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Phosphorus Fertilizer Management for Head Cabbage

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Head cabbage is an important vegetable crop in Hawai'i, ranking third, behind cucumbers and tomatoes, with a farmgate value of $2.7 million in 2004 (Statistics of Hawaii Agriculture 2004). In many cases, cabbage farms have been in operation for several decades, and the farmers have typically applied relatively large amounts of so-called "complete" fertilizers, blends of fertilizers that contain nitrogen (N), phosphorus (P), and potassium (K), to each crop. Although nutrient inputs in the form of "complete" fertilizers are often required to ensure good crop yields, nutrients tend to accumulate in soils receiving these fertilizers over the course of many years, and this is especially true for phosphorus.

Theoretically, when P concentrations are high in the soil, additions of more P fertilizer do not necessarily contribute to improved yields. In fact, adding P fertilizer to soils already high in P may be an unnecessary cost, reducing the farmer's profit margin. Furthermore, soils high in P that leave the farm as runoff during rainstorms threaten the quality of fresh and coastal waters.

A soil test for P is a useful tool farmers can use to determine whether their fields require P fertilizers or whether the soil contains sufficient P reserves for good crop growth. In this publication we summarize the results of several on-farm field trials testing the hypothesis that soils testing high in P do not require more P fertilizer to obtain good cabbage yields. We also provide a revised critical level for soil P that separates P-deficient soils from P-sufficient soils. We conclude with a brief economic analysis of alternative fertilizer options and the potential economic benefits farmers may obtain by using soil analysis information to guide their soil nutrient management program.

An intensively managed cabbage farm in Waimea, Hawai'i

We conducted five replicated field trials on four cabbage farms on Maui and Hawai'i between April and November 2005. The experiment locations, soil series, and selected soil chemical properties prior to the experiment are outlined in Table 1. Soil P, K, and calcium (Ca) levels at each of the farms were very high compared with current levels considered adequate by the UH-CTAHR Agriculture Diagnostic Service Center (ADSC). For growing cabbage in each soil, ADSC would recommend that only N fertilizer be applied to the field (except in the Kula soil, where lime would be recommended to increase soil pH). To test the hypothesis that the existing soil P levels were sufficient for good growth of cabbage, we evaluated the effect of three fertilizer treatments on cabbage yield.

Treatments tested and P fertilizer amounts applied for each experiment are summarized in Table 2. The

Table 1. The location, soil series, and selected chemical properties of the soils prior to the experiment at the four farms where on-farm cabbage yield trials were conducted.

				Soil P			
Farm	Location	Soil series*	pH	ppm	critical range[º]	Soil K	Soil Ca
1	Hawai‘i, Waimea	Kikoni (Haplustand)	5.7	1055	50–85	2325	5139
2	Maui, Kula	Kula (Haplustand)	4.9	1704	50–85	2032	4021
3a	Maui, Pūlehu	Keahua (Haplocambid)	6.6	775	25–35	1065	3735
3b	Maui, Pūlehu	Keahua (Haplocambid)	6.7	314	25–35	623	3242
4	Hawai‘i, Waimea	Kikoni (Haplustand)	6.0	351	50–85	543	4273

*Terms in parentheses are soil Great Group names.
[º]Range of soil P analysis values considered adequate by UH-CTAHR ADSC for the appropriate soil type.

N applications in the urea + P and urea treatments matched N applied in the farmer-practice treatments at each site. Treatments were replicated three times at all sites. At Farm 3 on Maui, the experiment was conducted in two locations (3a, high-P soil; 3b, low-P soil) within the same field, because their soil P concentrations differed widely.

Results

Figure 1 illustrates the results of our experiments comparing current farmer fertilizer application practices, where P is added as a component of a “complete” blended fertilizer formulation containing N, P, and K, with alternative fertilizer treatments that either leave P out (urea alone) or reduce the amount of P added (urea + P).

There was no significant difference in fresh head cabbage yield between the farmer practice and the N-alone treatment on the ash soils with high initial P at Waimea Farm 1 and at Kula (Farm 2) (Fig. 1). On the Keahua soil at Pūlehu (Farm 3), the initial soil P concentration influenced treatment effects on cabbage growth.

On Farm 3’s site B, where the mean initial soil P concentration was 314 ppm, there was a statistically significant yield decline when only urea was applied, compared to the yield in the plots where the farmer’s fertilizer blend containing P was applied. Fresh head cabbage yield was 46,000 lb/acre with the farmer’s practice, and it declined to 39,500 lb/acre in the urea-alone treatment.

On Farm 3’s site A, where the mean initial soil P concentration was 775 ppm, there was no significant difference in cabbage yield between the farmer-practice plots that had received P and the urea-alone plots.

Table 2. Fertilizer treatments and the amount of P applied at each of the experimental sites (FP = farmer practice).

		P applied (lb/acre)	
Farm	Treatments	FP	N + P
1	FP, urea + P, urea	177	63
2	FP + urea	68	
3	FP, urea + P, urea	241	63
4	P rate experiment	0, 44, 88, 176	

These results show that cabbage yield did not respond to P fertilizer additions when the soil P concentration was above 700 ppm, but it did respond to P fertilizer when the soil P level was near 300 ppm.

Now it remained to use these results to determine the soil P critical level for head cabbage. We established a P fertilizer experiment to determine cabbage yield response to increasing amounts of P fertilizer. We conducted the experiment at a farm in Waimea (Farm 4), where the mean soil P concentration was 351 ppm. The harvest showed clearly that cabbage yield increased with P fertilizer additions (Fig. 2a), with the largest response occurring with the smallest P addition (44 lb/acre). Adding greater amounts of P resulted in only small yield

Figure 1. Fertilizer treatment effects on head cabbage fresh weight grown on three types of soil at four farms (see Table 1). Yields represent all cabbage heads harvested within a 60 ft² area, and may not correspond to marketable yield. Error bars represent the standard error of the mean, and each bar is the average of three replicates. FP = farmer practice.

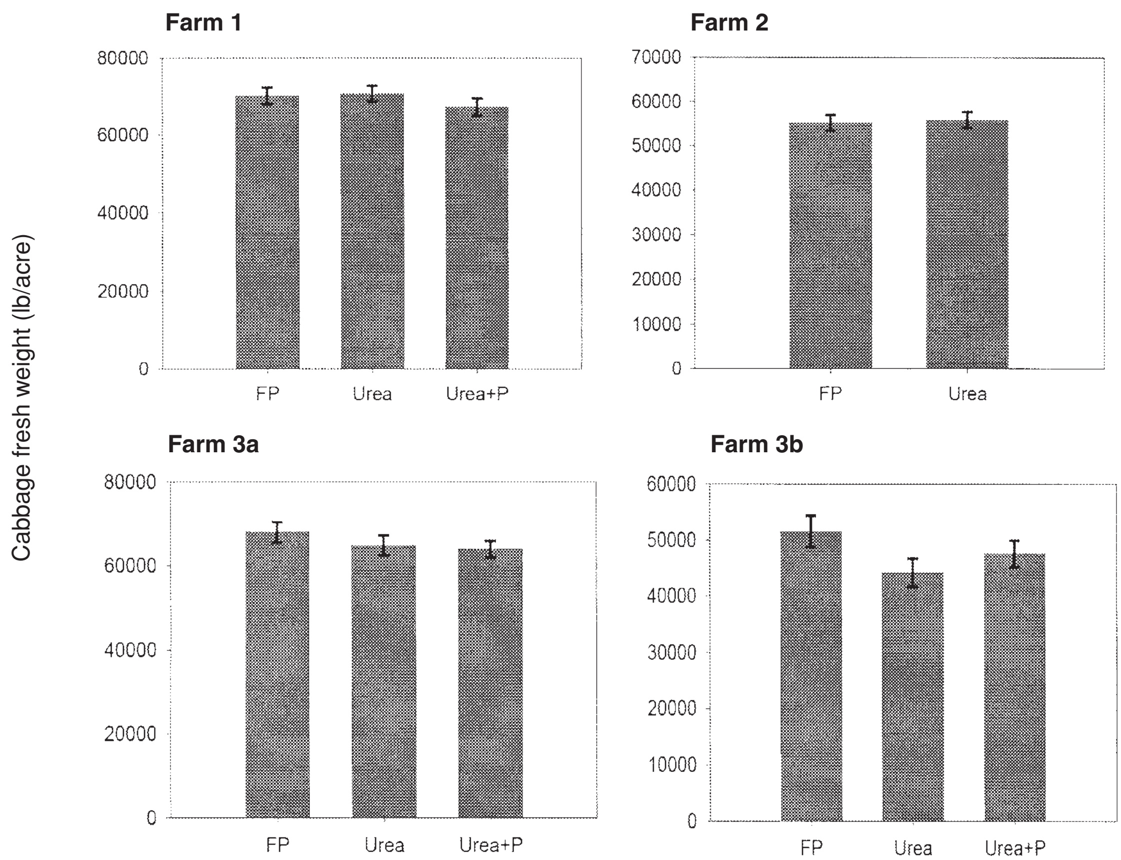


Figure 2. Head cabbage yield response on the Waimea soil series to added P fertilizer (a) and increasing soil P concentration (b). Points are a mean of three replicates, and error bars are the standard error of the mean. Extractable P is the amount of P extracted using the Modified Truog procedure.

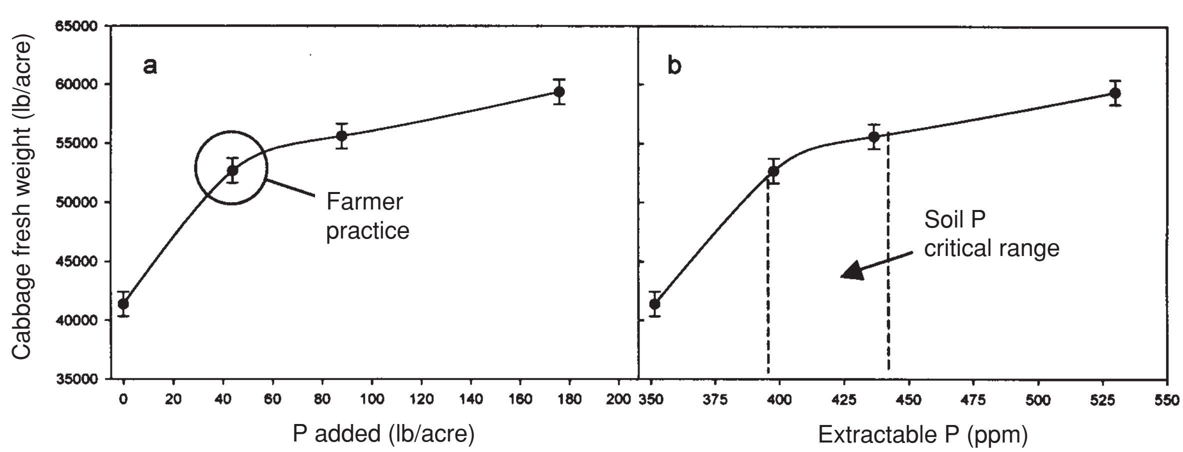


Table 3. Cost-benefit analysis showing the effect of P application amounts on revenues and the effect of rising fertilizer prices on net revenue.

				2002		2005		20xx	
P rate	Marketable yield†	Gross revenue‡	Additional revenue	Fertilizer cost§	Net revenue	Fertilizer cost§	Net revenue	Fertilizer cost	Net revenue
lb/acre		$/acre							
0	20,691	6,207	—	—	6,207	—	6,207	—	—
44	26,334	7,900	1,693	114	7,886	152	7,748	285	7,615
88	27,797	8,339	439	227	8,112	303	8,036	570	7,769
176	29,678	8,903	564	454	8,449	606	8,297	1,140	7,763

†Marketable yield was estimated at 50% of the total fresh weight yield obtained in the experiment at Farm 4.
‡Revenue was calculated assuming a cabbage farmgate price of $0.30 per pound.
§Values are from reports of the U.S. Senate Committee on Energy and Natural Resources:
http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=1529&Witness_ID=4326.

increases. Adding P fertilizer increased soil P above the baseline P level of 351 ppm (where no P was applied) to 530 ppm in the plots receiving the most P (Fig. 2b). The shape of the yield response curve in Figure 2 indicates that the optimum soil P concentration for cabbage growth is between 400 and 440 ppm in the Waimea soil. In the zero-P plots, P concentration in the cabbage tissue was 0.3%, which is the lower limit between a deficient and a sufficient level. Phosphorus concentration in the cabbage tissue increased to 0.5% with 44 lb/acre of P applied and to 0.6% with 88 lb/acre of P applied; these concentrations are within the established internal P content sufficiency range for cabbage (0.3–0.75%).

Revised soil P critical levels

Currently, ADSC assumes that the soil P critical level for cabbage is 35 ppm for heavy soils and 85 ppm for light soils. The results of our experiments show that these values are too low, and that cabbage growth responds to P fertilizer application when the soil P level is below 400 ppm.

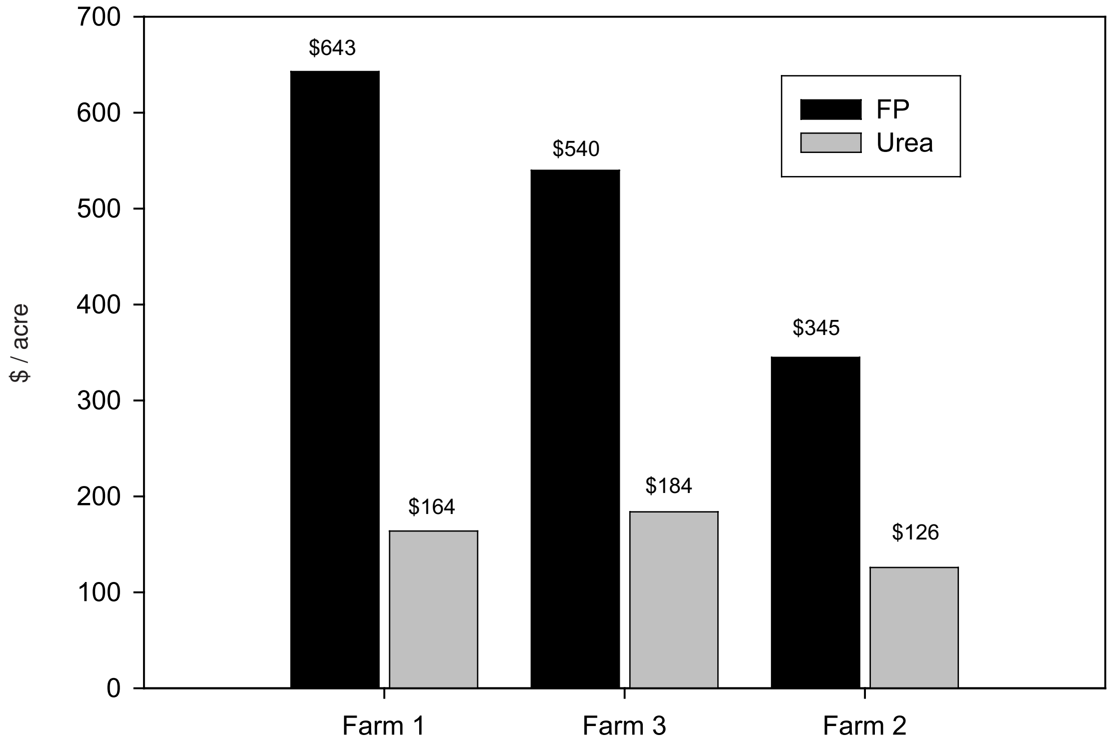
For the Waimea and Kula soil series (light soils in the current ADSC system), and other volcanic ash soils with similar properties, we propose that 400 ppm is the critical level for cabbage. If the soil P level is below 400 ppm, farmers should add P fertilizer. When the soil P level is above 400 ppm, P fertilizer effects on yield decrease.

For heavy soils, we propose that the critical range should be between 300 and 400 ppm. Soils with less than 300 ppm P should receive P fertilizers. However, this needs to be validated with P fertilizer trials in the field.

Table 4. Costs associated with using different fertilizer blends to achieve an N application of 200 lb/acre (cost = price on O‘ahu, 2006). The fertilizers within the shaded area are good options for soils having high soil P.

Fertilizer	Quantity	P added	K added	Cost
	lb/acre			$/acre
20-20-20 (Peters)	1000	88	166	698
10-30-10	2000	264	166	540
10-20-20	2000	176	332	534
10-5-29	2000	44	481	506
16-16-16	1250	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

Figure 3. Costs associated with fertilizer applications for farmer practices (FP) using blended fertilizers or applications of urea alone.



Fertilizer cost analysis and economic optimum

The results of our field trials have shown that when soils test high in P, adding P in blended, "complete" fertilizers does not necessarily increase cabbage yields. As Figure 3 clearly illustrates, cost differences between blended fertilizers and urea alone are significant. Farm 1, for example, spent an average of over $600 per acre using a blended fertilizer, but achieved the same cabbage yield with urea alone, and reduced fertilizer costs by over $400 per acre per cabbage crop. If we assume that Farm 1 plants four crops each year, savings in fertilizer costs could be more than $1,600 per acre per year. Similar situations were observed on Farms 3 and 4.

As illustrated in Figure 2a, once the biological requirements of the crop are met, adding more P does not necessarily lead to ever-increasing yields. The shape of the yield curve shows that each additional pound of P beyond the critical range is having less and less of an impact on yield. At some point, we expect that additional P will produce no further yield increase, or even that the level of P in the soil will become toxic and reduce yield. As we saw and described above, the farms in this study approach that point. The question, then, is what is the "best" amount of P to apply.

The idea of an "economic optimum" is based on the intuitively appealing notion of doing something only as long as it pays to do it. This "marginal principle" basically suggests that the farmer should apply fertilizer only as long as the cost is no more than the additional benefit from increased crop yield. In dollar terms, the end result is that the farmer will maximize net returns (revenue minus cost). To illustrate this point, we have performed a simple cost-benefit analysis with the results given in Table 3. We assumed a fixed farmgate cabbage price of $0.30 per pound, and we varied the cost of a common P fertilizer, diammonium phosphate (DAP), based on prices for 2002 ($227/ton) and 2005 ($303/ton) and, for purposes of discussion, a projected price for an unknown year in the future, $570/ton in 20xx. Farm revenue increased by $1,693, $439, and $564 per acre for each incremental increase in P fertilizer compared to the zero-P treatment. To achieve these revenues in 2002, the farmer had to spend $114, $227, and $454, respectively, for DAP fertilizer. By 2005, fertilizer costs had risen to $152, $303, and $606 for the P increments, and if fertilizer price increases continue, the farmer will be paying $285, $570, and $1,140 in 20xx to achieve the same revenues growing cabbage. As the fertilizer cost rises, profit margins decrease, but it still pays to apply more fertilizer in 2002 and 2005. In 20xx, the additional costs associated with the greatest fertilizer amount exceed added cabbage revenues, so a lower rate of 88 lb/acre P has the highest net revenue. On Farms 1–3, where soil P levels were significantly greater than at Farm 4, the lack of response to added P represented a net loss in revenue to the farmer.

Typically, farmers add "complete" fertilizers in amounts intended to meet the crop's N demand. For example, the recommended N rate for head cabbage in the subtropics is about 200 lb/acre N per crop (IFA 1992). The values in Table 4 illustrate how costs vary depending on the type of fertilizer blend a farmer might use to satisfy the 200 lb/acre N recommended for cabbage. The most expensive options are the blends that contain a lot of P. The fertilizers that contain only N are the least expensive options. Our field trials showed that when a soil tests high in P (>400–450 ppm), adding P fertilizer has no significant beneficial effect on cabbage yield. Therefore, fertilizer should be added to satisfy the crop's N requirement, and its 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.

Summary

- On many intensively cropped vegetable farms, applying complete fertilizers over many years has raised the soil P level beyond the critical range needed for good crop growth. At these high soil P levels, crop yield does not increase with additional P application.
- For head cabbage, the critical level for soil P is 400–450 ppm.
- Because cabbage prices are remaining stable while fertilizer costs are increasing, farmers need to manage fertilizer inputs carefully to maintain profits.
- Farmers who use soil analysis to monitor critical levels of soil nutrients have the opportunity to reduce fertilizer costs significantly, maintain a profitable business, and keep the environment healthy and productive.

Literature cited

International Fertilizer Industry Association (IFA). 1992. IFA world fertilizer use manual. BASF Aktiengesellschaft, Agricultural Research Station, Limburgerhof, Germany.

Acknowledgements

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