SAMPLING METHODS FOR OPTIMIZING SOIL TEST BASED PHOSPHORUS FERTILZER RECOMMENDATIONS FOR LETTUCE

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Abstract

Lettuce produced in the desert receives large annual applications of phosphorus (P) fertilizer. However, rapidly depleting P reserves, erratic fertilizer costs, and concerns about water pollution, has created incentives for improved efficiency. In previous work we have shown that pre plant soil tests are a viable means for predicting response to P fertilizer and for adjusting applications that result in reduced costs and higher returns to growers. These initial studies were conducted in small plots where soil sampling error was minimal. However, we have no information on the soil test P variation in larger commercial production units and its potential impact on fertilizer recommendations. The objective of these studies is to evaluate in-field variation of soil test P and develop soil sampling protocols appropriate for making P fertilizer recommendations for commercial lettuce fields. Production fields were sampled on one-acre resolution and analyzed for soil test P. The data show very large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). This variation in soil test P shows that it would be extremely difficult to develop an effective single composite sampling scheme for commercial production units. Preliminary analysis shows that there are potential economic returns to lettuce producers by coupling spatial sampling methods and analysis with variable rate P applications technologies. These data need to be validated in studies where lettuce production to these alternative fertilization scenarios is evaluated.

Introduction

Lettuce produced in the desert receives large annual applications of phosphorus (P) fertilizer. Amounts of P applied for lettuce production often approach and exceeds 200 kg P/ha and crop recoveries of P fertilizers are generally less than 25%. While much of the added P is converted to insoluble forms in the calcareous soils of the region (Porter and Sanchez 1992; Sanchez, 2007), some of it is carried in runoff and drainage water into receiving surface waters having adverse ecological effects (Izuno et al., 1991; 1995).

Over the past two decades, desert vegetable growers have been disinclined to reduce P inputs in agricultural systems due to large crop yield and quality responses and low fertilizer costs. However, erratic fertilizer pricing over the past three years has created incentives for improved efficiency. Approximately one year ago, the costs of mono-ammonium phosphate (MAP), a formulation widely used for desert vegetable production, exceeded $1,200.0 per ton. Although costs have since declined, rapid increases are anticipated as the world economy recovers and resource demand in the developing world regains momentum. World P reserves are rapidly declining and there is concern that a shortage of P fertilizers will ultimately compromise world food production (Vaccari, 2009).

Recent research we have conducted showed a strong relationship between pre-plant soil test P and relative lettuce yield. These data show that P fertilizer use can be reduced substantially without compromising crop yield and quality by taking into account residual soil P. These initial studies were conducted in small plots where soil sampling error was minimal. Sampling large fields is considerably more complicated and we currently do not have sampling protocols for large commercial blocks. The objective of these studies is to evaluate in-field variation of soil test P and develop soil sampling protocols appropriate for making P fertilizer recommendations for commercial lettuce fields.

Materials and Methods

Commercial lettuce fields selected by grower-cooperators were sampled on a one acre resolution prior to fertilization in the fall of 2010. The soil samples were air-dried, ground, and stored in the laboratory until analysis. In the laboratory we measured soil pH, saturation percentage (an index of soil texture), electrical conductivity (a measure of soil salinity), sodium bicarbonate extractable P (a measure of readily available soil P), and soil nitrate. The data were analyzed statistically using SAS and maps were generated using mapping software.

Results and Discussion

The mean soil test P levels and standard deviation for each production unit are shown in Table 1. The data show very large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). The distributions of P within the fields on a one acre resolution are shown in Figures 1 through 5. This variation in soil test P within production unit shows that it would be extremely difficult to develop a sampling scheme for collection of a meaningful composite soil sample. Using a composite sample would results in significant portions of the field being both under fertilized and over fertilized. Lettuce is extremely sensitive to P deficiency and the portions of the fields under fertilized would result in significant economic loss to growers. Further, the portion of the field over-fertilized not only represents unneeded expenditures by the grower, it can result in very high available P levels over part of the field and potential adverse production consequences such as P induced micronutrient deficiency (particularly Zn).

It is clear that the most promising approach for exploiting soil testing is coupling it with variable rate technologies (VRT). Because we were uncertain if collecting soils samples on a one acre resolution (VRT1) is economically feasible, we approximated hypothetical sampling on a five acre resolution (VRT5) with the averages of those generated on the once acre sampling (Figures 5 to 10). The relationship between pre-plant soil test P and relative response of lettuce to fertilizer P is shown in Figure 11. These and other data were used to generate the fertilizer recommendations shown in Table 2. From these fertilizer recommendations we approximated fertilizer costs (sampling, soil analysis, application costs and fertilizer costs) to various application technologies compared to the standard grower practice (GSPU) of applying 550 lbs MAP to the acre every season (Table 3). We wish to note that these estimates only represent fertilizer savings and do not consider production implications since we do not have this data at this time. The greatest savings appear to be associated with application based on a soil test from a composite field sample (CSTU) since sampling and analysis costs are minimal. However, as noted above, using this approach will likely have economic consequences in production because the variation in soil test across a production unit is large and a significant portion of the field would be under fertilized. Interestingly when evaluating the one acre sampling resolution VRT strategy (VRT1), 8 of the 11 sites showed fertilizer costs savings, one was break even, and two were a loss due to sampling costs exceeding fertilizer cost savings. Again we did not consider production implications. A number of studies have shown similar yields to uniform application strategies but significant cost savings in fertilizer to VRT (Yang et al., 2001; Wittry and Mallarino, 2004). However, most of these studies were conducted with crops less responsive to P than lettuce. We speculate that a production increase to applying sufficient, but not excess, P across the entire field is possible for lettuce. The results show greater fertilizer costs savings to 5 acre resolution VRT (VRT5) compared to VRT1 because sampling and analysis costs are substantially less. However, again the lower resolution sampling would result in some under and over fertilization and we have no data to determine production consequences.

We compared the areas under and over fertilized using VRT1 as a basis. Under fertilization has potentially large production and economic consequences in lettuce. Depending on a number of factors including soil test P conditions, and crop yield potential as related to factors other than P fertility, we may or may not detect production differences when 50 lbs MAP less than that recommended is applied. However, almost invariably we should detect differences to a deficiency of 100 lbs MAP/A. Therefore the total area shorted 50 lbs/A MAP or more and 100 lbs/A MAP or more are shown (Table 4). This data does not include the GSPU treatment since these received a uniform application of 550 lbs MAP/acre, our highest recommendation at lower soil tests, and this would not be shorted by our soil test recommendation criteria. Overall, these data show that CSTU and VRT5 were not appreciably different in area under fertilized compared to VRT1.

The actual production consequences of excess P are less certain. While excess P can tie up micronutrients, our soils are well buffered by calcium carbonate and this response is not readily predictable. It is our experience that producers should not be concerned about adverse production effects to excess soil P until soil tests exceed 50 mg/kg. Nevertheless, excess P does have economic consequences in that producers are purchasing an input not needed and excess P has potential adverse environmental impacts on surface water. The area over fertilized was extremely large for GSPU (Table 5). The areas over fertilized by 50 lbs/A MAP or more were similar for CSTU and VRT5, both of which were substantially less than GSPU. Interestingly, VRT5 did not result in over fertilization by

100 lbs/A MAP or more. The economic viability of these various strategies needs to be addressed in future studies which actually measure production impacts.

An alternative to gird sampling is defining management zones based on known soil properties. Preliminary data we collected show some relationship of soil test P to other soil properties such as soil pH and saturation percentage (Table 6).

Literature Cited

Izuno, F. T., C. A. Sanchez, F. J. Coale, A. B. Bottcher, and D. B. Jones. 1991. Phosphorus concentrations in drainage water in the Everglades Agricultural Area. J. Environ. Qual. 20:608-619.

Izuno, F. T., A. B. Bottcher, F. J. Coale, C. A. Sanchez, and D. B. Jones. 1995. Agricultural BMPs for phosphorus reduction in South Florida. Trans. of ASAE 38:735-744.

Sanchez C.A. 1990. Soil testing and fertilizer recommendations for crop production on organic soils in Florida. University of Florida Agricultural Experiment Station Bulletin 876, Gainesville.

Sanchez, C. A. 2007. Chapter 3. Phosphorus. In A. V. Barker and D. J. Pilbeam (ed.). Handbook of Plant Nutrition. CRC Press, Taylor and Francis Group, New York

Sanchez, C.A., S. Swanson, and P.S. Porter. 1990. Banding P to improve fertilizer use efficiency in lettuce. J. Am. Soc. Hort. Sci. 115:581-584.

Sanchez, C. A., and N. M. El-Hout. 1995. Response of different lettuce types to fertilizer phosphorus. HortScience. 30:528-531.

Sanchez C.A., P.S. Porter, and M.F. Ulloa. 1991. Relative efficiency of broadcast and banded phosphorus for sweet corn produced on Histosols. Soil Sci. Soc. Am. J 55:871-875.

Sanchez, C. A., and E. A. Hanlon. 1990. Evaluation of selected phosphorus soil test for lettuce on Histosols. Commun. Soil Sci. Plant Anal. 21:1199-1215.

Porter, P. S, and C. A. Sanchez. 1992. The effect of soil properties on phosphorus sorption by Everglades Histosols. Soil Sci. 154:387-398.

Vaccari, D. A. 2009. Phosphorus-A looming crisis. Sci. Amer. 54:59.

Wittry, D. J., and A. P. Mallarino. 2004. Comparison of uniform and variable rate phosphorus fertilizer application for corn-soybean rotation. Agron. J.96:26-30

Yang, C, J.H. Everitt, and J.M. Bradford. 2001. Comparisons of uniform and variable rate nitrogen and phosphorus fertilizer applications for grain sorghum. Trans. of the ASAE. 44:201-209.

Table 1. Mean and standard deviation of soil test P (mg/kg) in 11 production fields in southwestern Arizona.

Field	Samples	Mean Soil Test P (mg/kg)	Standard Deviation Soil Test P (mg/kg)
141	52	14.0	8.2
180	36	31.1	11.9
184	20	12.6	7.8
358	36	13.5	6.5
360	36	13.0	12.7
366	18	16.7	3.1
368N	12	18.2	10.5
368S	8	29.1	17.6
676	28	22.7	4.0
679	42	9.0	5.0
680	34	9.1	6.3

Table 2. Current P fertilizer recommendations for desert lettuce.

Soil Test P	Broadcast Fertilizer Recommendation[a]
< 10 mg/kg	550 lbs MAP/acre
10 to 15 mg/kg	500 lbs MAP/acre
15 to 20 mg/kg	450 lbs MAP/acre
20 to 25 mg/kg	400 lbs MAP/acre
25 to 30 mg/kg	350 lbs MAP/acre
30 to 35 mg/kg	300 lbs MAP/acre
>35 mg/kg	Starter only

[a]We have and band application credit results in a recommendation 60% that for broadcast application.

Table 3. Estimated fertilizer costs savings to soil testing including composite sample, VRT on one acre grid, and VRT on five acre grid.

	Soil Test P (mg/kg)		Fertilization cost savings ($/acre)[a]		
Field	Mean	Range	CSTU	VRT1	VRT5
141	14.0	1.9 to 35.5	18.4	6.2	18.1
180	31.1	7.2 to 67.7	93.2	85.3	106.8
184	12.6	0.1 to 25.7	17.8	0.05	15.9
358	13.5	0.7 to 23.0	18.3	1.51	8.5
360	13.0	6.4 to 85.8	18.2	2.88	18.8
366	16.7	11.3 to 22.2	36.5	10.6	30.2
368N	18.2	5.2 to 30.4	35.7	17.3	30.2
368S	29.1	0.2 to 63.7	72.9	68.5	75
676	22.7	16.5 to 30.6	55.6	34.9	56
679	9.0	1.8 to 22.5	-0.47	-12.9	7.1
680	9.1	1.4 to 29.3	-0.57	-15.8	3.4

[a]We have estimated costs of soil sampling, analysis and VRT of $20 per sample and fertilizer cost of $750 per ton.

CSTU=uniform application based on soil test from composite sample, and VRT1=variable rate application on a one acre resolution sampling, and VRT5=variable rate application based on a five acre resolution sampling.

Table 4. Estimated area of field under fertilized by 50 and 100 lbs MAP/acre when comparing CSTU and VRT5 to VRT1.

Field	Area of field (%) under fertilized by >50 lbs MAP/acre		Area (%) under fertilized by >100 lbs MAP/acre	
	CSTU	VRT5	CSTU	VRT5
141	19	26	0	0
180	23	16	7	0
184	31	45	0	10
358	7	58	0	0
360	17	21	0	10
366	45	14	0	0
368N	5	46	2	32
356S	2	2	1	1
676	5	29	0	0
679	0	7	0	0
680	0	11	0	3

CSTU=uniform application based on soil test from composite sample, and VRT5=variable rate application based on a five acre resolution sampling.

Table. 5. Estimated area of field over fertilized by 50 and 100 lbs MAP/acre when CSTU, and VRT5 to VRT1.

Field	Area of field (%) over fertilized by >50 lbs MAP/acre			Area of field (%) over fertilized by >100 lbs MAP/acre		
	GSPU	CSTU	VRT5	GPU	CSTU	VRT5
141	81	49	16	29	9	0
180	100	24	16	98	24	0
184	68	29	46	29	10	0
358	82	33	57	33	0	0
360	83	12	20	12	9	0
366	100	8	14	55	0	0
368N	86	41	55	55	17	0
356S	100	37	37	96	13	0
676	100	11	29	100	0	0
679	35	35	7	2	6	0
680	14	14	12	1	6	0

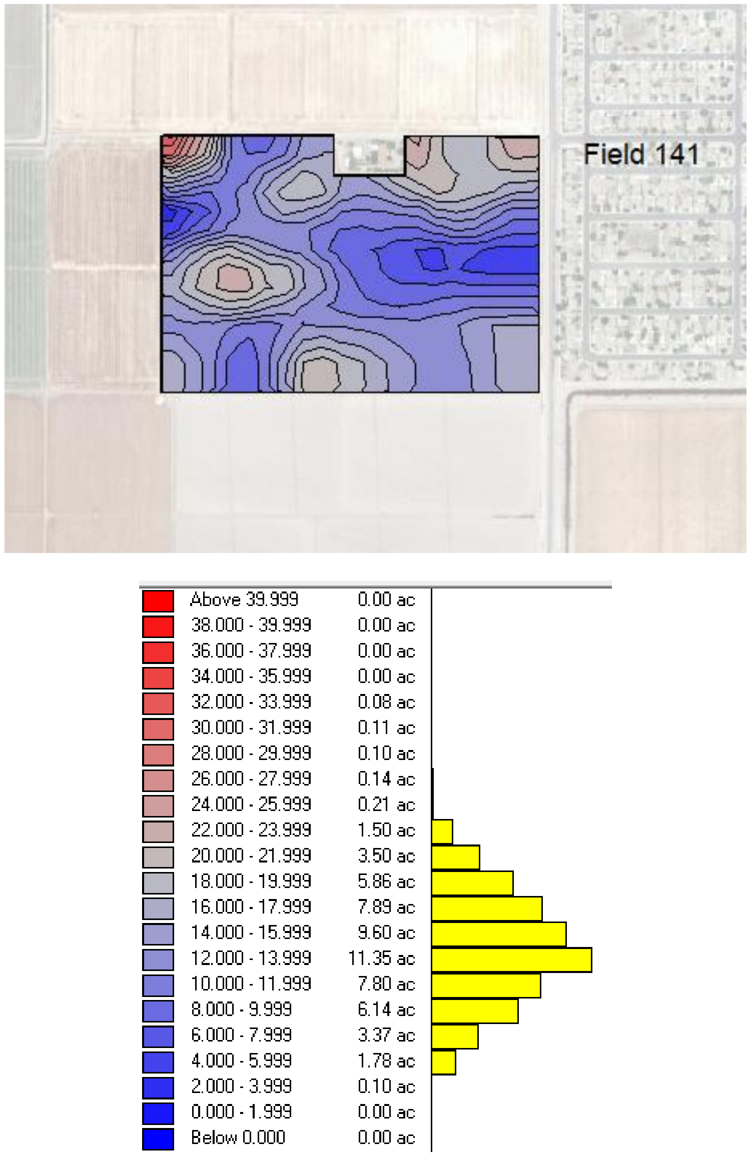
GSPU=uniform application by grower standard practice, CSTU=uniform application based on soil test from composite sample and VRT5=variable rate application based on a five acre resolution sampling.

Table 6. Correlation between the various soil properties evaluated.

Field	**Variables**	**Correlation coefficient**
141	SP vs EC	-0.59**
180	SP vs EC	-0.72**
184	SP vs EC	-0.60**
358	pH vs EC	-0.52**
	SP vs EC	-0.52**
	STP vs EC	-0.38*
360	pH vs EC	-0.36*
	SP vs EC	-0.49**
366	pH vs STP	-0.51*
	SP vs STP	0.63**
368N	pH vs EC	-0.57*
	pH vs STP	0.59*
368S	pH vs EC	-0.68*
	pH vs STP	0.68*
676	pH vs STP	0.42*
	SP vs EC	-0.71
679	pH vs SP	-0.41**
	pH vs STP	-0.34*
	SP vs EC	-0.51**
	SP vs STP	0.41**
680	SP vs EC	-0.49**
	SP vs STP	-0.41*
Overall	pH vs SP	-0.23**
	pH vs EC	-0.51**
	pH vs STP	-0.17**
	pH vs STN	-0.42**
	SP vs STN	0.21**
	EC vs STP	0.22**
	EC vs STN	-0.42**
	STP vs STN	0.28**

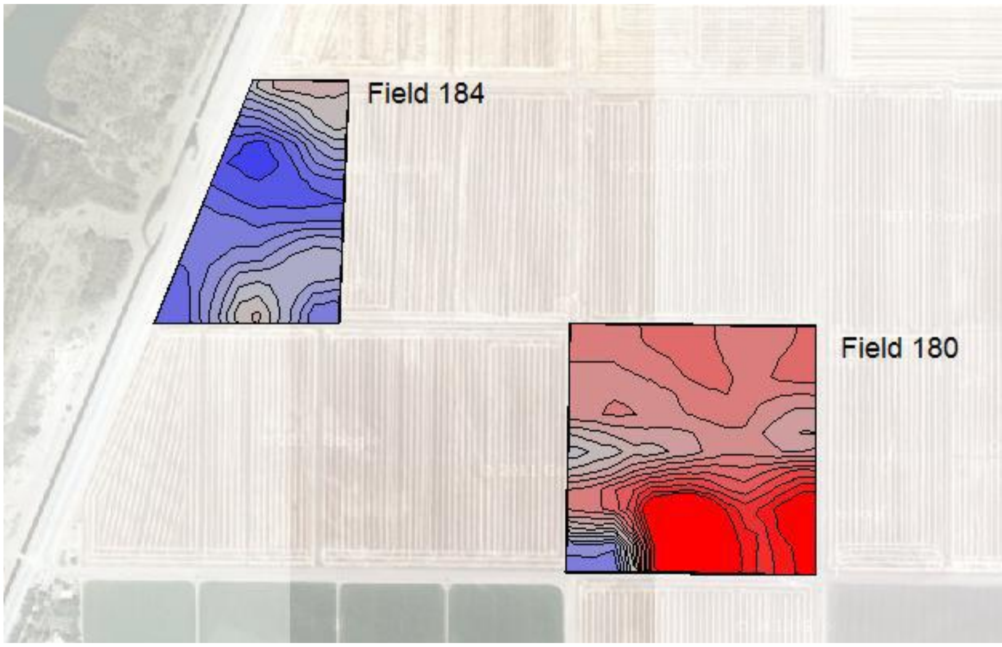
SP=saturation percentage, EC=electrical conductivity, STP=soil test phosphorus, STN=soil test nitrate.

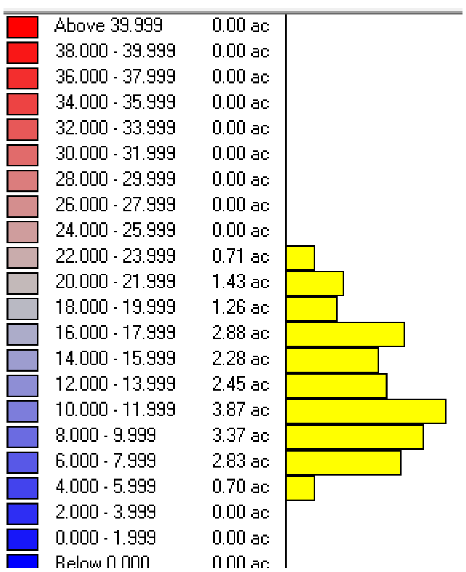
*,** Significant at the 5% and 1% levels, respectively.

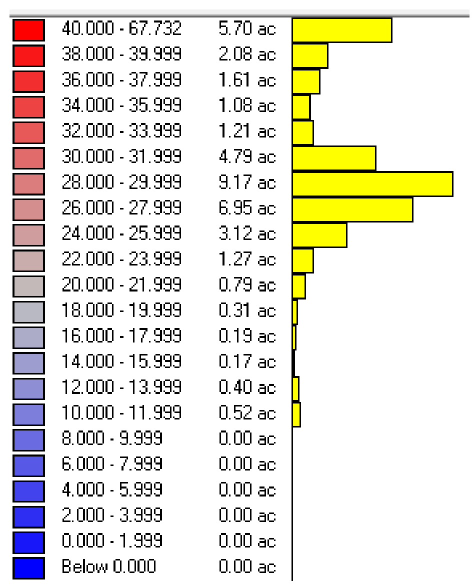


Field 141

Figure 1. Variation in soil test P in a production field (Field 141) in the Yuma Valley on one acre sampling resolution.

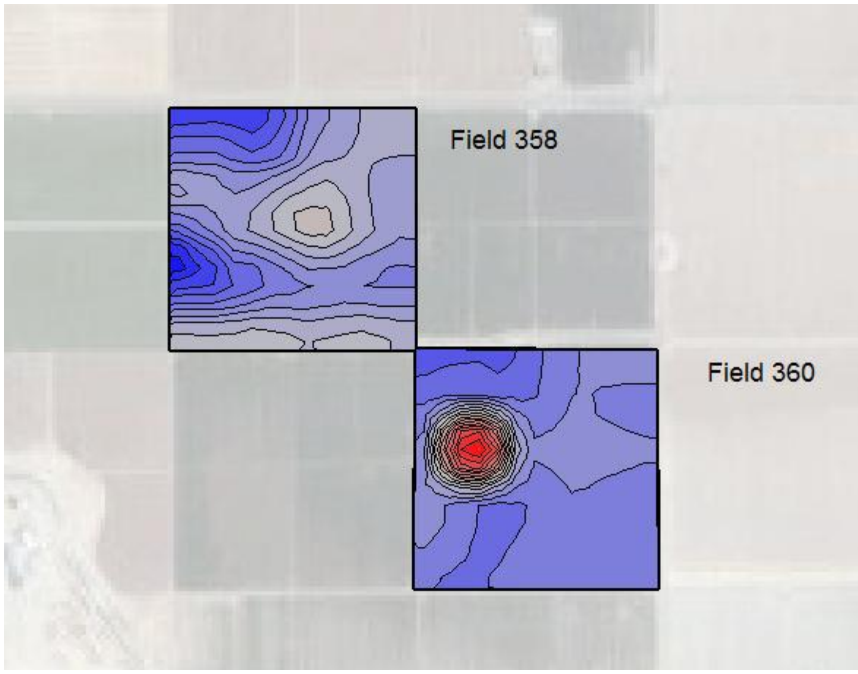


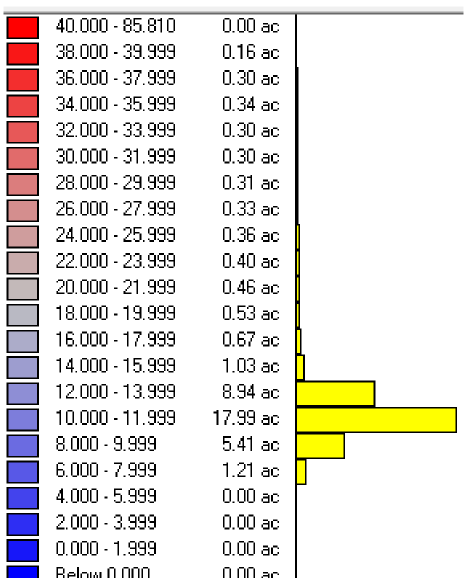




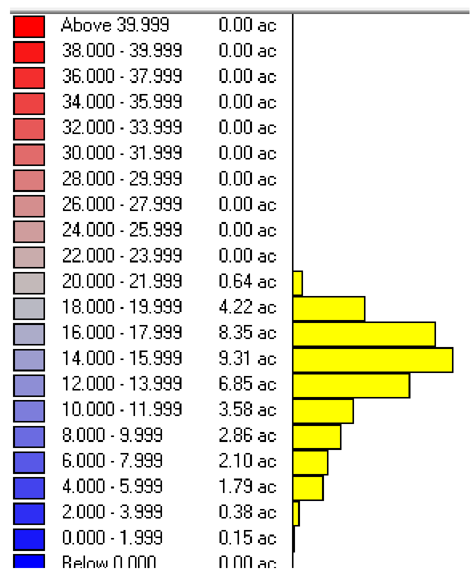
Field 184 Field 180

Figure 2. Variation in soil test P in two production (180 and 184) fields in the Yuma Valley on one acre sampling resolution.



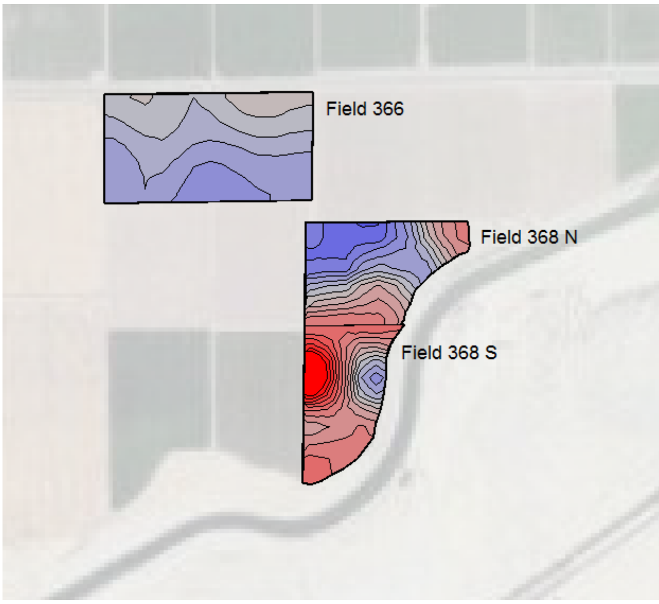


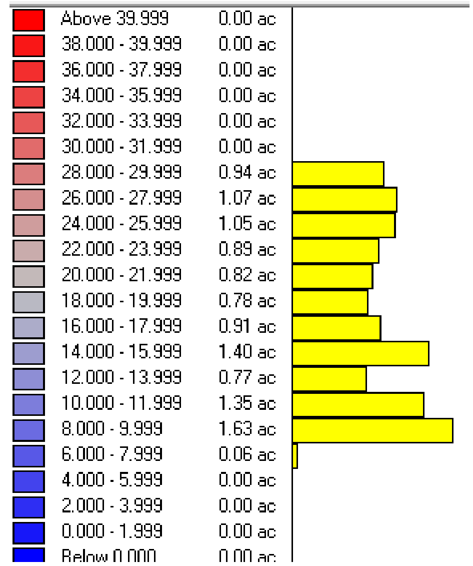
Field 360



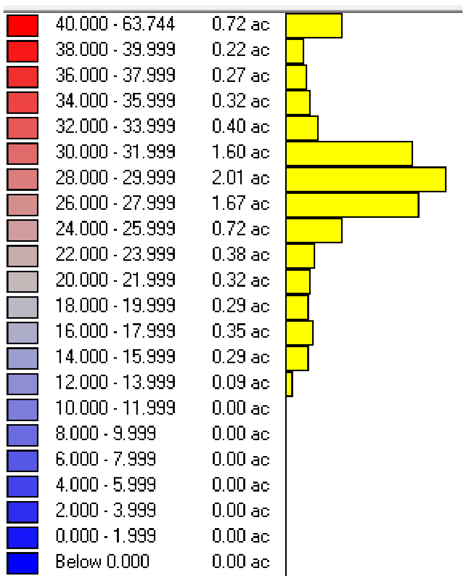
Field 358

Figure 3. Variation in two production fields (358 and 360) in the south Gila Valley on one acre sampling resolution.





Field 368N



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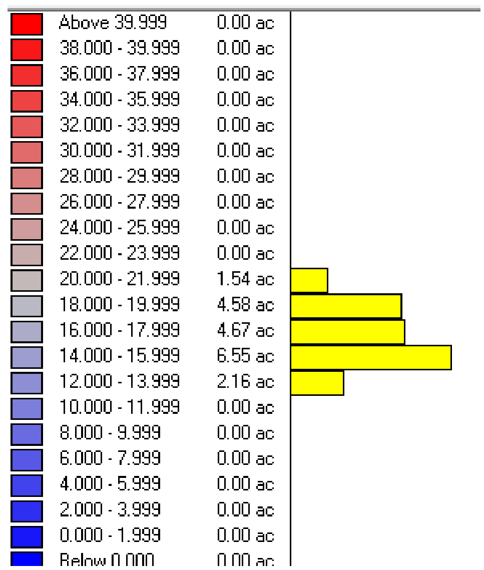
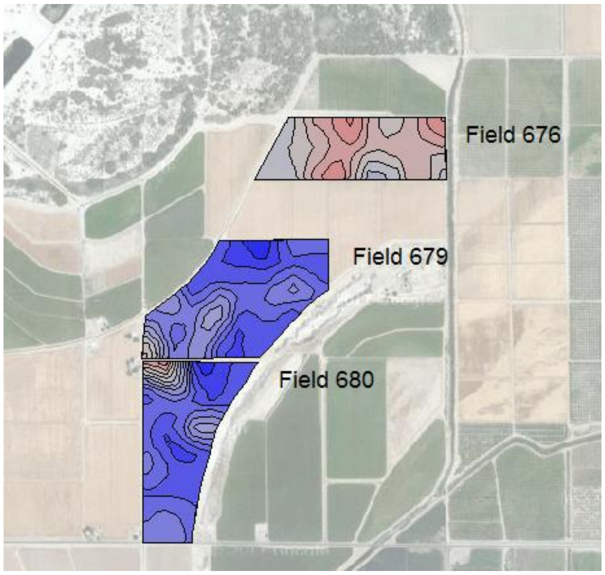
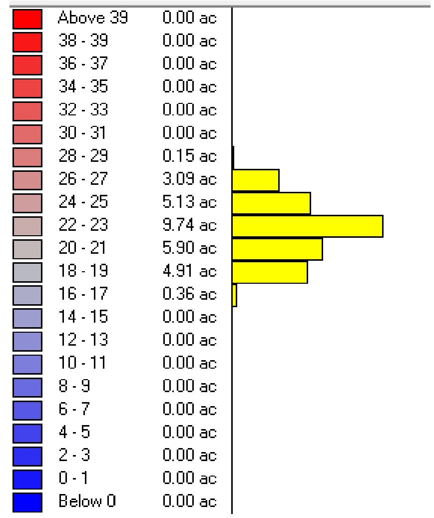


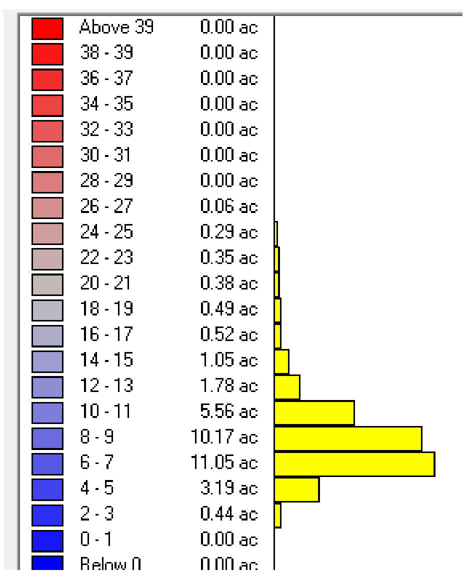
Field 366

Figure 4. Variation in soil test P in three production fields (366, 368N and 368S) in south Gila Valley on one acre sampling resolution.

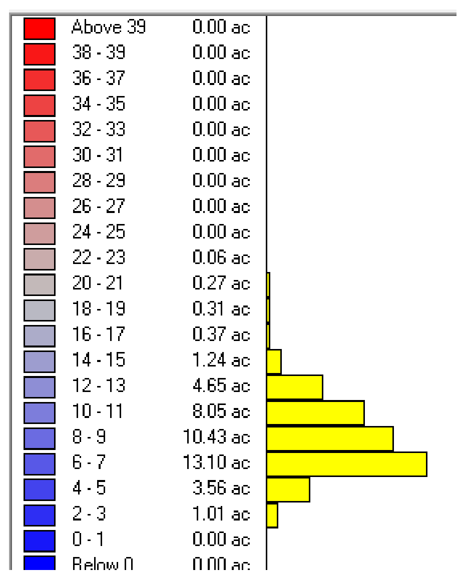




Field 676



Field 680



Field 679

Figure 5. Variation in soil test P in three production fields (676, 679, and 680) in the Bard Valley on one acre sampling resolution.

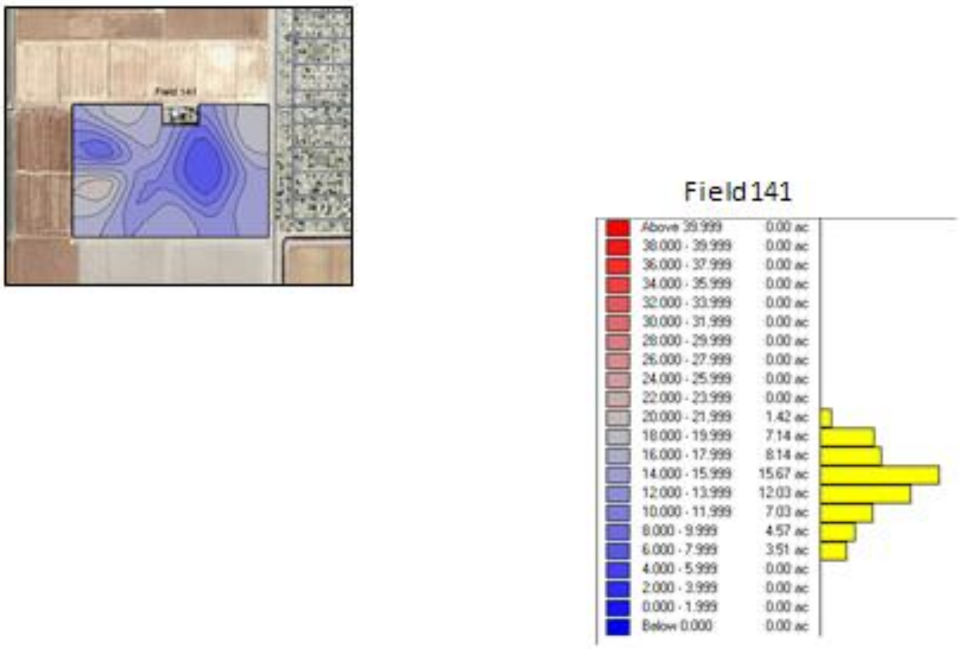


Figure 6. Variation in soil test P in a production field (Field 141) in the Yuma Valley on five acre sampling resolution.

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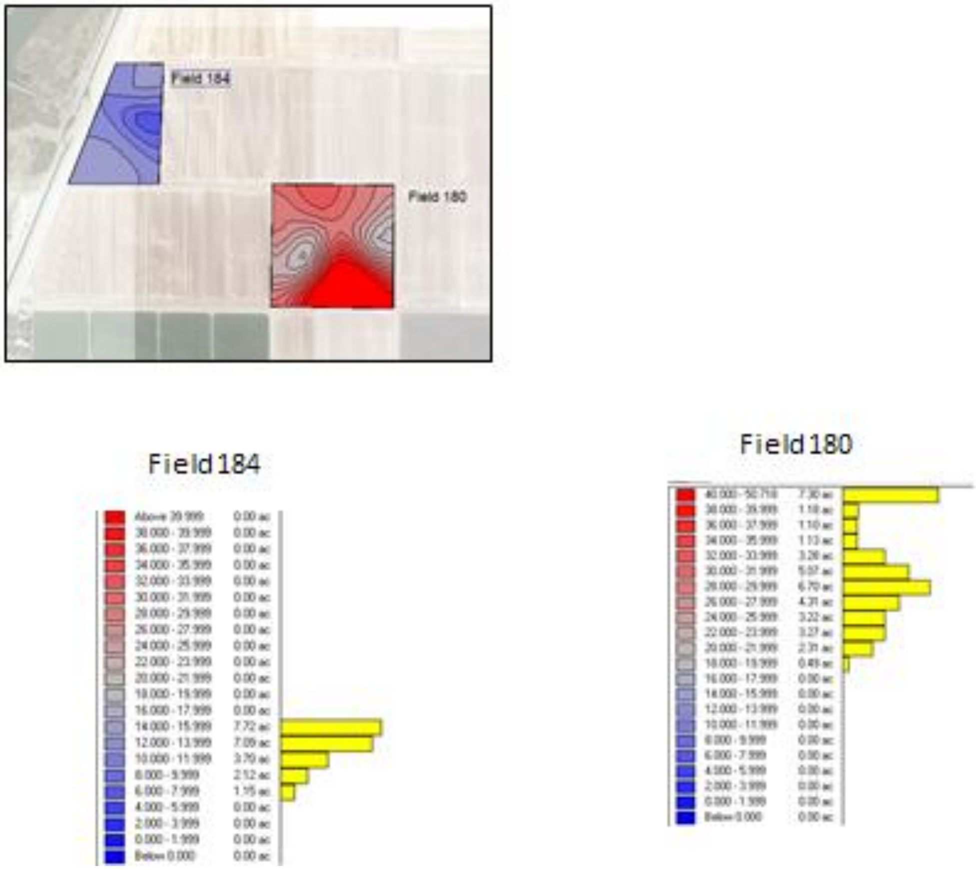

Figure 7. Variation in soil test P in two production (180 and 184) fields in the Yuma Valley on five acre sampling resolution.

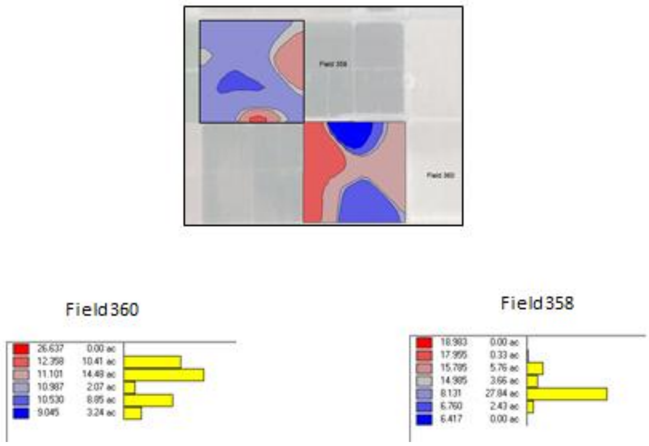

Figure 8. Variation in two production fields (358 and 360) in the south Gila Valley on five acre sampling resolution.

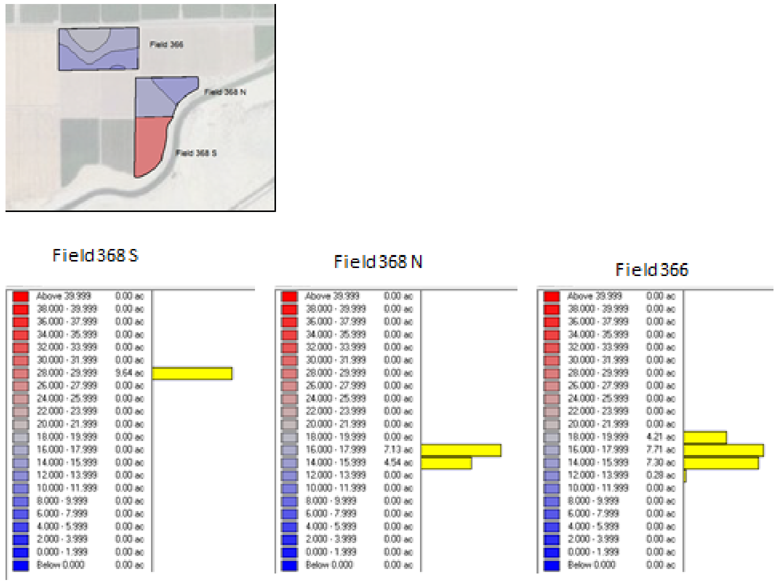

Figure 9. Variation in soil test P in three production fields (366, 368N and 368S) in south Gila Valley on five acre sampling resolution.

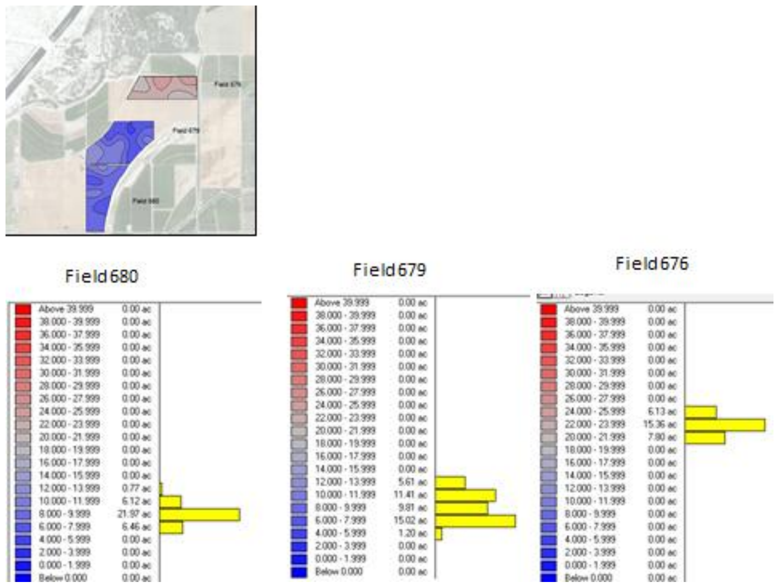

Figure 10. Variation in soil test P in three production fields (676, 679, and 680) in the Bard Valley on five acre sampling resolution.

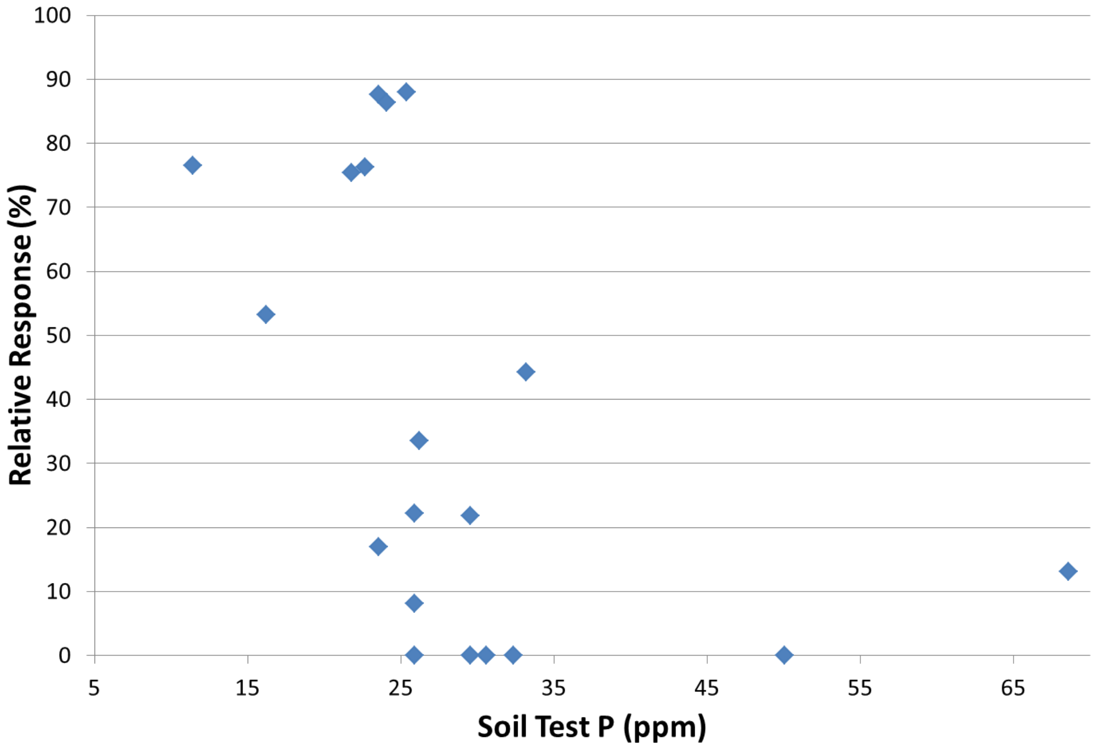

Figure 11. Relationship between soil test P and relative response of lettuce in the low desert.