Final Report for FREP 12-0386-SA

A. Project Information.

Period: January 1, 2012 March 31, 2017

Title: Development of Economically Viable Variable Rate P Application Protocols for Desert Vegetable Production Systems

Project Leaders:

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B. Objectives

The objective of this project is to 1. Develop economically viable and effective sampling protocols to generate prescription maps for the variable rate application of P, 2, Compare variable rate P application to current methods and evaluate alternative economic outcomes. In the first phase of the project we will test alternative sampling schemes. Sampling schemes evaluated will include grid sampling at various resolutions and sample schemes which seek to define management zones directed by other indices of in-field variability. In the second phase we will evaluate the efficacy and economic returns to variable rate P application. Project success will be the development of economically viable protocols for the implementation of variable rate P application technologies. The target audience will be crop advisors in the public and private sector that make fertilizer recommendations to producers, the fertilizer industry that can offer this as a value added service to producers, and growers that make production decisions on economic returns and, depending on their size may invest in infrastructure to implement this technology themselves.

C. Abstract

Vegetable crops produced in the desert receive large annual applications of phosphorus (P) fertilizers. Amounts of P applied to vegetable production systems often approach and exceed 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, some of it is carried in runoff and drainage water into receiving surface waters having adverse ecological effects. Further, erratic fertilizer pricing over the past several years has created incentives for improved efficiency. Approximately three years 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. In addition, world P reserves are

rapidly declining and there is concern that a shortage of P fertilizers will ultimately result in large fertilizer P price increases and ultimately compromise world food production.

In studies we have shown most cool seasons vegetables produced in the desert will respond to P fertilizer up to a sodium bicarbonate P soil test level of 30 to 35 mg/kg. As pre-plant soil tests approach these critical soil test P levels, the probability of crop response to P fertilizer drops dramatically. However, P fertilization based on a composite soil sample from a production unit assumes relatively uniform fertility within the unit which is inconsistent with our findings. In high resolution sampling of vegetable production fields in the desert we have found large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). Thus, if we made adjustments in pre-plant P recommendations to minimize economic losses due to under-fertilization, we would have to over-fertilize a large portion of the field. This not only has economic consequences, it can result in very high available P levels over part of the field and adverse consequences such as P induced micronutrient deficiency (particularly Zn).

The prospect of variable rate pre-plant P fertilizer application had not been evaluated in desert vegetable cropping systems. The objective of this project was to 1. Develop economically viable and effective sampling protocols to generate prescription maps for the variable rate application of P, 2, Compare variable rate P application to current methods and evaluate alternative economic outcomes. Sampling schemes evaluated included grid sampling at various resolutions and samples schemes which seek to define management zones directed by other indices of in-field variability. In a few situations, variable rate based applications resulted in a higher net P application rate than the grower standard practice (GSP) but not for most sites. The net fertilizer savings over all sites was 20% for grid and 12% for zone based sampling schemes compared to the GSP. However, the fertilizer cost savings often did not cover the additional costs involved in surveys, sampling, and sample analysis involved in grid and zone sampling based applications. Over ten sites, yields were increased very slightly by variable rate application but the differences were not statistically significant. Overall, this study demonstrated that variable rate management is a viable strategy for P management in vegetables but will be more economically viable as P fertilizer costs increase. This strategy may be immediately applicable where environmental issues restrict P fertilization rates.

D. Introduction

Vegetable crops produced in the desert receive large annual applications of phosphorus (P) fertilizers. Amounts of P applied to vegetable production systems often approach and exceed 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, some of it is carried in runoff and drainage water into receiving surface waters having adverse ecological effects. Further, erratic fertilizer pricing over the past several years has created incentives for improved efficiency. Approximately three years 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. In addition, world P reserves are rapidly declining and there is concern that a shortage of P fertilizers will ultimately result in large fertilizer P price increases and ultimately compromise world food production.

In studies we have shown most cool seasons vegetables produced in the desert will respond to P fertilizers up to a sodium bicarbonate P soil test level of 30 to 35 mg/kg. As pre-plant soil tests approach these critical soil test P levels, the probability of crop response to P fertilizer drops dramatically. However, P fertilization based on a composite soil sample from a production unit assumes relatively uniform fertility within the unit which is inconsistent with our findings. In high resolution sampling of vegetable production fields in the desert we have found large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). Thus, if we made adjustments in pre-plant P recommendations to minimize economic losses due to under-fertilization, we would have to over-fertilize a large portion of the field. This not only has economic consequences, it can result in very high available P levels over part of the field and adverse consequences such as P induced micronutrient deficiency (particularly Zn).

The prospect of variable rate pre-plant P fertilizer application had not been extensively evaluated in desert vegetable cropping systems.

E. Work Description

Task 1

Evaluate alternative sampling schemes including various resolutions of grid sampling and zone sampling based on soil properties that may serve as covariates.

During 2013-2014 four research sites were established. One was iceberg lettuce in Imperial County, CA (Bard), one was broccoli in Riverside County CA (Coachella Valley), one was romaine lettuce in Yuma AZ, and one was potato in Maricopa AZ. In September we performed soil EC surveys at the first three sites as a basis for zone sampling (Figure 1, example from Coachella Valley). The last survey for potato was performed in late January. The Veris 3100 is simple to use and user-friendly for producers but the EM-38 gives higher resolution map. It is one of our objectives to evaluate these two systems as alternatives for deriving zone-based sampling schemes. An example of the electronic surveys are shown in figure 2 for the Bard CA site.

Each production field was divided into three equal areas. For one, prescription fertilization maps would be developed based simple grid based sampling, for another they would be developed based on zone sampling, and for the third P fertilizers were applied based on the growers normal practice. Conductance measurements were processed using the USDA-ESAP program to locate soil samples for the zone sample method based on natural variability of the soil. Immediately after these surveys, we collected soil samples for both grid and zone based fertilizer application comparisons (Figure 3a and b are examples from the 2013-2014 Bard site).

The samples were analyzed for P and salinity in our laboratory. The salinity data is used to statistically distinguish salinity and soil texture as sources of variation in the electronic surveys. The P soil tests were used to develop P soil test maps and corresponding prescription maps (Figures 4 and 5 examples from the 2013-2014 Bard site). The grower in the Coachella Valley had a preference for liquid P fertilizer so we used liquid P at this site. The growers in Yuma, Bard, and Maricopa preferred dry P sources so we used dry fertilizer in these sites.

Task 2 Field testing of VRA and standard grower practice.

Field testing of VRT and grower practices were conducted during the fall-winter–spring period in 2013-2014. The sites in the Coachella Valley, Yuma, Bard, and Maricopa were planted to broccoli, romaine lettuce, iceberg lettuce, and potato respectively. In 2013-2014 we had not completed the yield monitoring systems so yield data were collected by hand on less than a 0.25 acre resolution. The romaine and broccoli were harvested in January. The iceberg lettuce was harvested in February, and the potato were harvested in July. For, potato, our grower-cooperator had filled his contract before harvesting our field and there was no market for non-contracted potato. However, he agreed to take machines into the field and he harvested a few strips for us so that we could calculate average yields from each plot.

Task 3 Repeated evaluation of alternative sampling schemes including various resolutions of grid sampling and zone sampling based on soil properties that may serve as covariates.

Filed testing on four sites was completed in 2014-2015. One site was broccoli in the Coachella Valley (Riverside County CA), one site was iceberg lettuce in the Yuma Valley, one site was iceberg lettuce in Bard (Imperial County, CA), and one site was potato in Maricopa County, AZ. All sites were surveyed and sampled as in year one and prescription maps were developed as described above. Fertilizer was applied in accordance with these prescription maps. The broccoli sites was planted in September, the lettuce in Yuma in October, and the lettuce in Bard in November. The potato site was planted in mid-February. The sites were surveyed, sampled, and prescription maps were developed as described above for 2013-2014.

This year, we mounted GPS and box counting apparatus on harvest machines. Broccoli harvests at the Coachella sites were collected January 2 through 15. Lettuce yields in Yuma were collected January 19 through 24. The second lettuce site in Bard was harvested March 11 and 12. Unfortunately, we lost the potato site this year because the grower went in and harvested without notifying us.

Tasks 4

Field testing of VRT and grower practices were again initiated in the fall 2015. One study was with iceberg lettuce in Yuma County, one study was with broccoli in the Bard Valley of Imperial County, California, and one was with spinach in the Bard Valley.

The sites were surveyed, sampled, and prescription maps were developed as described above for 2013-2014 and 2014-2015. These sites were planted in November. Harvests were completed in March 2016. We used GPS and box counting methodology developed in 2014-2015 to complete the 2015-2016 studies.

We conducted one final spinach experiment in Bard, California in fall-winter 2016-2017. The site was surveyed, sampled, and prescription maps were developed as described above for 2013-2014, 2014-2015, and 2015-2016. Again we used the GPS box counting methodology we developed in previous studies. Unfortunately, the GPS coordinates for yield were corrupted in the post processing of this data set and yield positions were assigned outside the field. We spent considerable time trying to correct this data, however, because of lingering uncertainty in the yield positions, we elected not to use this data set.

Task 5

Data from 2013 through 2016 were compiled and subjected to an economic analysis. These data included costs of P fertilizer management in each of the GSP (grower standard practice), grid, and zone management schemes and value of resulting yield. The costs of fertilization included the cost of the fertilizer, the costs of application, and where appropriate the costs of surveys, soil sampling, and sampling analysis. For the grid we assumed a sampling resolution of 1 acre and previous work we found this the best compromise between costs and accuracy. For zone we estimated a total cost of $20 per acre for surveys and sample analysis. For this analysis we assumed a range of P fertilizer prices from $0.48 to $1.44 per pound. The lower costs represents the current price of P fertilizer. For crop value we assume a range of prices. For lettuce we assumed crop value of $0.25, 0.50, and 0.75 per pound of product. For broccoli we assumed crop value of $0.40, $0.6, and $0.8 per pound. For spinach we assumed prices of $0.50, $0.70, and $0.90 per pound. Potato prices were assumed at 0.07, 0.09, and 0.11. These ranges represent historical ranges for the crops considered.

F. Data/Results

During 2013 the following was accomplished. We built and tested a combined platform for soil apparent conductance measurements with Veris 3100 and EM-38. Hardware included GPS for data geo-referencing. We set up instrumentation supported by a CAT II tractor. This included a Trimble FMX with integrated GPS receiver and variable-rate function unlocked, Field IQ, Rawson controller and associated harnesses and power connections. We also built a 3-point hitch frame to support tank, hoppers, drive shafts, pumps, soil-engaging tooling and other hardware for precise application of P fertilizer.

In September 2013 we performed soil conductance surveys at three locations for zone sampling (Figure 1). Sites were located in Imperial County, CA (Bard), Riverside County CA (Coachella Valley) and Yuma AZ.

Processed conductance measurements in USDA-ESAP was used to locate soil samples for zone sample method based on natural variability of the soil. Immediately after these surveys, we collected soil samples for both grid and zone based fertilizer application comparisons. Fertilizer applications were made using these prescription maps. Examples of surveys, sampling schemes, and fertilizer application maps for the Bard site as shown as examples in Figures 2 through 5. These steps were repeated in 2014-2015, 2015-2016, and 2016-2017.

In 2013-2014 data were collected manually as described above. Data show that yields in the zone and grid managed plots were generally similar to those obtained in the grower managed section of the field (Figures 9 to 11). These similar yields were achieved at substantially reduced rates of P fertilizer.

In the fall of 2014 we started working on the design and construction of an electronic yield monitor system for in-field evaluations (Figures 6 through 8). We developed a system whose basic components consisted of: a) GPS receiver to generate positioning data. We used a variety of Trimble systems with differential correction for sub-meter accuracy (typically within 12 in); b) Box counting hardware which consisted of either a handheld button assembly to generate counts manually, or a sensor-based approach that used laser sensors (Keyence model LR-ZB240CB) for automatic counting of boxes moving along the machine conveyers; and c) Field-ready electronic data acquisition (Campbell Scientific CR3000 and CR 1000) with serial and analog ports to accommodate GPS string data, pulses from handheld manual counters, and differential voltage generated by the laser sensors. This was a customized solution and therefore we wrote CR-basic code with specific instructions for the logger to handle the data inputs and integrate it on 10 sec intervals, which corresponded to about 9 inches in the direction of machine travel. Three units were set up to account for the possibility that multiple machines were used in the field under study. Yield maps for lettuce and broccoli from the 2014-2015 studies are shown in Figures 12 and 13. The broccoli data show a clear yield increase to grid and zone based P fertilizer application compared to grower standard practice. The results for lettuce were less conclusive. This field had very high yields and was harvested west to east over a period of a week. On day 1 of harvest only one harvest machine was used. On days two through four three harvest machines were used. By day five, five harvest machines were used because the lettuce was passing optimal maturity. Thus, on day 5 and 6, more lettuce was passed over because it was no longer of quality to harvest. This is particularly evident in the last transect of the east side of the field that required an extreme level of selectivity to pick only the best heads still standing in the field. This happened to be in the zone area.

In fall of 2015 we set up a study with broccoli and spinach in Bard, California and a lettuce study in Yuma. As previously, we conducted surveys and soil samples and applied P using prescription maps generated by zone and grid based samples. Yield data were collected using the GPS referenced box counting apparatus. The yield maps, for lettuce, broccoli, and spinach are shown in Figures 14, 15, and 16, respectively.

G. **Discussion**

Out of 12 field experiments put out between 2013 and 2016, we got meaningful yield data from ten studies. A potato study put out in 2015 was lost because the grower went in and harvested it without notifying us. In 2017, the GPS coordinates corresponding to yield in a spinach trail were corrupted in the post processing operations and after spending considerable time trying to rescue this data set, we has to conclude that we had no confidence in the yield results of this study and we declined to utilize them in the final conclusion. Since these two studies lacked yield information, they will not be addressed further in our discussion.

Interestingly, in three studies at least one of the variable rate application strategies (grid, zone, or both) resulted in more applied P fertilizer then the GSP. Based on University calibrated soil test based fertilizer recommendations, it would seem that the grower under-fertilized portions of the field in these situations. Considering all 10 sites combined, grid based fertilizer application resulted in 20% less P fertilizer and zone 12% less P than the grower standard practice. It is reasonable to conclude that, overall, variable rate application technologies would reduce P use over the longer term. However, comparing fertilization costs among all strategies, these fertilizer savings compared to GSP, would not cover the additional costs of surveys, sampling, and sample analysis associated with variable rate strategies at current fertilizer prices. P fertilizer costs would have in increase appreciably for variable rate applications to be economically justified (Table 2). In some regions P fertilizer applications are restricted due to the impact of P fertilizer on surface water and in this instance variable rate application would be a viable means to reduce fertilizer P inputs while minimizing or eliminating adverse yield impacts. These particular environmental issues are not of concern in the desert, where P runoff from agricultural fields is negligible.

At noted previously, in 2013-2014 all yields were collected by hand on the same day in each site. The broccoli in the Coachella valley was harvested twice but the commercial harvests stayed out of our flagged areas for our 2nd harvest. From 2014 through 2016, yields were collected with GPS referenced box counting apparatus installed on commercial harvesting machines. However, in hindsight we have concluded that these yield should be interpreted with caution because for fresh vegetables, the crops can change over the harvest period, and yields can be impacted by time as much or more as by P treatment. As noted above, this was the case for lettuce in 2014-2015. This field had very high yields and was harvested west to east over a period of a week. On day one of harvest, only one harvest machine was used. On days two through four three harvest machines were used. By day five, five harvest machines were used because the lettuce was passing optimal maturity. Thus, on day 5 and 6, more lettuce was passed over because it was no met of quality standards (over mature) and these passes were located in the grid and zone areas. Most of the other harvest occurred over a period of three days or less, and in all of these experiments variable rate applications resulted in similar or only slightly higher yields than GSP.

Looking at all data, including the lettuce data from 2014-2015, including where delayed harvest compromised yields in the grid and zone treatments, yields for grid averaged 2% higher and zone less than 1%, higher, than the GSP. However, because variation within plots exceeded 10%, we cannot conclude yield differences are statistically significant. Using these data to estimate hypothetical returns we see that in some years profits were reduced and in some years increased by grid and zone compared to the control (Table 3). However, because we cannot conclude yields were significantly different, the best economic indicator is the cost of fertilizer application for each treatment shown in Table 2. With current P fertilizer prices, the cost of employing variable rate technologies usually exceeded the value of the fertilizer saved.

H. Project Impacts

We demonstrated the feasibility of variable rate P fertilizer practices in desert vegetable production systems. The economic viability will increase as P fertilizer prices increase and technology developments continue.

I. Outreach

We conducted four formal outreach activities associated with this project during 2014. These included presentations at the SW Ag Summit in Yuma on February 27, 2014, the Western Plant Health meeting in Yuma on March 4, 2013, and the Desert Ag Conference in Chandler Arizona on May 8, 2014, and the Fall Pre-season Vegetable Workshop in Yuma on Sept. 4, 2014.

Outreach activities conducted during 2015 included presentations at the southwestern Ag Summit on February 26, 2015, the Desert Ag Conference in Chandler on May 7, 2015, the FREP annual conference on November 6, 2015 and the CCA Nutrient Seminar in Ontario California on November 17, 2015.

Another presentation was made as the SW Ag Summit on February 23, 2016. In addition to these field days we have work with growers in the field on demonstration and training with respect to the technologies developed and deployed.

J. Factsheet Database Template

1. Project Title: Development of Economically Viable Variable Rate P Application Protocols for Desert Vegetable Production Systems

2. Grant Agreement Number FREP 12-0386-SA

3. Project Leaders Charles A. Sanchez, Professor, University of Arizona, Maricopa Agricultural Center, 37860 W Smith Enke Rd, Maricopa, AZ 85138, phone 928-941-2090, e-mail sanchez@ag.arizona.edu

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pandrade@ag.arizona.edu

4. Start/end date — January 2012 through March 2017

5. Project Location — Low Desert Region of Southwestern US

6. Counties — Imperial and Riverside Counties, CA, Yuma and Pinal Counties AZ

7. Highlights — Variable rate P application technologies will work for desert vegetables.

8. Introduction

Vegetable crops produced in the desert receive large annual applications of phosphorus (P) fertilizers. Amounts of P applied to vegetable production systems often approach and exceed 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, some of it is carried in runoff and drainage water into receiving surface waters having adverse ecological effects. Further, erratic fertilizer pricing over the past several years has created incentives for improved efficiency. Approximately three years 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. In addition, world P reserves are rapidly declining and there is concern that a shortage of P fertilizers will ultimately result in large fertilizer P price increases and ultimately compromise world food production.

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The prospect of variable rate pre-plant P fertilizer application had not been extensively evaluated in desert vegetable cropping systems.

9. Methods/Management

From 2013 to 2017 studies were conducted in commercial produce fields with grower cooperators to evaluate variable rate P fertilizer practices and compare them to grower standard P fertilizer practices. Studies were conducted with lettuce, broccoli, spinach, and potato. Sites included, the Coachella Valley, CA, Bard, CA, Yuma Valley, and Maricopa Valley. Sampling schemes evaluated included grid sampling at various resolutions and samples schemes which seek to define management zones directed by other indices of in-field variability. Each production field was divided into three equal areas. For one, prescription fertilization maps would be developed based simple grid based sampling, for another they would be developed based on zone sampling, and for the third P fertilizers were applied based on the growers normal practice. The P soil tests were used to develop P soil test maps and corresponding prescription maps.

10. Findings

In a few situations, variable rate based applications resulted in a higher net P application rate than the grower standard practice (GSP) but not for most sites. The net fertilizer savings over all sites was 20% for grid and 12% for zone based sampling schemes compared to the GSP. However, the fertilizer cost savings often did not usually cover the addition costs involved in surveys, sampling, and sample analysis involved in grid and zone sampling based applications. Over all ten sites, yields were increased slightly by variable rate application but the differences were not statistically significant. Overall, this study demonstrated that variable rate management is a viable strategy for P management in vegetables but will be more economically viable as P fertilizer costs increase. This strategy may be immediately applicable where environmental issues restrict P fertilization rates.

Figure 1. Veris and EM38 survey in the Coachella Valley, Riverside County, CA.

Figure 2. Results from electronic survey in zone sampling area in Bard, CA site.

Figure 3. A comparison of grid and zone sampling schemes at the Bard, CA site.

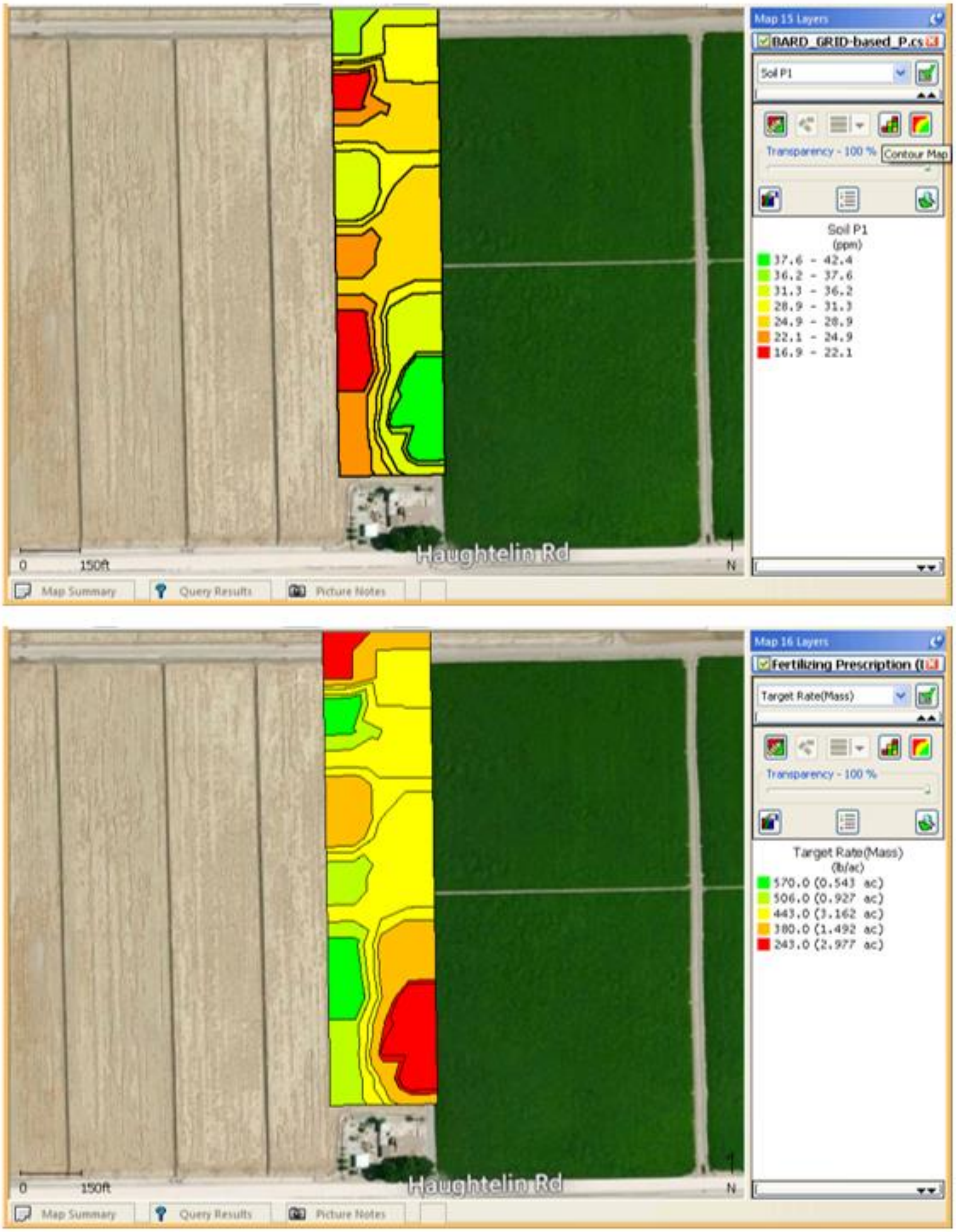


Figure 4. Interpolated soil test P values based on zone samples and corresponding prescription P fertilization map for Bard grid site.

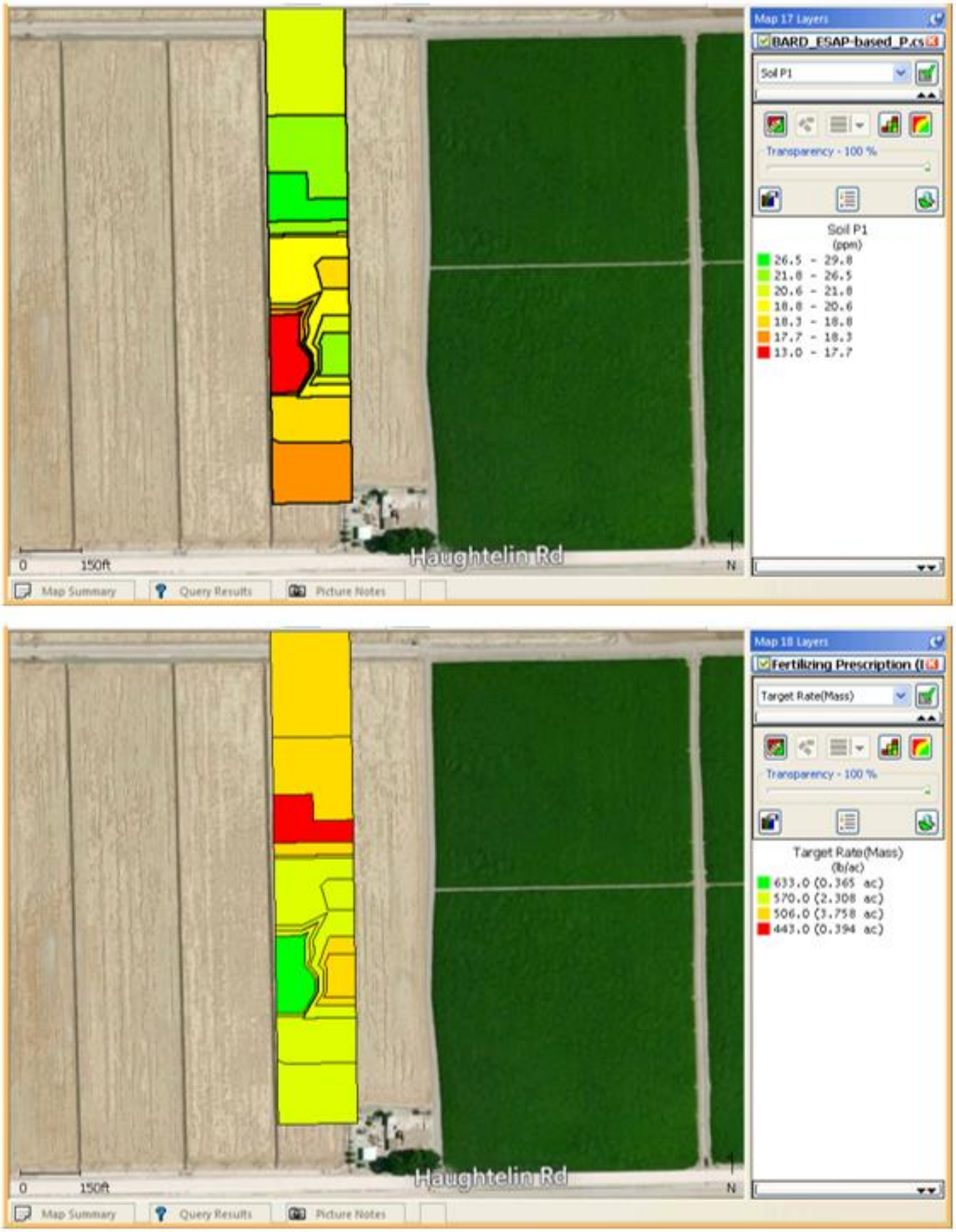


Figure 5. Interpolated soil test P values based on zone samples and corresponding prescription P fertilization map for Bard zone site.

Figure 6. Laser system tested in broccoli harvest in 2015.

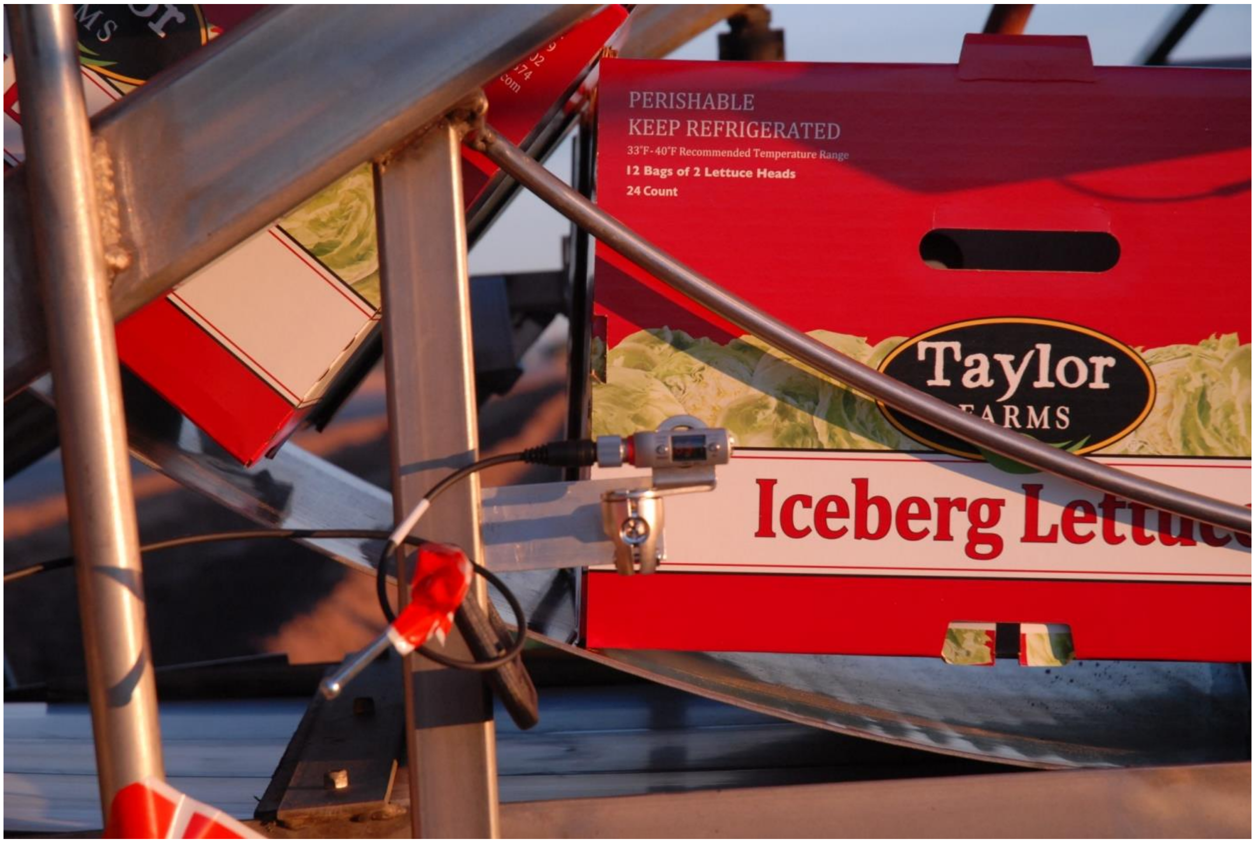


Figure 7. One of the box counting systems tested in lettuce in 2015.

Figure 8. GPS system on harvesting machines.

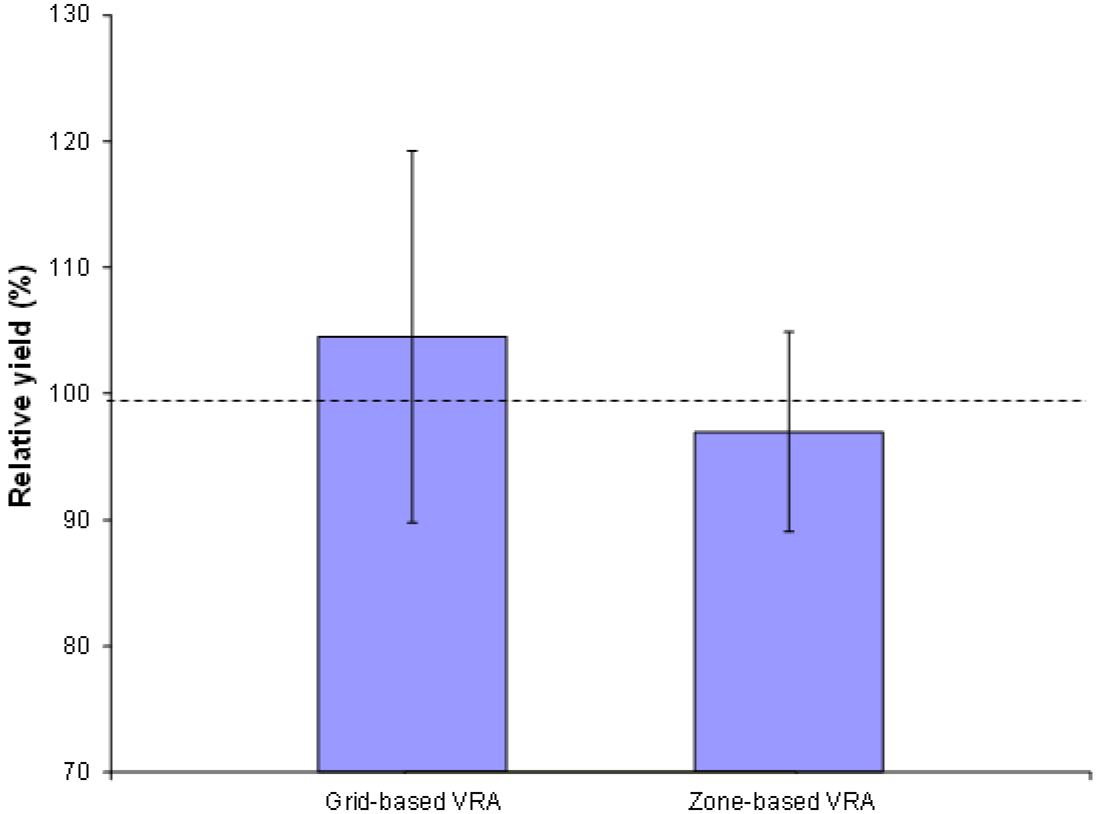


Figure 9. Comparison of total relative yield from grid and zone based fertilization schemes compared to grower practice in Coachella Valley site in 2013-2014.

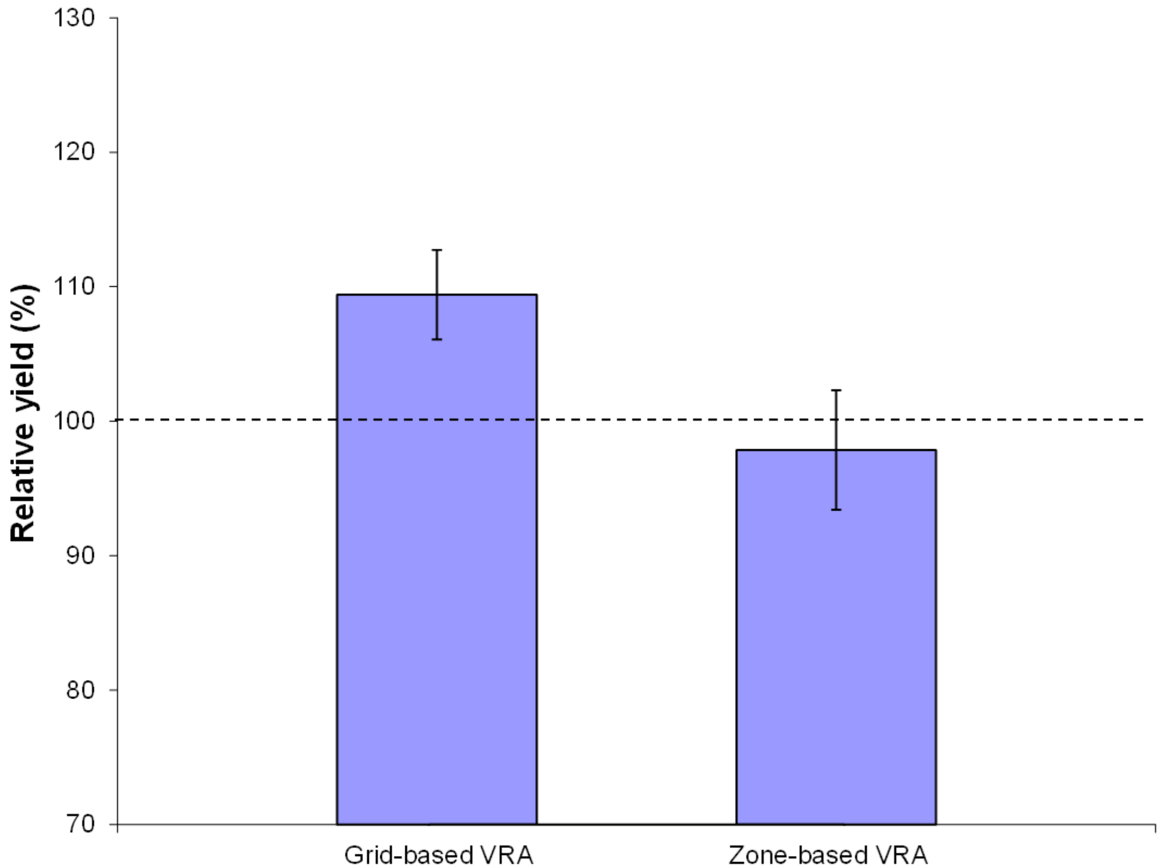


Figure 10. Comparison of total relative yields from grid and zone based fertilization schemes compared to grower practice in Yuma alley site in 2013-2014.

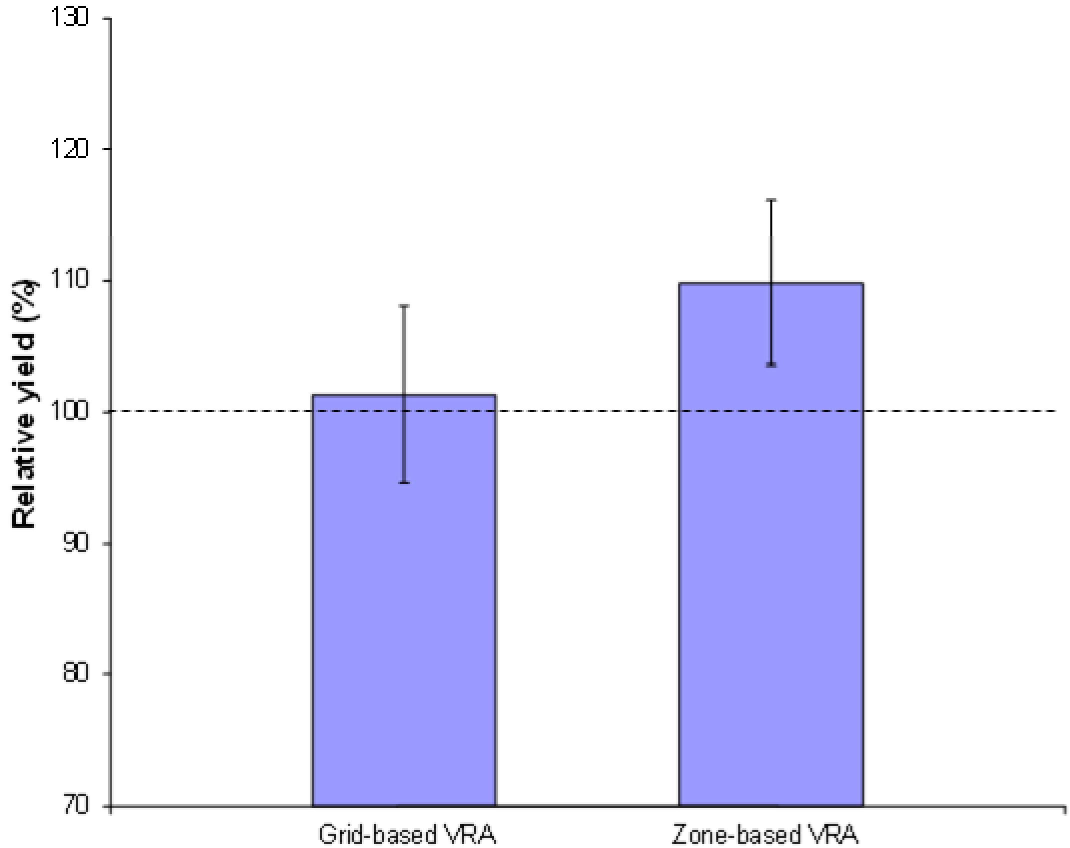


Figure 11. Comparison of total relative yields from grid and zone based fertilization schemes compared to grower practice in Bard Valley site in 2013-2014.

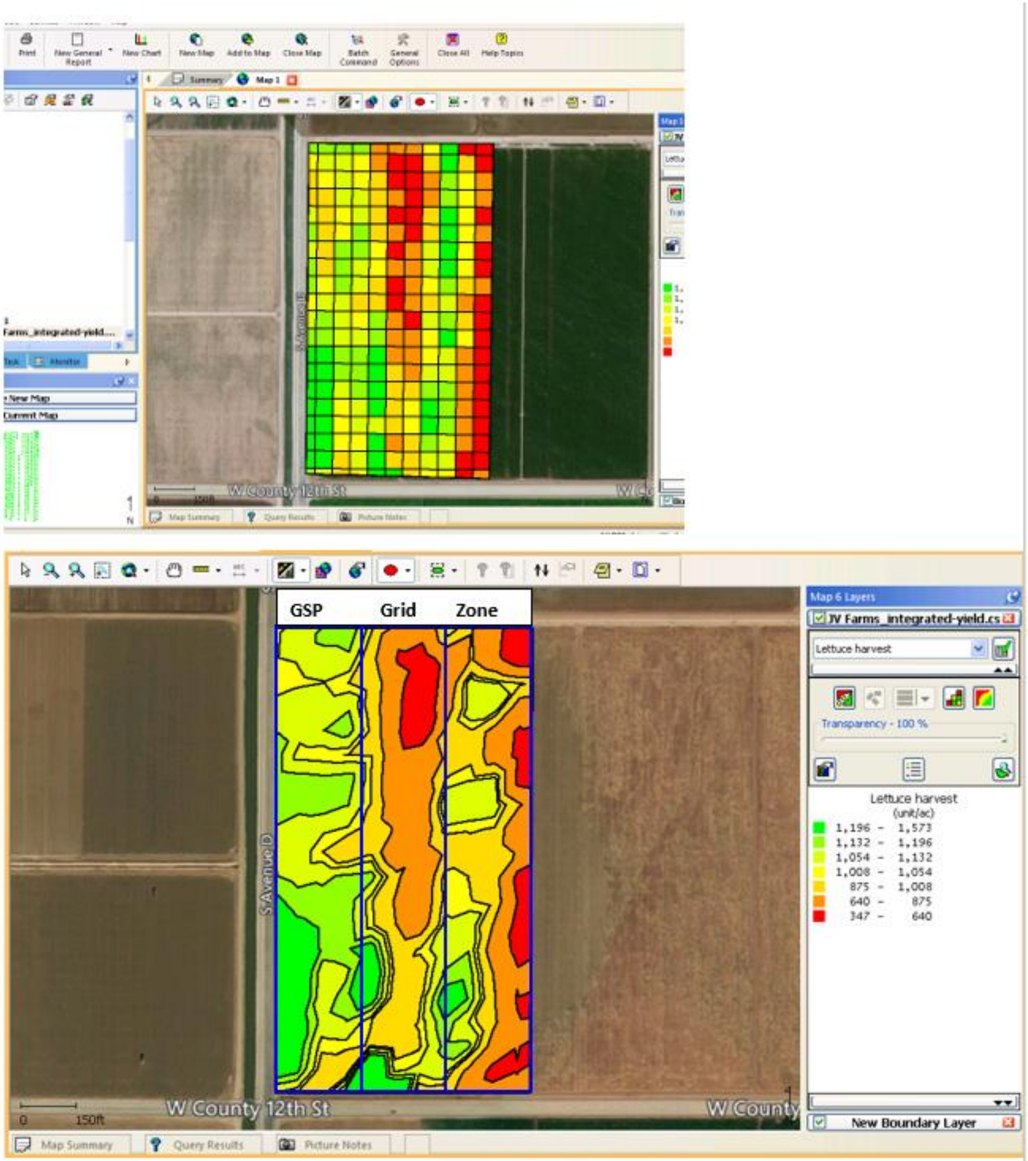


Figure 12. Lettuce yields in 2014-2015 study.

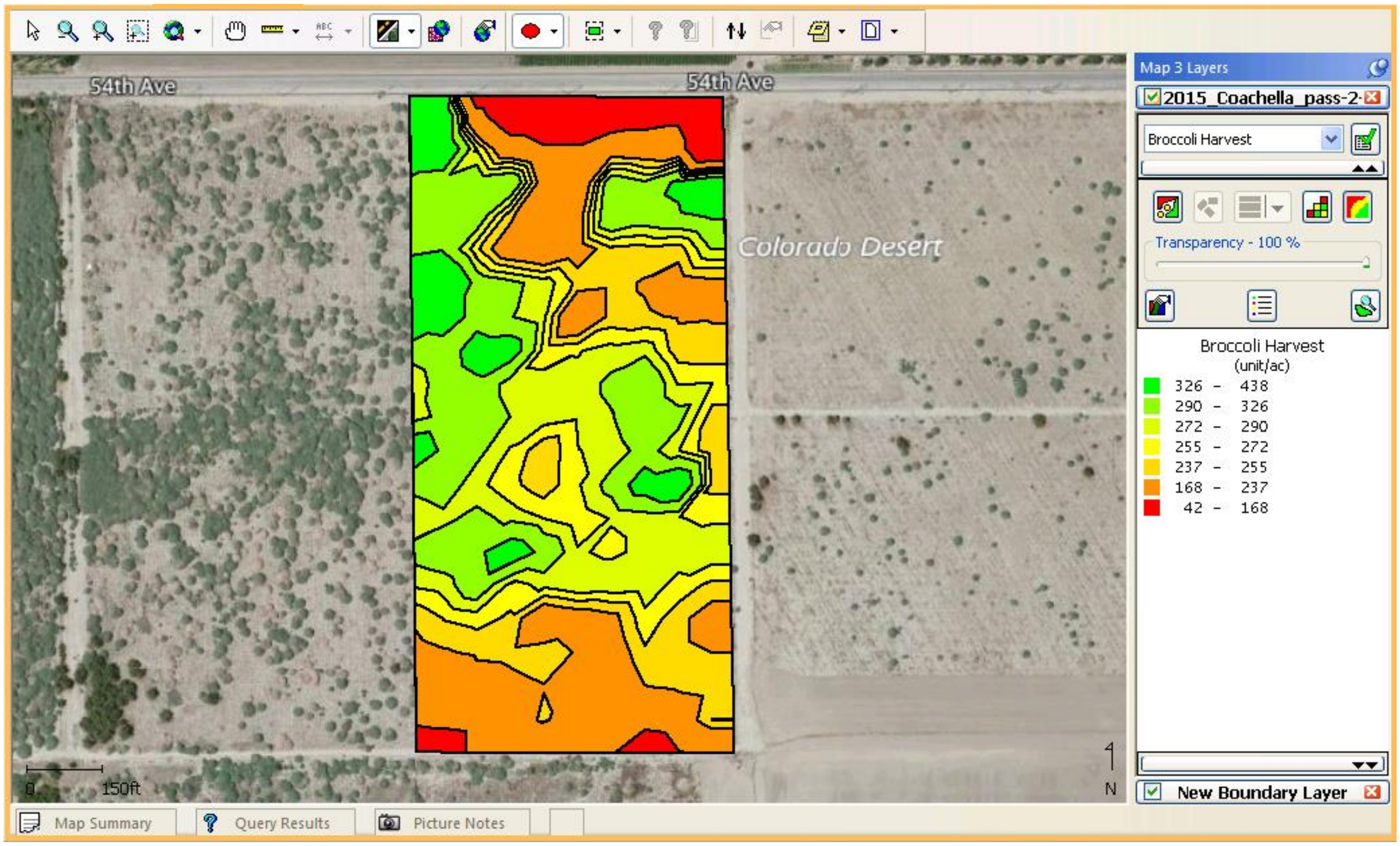
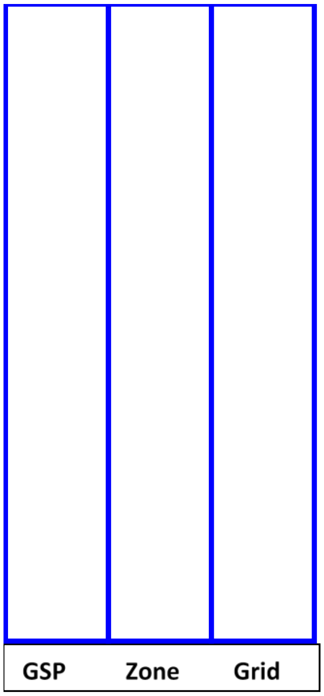


Figure 13. Broccoli yields in 2014-2015 study.



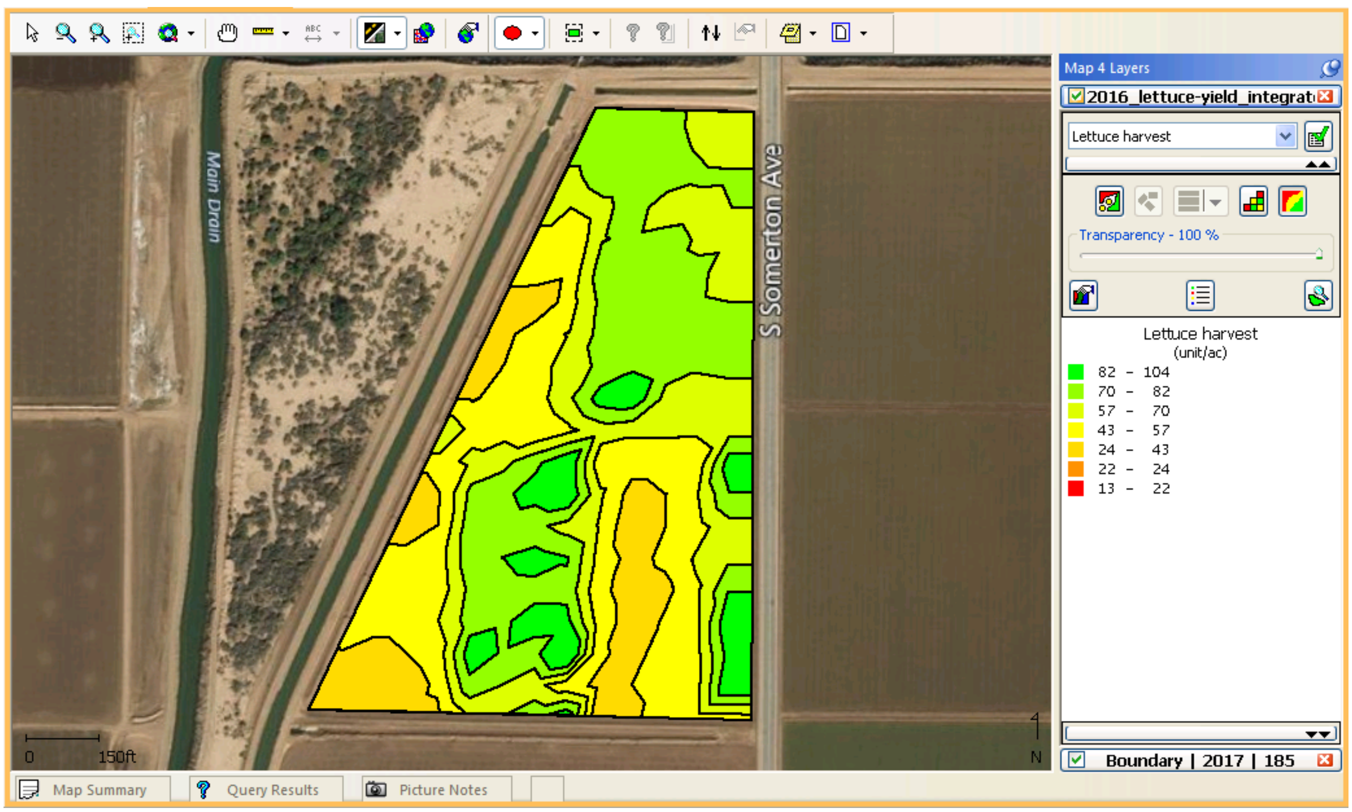


Figure 14. Lettuce yields in 2015-2016 study.

Figure 15. Broccoli yield in 2015-2016 study.

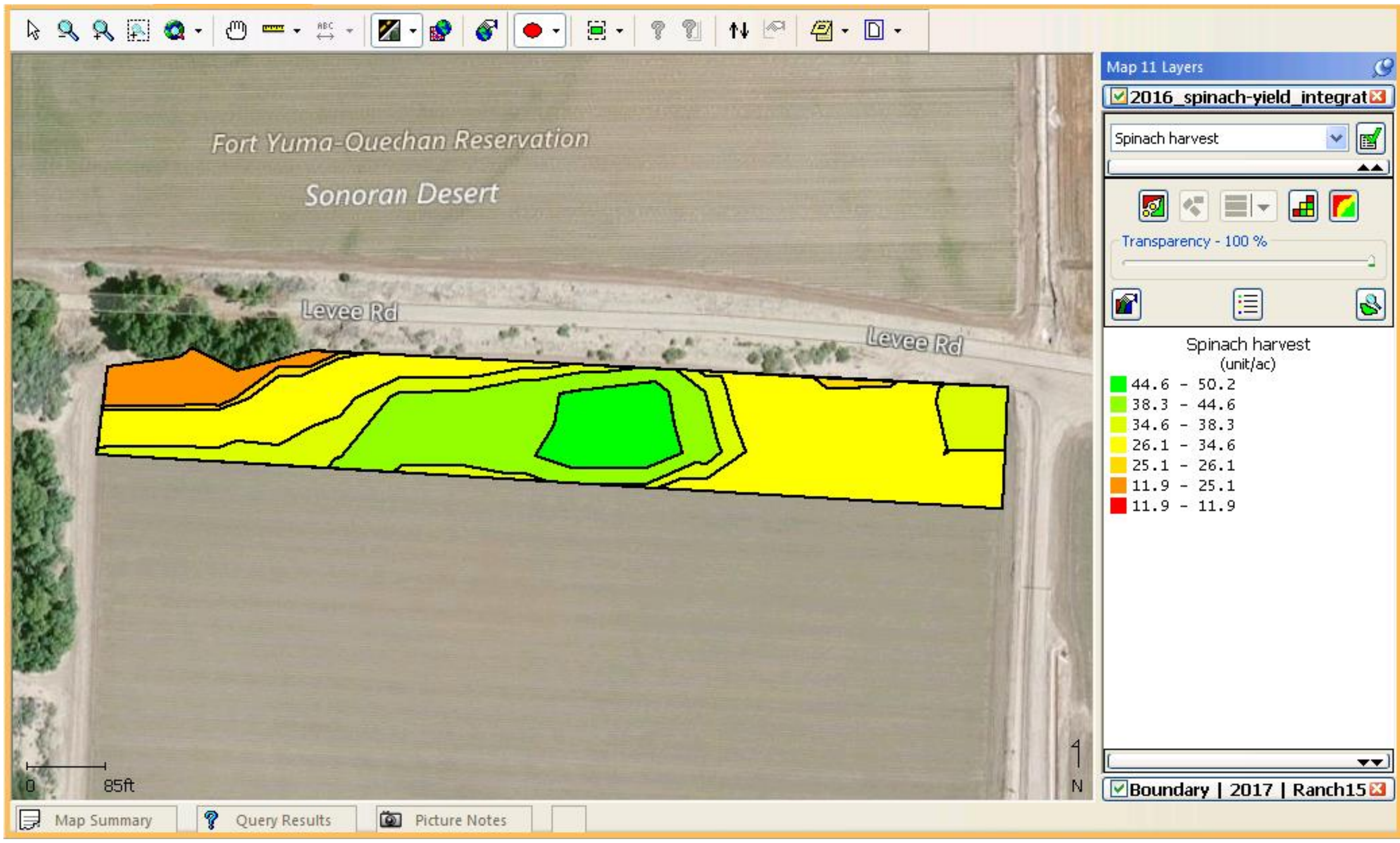


Figure 16. Spinach yield in 2015-2016 study.

Table 1. Experiment, crop, fertilizer applied, and yield.

Experiment	Location	Crop	Sample Scheme	# Soil Samples	Area (A)	Fertilizer Applied Mean (lbs P2O5/A)	Fertilizer Applied Range (lbs P2O5/A)	Yield Mean (lbs/A)	Yield CV (%)
2013-2014									
1	Yuma, AZ	Romaine Lettuce	GSP	1	5.0	277	277	46,074	8
			Grid	24	5.58	233	196-293	50,407	6
			Zone	12	5.68	227	175-233	45,084	9
2	Coachella CA	Broccoli	GSP	1		207	207	26,577	12
			Grid	26	4.22	85	41-165	27,777	28
			Zone	12	4.22	107	83-165	25,775	14
3	Bard, CA	Iceberg Lettuce	GSP	1	6.00	156	156	42,533	13
			Grid	22	6.06	216	100-263	42,484	12
			Zone	12	5.79	275	204-291	46,202	11
4	Maricopa AZ	Potato	GSP	1	8.24	112	112	32,000	-
			Grid	40	8.24	17	0-97	29,319	8
			Zone	20	8.24	31	0-112	39,291	3

2014-2015

5	Yuma, AZ	Iceberg Lettuce	GSP	1	6.0	233	**233**	50,265	21
			Grid	22	6.02	210	99-286	43,065	36
			Zone	12	5.59	244	208-260	40,995	37
6	Coachella CA	Broccoli 1	GSP	1	5.78	207	207	9,768	21
			Grid	28	5.78	193	165-207	11,946	25
			Zone	12	5.78	192	124-207	9,724	37
7	Bard, CA	Iceberg Lettuce	GSP	1	5.78	156	156	37,800	--
			Grid	22	5.78	154	100-208	35,010	19
			Zone	12	5.77	169	100-234	31,860	25

2015-2016

8	Yuma, AZ	Iceberg Lettuce	GSP	1	5.90	207	207	49,300	39
			Grid	20	5.89	125	100-156	54,400	40
			Zone	12	5.90	124	100-156	52,700	32
9	Bard, CA	Broccoli	GSP	1	9.32	156	208	8,580	28
			Grid	20	9.32	192	100-208	8,822	38
			Zone	12	9.32	203	100-208	10,604	24
10	Bard, CA	Spinach	GSP	1	0.70	208	208	9,840	14
			Grid	20	0.82	159	50-182	17,040	39
			Zone	12	0.76	159	50-182	13,120	52

Table 2. Costs of P fertilization at three prices of P fertilizer

Experiment	Treatment	P at 0.48/lb	P at 0.96/lb	P at 1.44/lb
1	GSP	153	286	419
	Grid	152	264	376
	Zone	149	258	367
2	GSP	119	219	318
	Grid	81	122	162
	Zone	91	143	194
3	GSP	95	170	244
	Grid	144	247	351
	Zone	172	304	436
4	GSP	74	128	181
	Grid	48	56	64
	Zone	55	70	85
5	GSP	132	244	356
	Grid	141	241	342
	Zone	157	274	391
6	GSP	119	219	318
	Grid	133	225	318
	Zone	132	224	316
7	GSP	95	170	245
	Grid	114	188	262
	Zone	121	202	283
8	GSP	119	219	318
	Grid	100	160	220
	Zone	100	159	219
9	GSP	95	170	245
	Grid	132	224	316
	Zone	137	225	332
10	GSP	120	220	320
	Grid	116	193	269
	Zone	116	193	269
11	GSP	120	220	320
	Grid	98	156	214
	Zone	112	184	256
Average	GSP	113	206	298
	Grid	114	189	263
	Zone5	122	204	286

The total costs include costs of fertilizer, costs, of application, and where appropriate costs of survey, and costs soil sampling, and sample analysis.

Table 3. Economic returns to grid and zone P fertilizer management compared to GSP in each experiment.

		P at 0.48 per pound			P at 0.96 per pound			P at 1.44 per pound		
Exp.		Crop at Price/pound			Crop at Price/pound			Crop at Price/pound		
		1	2	3	1	2	3	1	2	3
1	Grid	1085	2168	3250	1107	2190	3273	1150	2233	3316
	Zone	-243	-491	-739	-216	-463	-711	-164	-411	-659
2	Grid	519	759	999	616	856	1096	771	1011	1251
	Zone	-293	-453	-614	-217	-377	-538	-93	-253	-414
3	Grid	-61	-73	-86	-139	-151	-163	-245	-257	-270
	Zone	840	1757	2674	706	1623	2541	514	1432	2349
4	Grid	-162	-215	-269	-91	-145	-198	26	-27	-81
	Zone	530	675	820	587	723	878	684	829	975
5	Grid	-1809	-3609	-5409	-1807	-3607	-5407	-1794	-3594	-5394
	Zone	-2343	-4660	-6978	-2373	-4691	-7008	-2409	-4727	-7044
6	Grid	858	1294	1729	851	1287	1723	852	1287	1723
	Zone	-30.4	-39.2	-48	-36	-45	-54	-34	-43	-52
7	Grid	-717	-1414	-2112	-735	-1432	-2130	-752	-1449	-2147
	Zone	-1511	-2996	-4481	-1544	-3029	-4514	-1582	-3067	-4552
8	Grid	1294	2569	3844	1353	2628	3903	1451	2726	4002
	Zone	870	1720	2570	930	1780	2630	1029	1879	2729
9	Grid	60	108	156	5	53.4	102	-67	-18	30
	Zone	767	1172	1577	702	1107	1511	614	1019	1423
10	Grid	3604	5044	6484	3631	5071	6510	3681	5121	6561
	Zone	1644	2300	2956	1671	2326	2983	1721	2377	3033
All	Grid	518	603	780	435	613	792	507	639	817
	Zone	25	-92	-206	19	-94	-207	25	-87	-200

For lettuce we assumed P1, P2, and P3 of $0.25, 0.50, and 0.75 per pound of product. For broccoli we assumed P1, P2, and P3 of $0.40, $0.6, and $0.8 per pound. For spinach we assumed P1, P2, and P3 were $0.50, $0.70, and $0.90 per pound. For potato P1, P2, and P3 are 0.07, 0.09, and 0.11 per pound.