed no significant response to fertilizer blends containing P when initial soil P concentration was 1104 ppm. In fact, the plots receiving urea alone showed the lowest amount of variability. Both experiments confirmed that initial soil P concentrations were high enough to maintain adequate bean and onion growth without additional P fertilizers.

Cabbage and Lettuce Response to P Fertilizer

The differential cabbage response to P fertilizer that we observed at Farm 7 suggested that the soil P sufficiency level may be some where between 300 and 700 ppm as opposed to the 25-50 ppm sufficiency level used by the ADSC for that particular soil. Results from the two P fertilizer experiments on cabbage and lettuce showed that current P sufficiency ranges used by the ADSC are too low for cabbage and lettuce and cannot be used to accurately separate P responsive from unresponsive soils. Based upon these two experiments we have preliminary evidence that the P critical level for cabbage and lettuce grown on an Andisol is closer to 400 ppm using the modified truog extraction (Fig. 3). These results provide evidence that the soil P critical levels currently used by the ADSC need to be revised for vegetable crops. The current critical levels are based on limited field data from corn and sugarcane experiments.

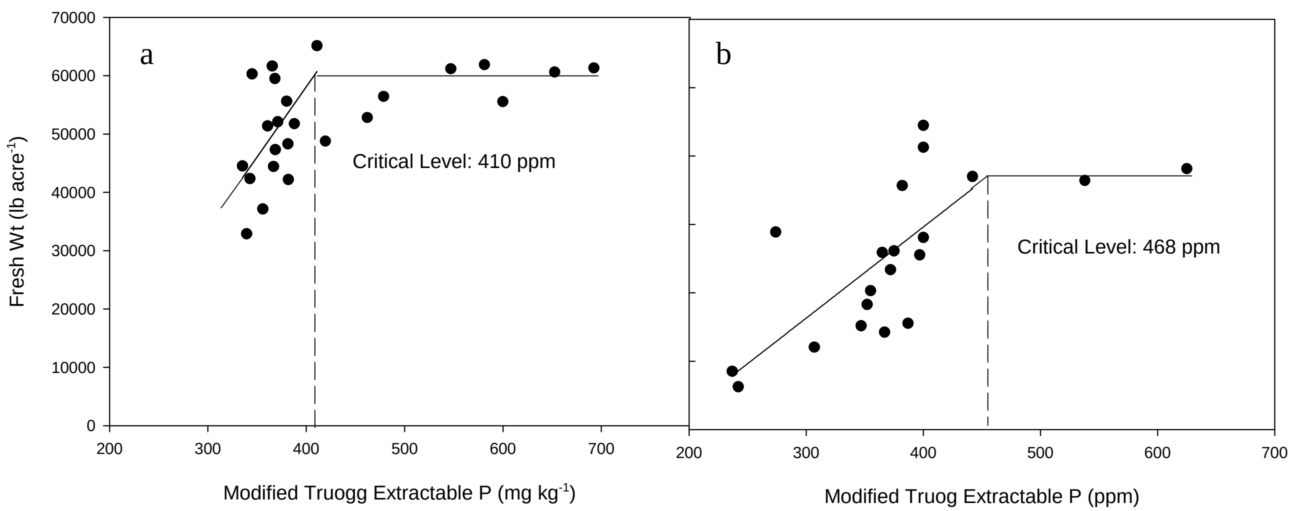

Figure 3. Head cabbage (a) and romaine lettuce (a) response to increasing soil P concentration on an Andisol. P critical levels were estimated by fitting a linear plateau model (Shuai et al., 2000).

Economic Implications

The results of field trials have shown that when soils test high in P, adding P in blended fertilizers does not necessarily increase crop yields. Figure 4 clearly illustrates, however, that there are significant cost differences between blended fertilizers and urea alone. Farm 2, for example, spent an average of $772 per acre using a blended fertilizer, but reduced fertilizer costs by about $575 per acre per cabbage crop when he used urea alone with no reduction in cabbage yield. If we assume that Farm 2 plants four crops per year, savings in fertilizer costs could be more than $2,300 per acre per year; on his 25 acre farm that amounts to almost $60,000 in savings per year. Similar situations were observed on Farms 8 and 9.

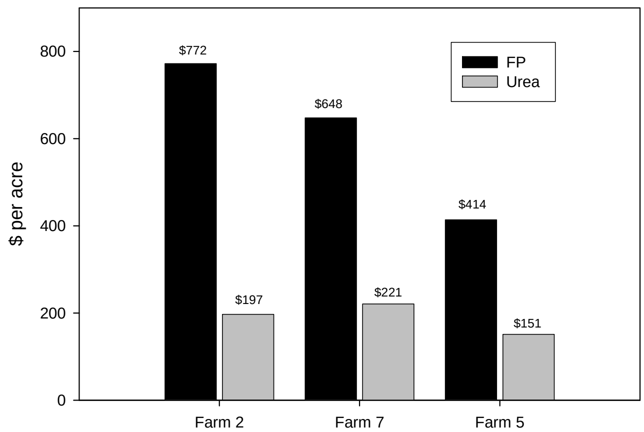

Figure 4. Costs associated with different fertilizer types for cabbage production.

Typically, farmers add fertilizers to meet the N demand of the crop. For example, the recommended N rate for head cabbage in the sub-tropics is about 200 lb N per acre per crop. The figures in Table 4 illustrate how costs vary depending on the type of fertilizer blend a farmer might use to satisfy 200 lb N per acre recommended for cabbage. The most expensive options are the blends that contain a lot of P. The fertilizers that contain only N are the lowest-cost options. Our field trials have shown that when a soil tests high in P (>400-450 ppm) adding P fertilizers have no significant beneficial effects on cabbage yields. Therefore, fertilizer should be added to satisfy the crop's N requirement, and K requirement if the soil is low in K. The fertilizers that fall within the shaded area in Table 4 would be good options for a soil testing high in P.

Table 4. Costs associated with different fertilizer blends to achieve an N rate of 200 lb per acre.

Fertilizer Blend	Quantity	P Added	K Added	Cost
		lb per acre		$ per acre†
20-20-20 (Peters)	1,000	88	166	698
10-30-10	2,000	264	166	540
10-20-20	2,000	176	332	534
10-5-29	2,000	44	481	506
16-16-16	1,250	88	166	344
21-7-14	950	29	110	294
21-0-32 (A-1)	950	0	268	275
21-0-0	950	0	0	216
46-0-0	435	0	0	137

†Calculations based upon 2006 fertilizer costs in Hawaii.

CONCLUSION

Years of fertilizer applications on many intensive vegetable farms in Hawaii has raised soil P levels well beyond the critical concentration. At these high concentrations, crop yields do not increase with additional P applications. Because crop prices are remaining stable, but fertilizer costs are increasing dramatically, farmers need to manage fertilizer inputs carefully to maintain profits. Current values used by ADSC for soil P critical levels are not valid and must be revised based upon field experiments. We have established a series of P fertilizer trials to obtain data to revise soil P critical levels for vegetable crops grown on a range of soils in Hawaii. We predict that by continuing to interact with farmers in the field and improving our fertilizer recommendation procedures, we can increase farmer adoption of soil testing and improve P fertilizer management.

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