SITE-SPECIFIC FERTILIZATION OF ALFALFA FIELDS: IMPROVED YIELD AT LOWER COSTS?

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ABSTRACT

Alfalfa accounts for the largest cropping area in both the High Desert and Intermountain regions in California, and the use of site-specific management (SSM) can potentially improve growers' fertilization practices. There are limited to no studies regarding nutrient SSM in California, and variable rate (VR) fertilizer application has not been commonly used by alfalfa farmers. Considerable range of soil nutrient levels have been indentified in some alfalfa fields in California, however, this variability has not been considered for nutrient management. The objectives of this project were to assess soil phosphorus (P) and potassium (K) variability, compare fertilizer usage and costs between VR and uniform rate (UR) fertilizer application methods, and to compare three soil sampling densities in order to establish a pattern for future soil sampling for nutrient variability assessment in alfalfa fields in the High Desert and Intermountain regions. Two hundred and four samples were collected in five alfalfa fields located in Los Angeles and Siskiyou Counties, CA, based on a sampling grid density of 1 sample/3 acres. Most of the soil P and K variability and fertilizer savings due to VR occurred in Intermountain alfalfa fields. Overall, maps produced with sampling densities of 3 and 6 acres/sample were very similar for most of the fields. Total fertilizer savings due to VR application in all 5 fields (610 acres) was $3,385. In addition, the more intensive soil sampling of the VR method identified areas of the fields that were deficient, which would have been overlooked with the UR method. The variable rate fertilizer application method shows significant potential for alfalfa production to enable growers to tailor fertilizer application rates to the actual soil fertility of the fields.

Keywords: Site-Specific Management (SSM), Soil Spatial Variability, Soil Grid Sampling, Soil Sampling Density, Variable Rate (VR), Uniform Rate (UR).

INTRODUCTION

Alfalfa accounts for the largest cropping area in both the High Desert and Intermountain regions in California. Those areas have limited to no studies regarding nutrient Site-Specific Management (SSM), and variable rate (VR) fertilizer application has not been commonly used by growers in either area. Although the use of precision agriculture techniques has become common practice in the Midwestern US, growers and researchers in California have largely not adopted the technology but should consider exploring the benefits of this technique to support a more competitive alfalfa forage production system.

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Site-specific management considers field and soil spatial variability for crop management. Soil formation and differentiation is the result of natural and man-made factors including relief, parent material, climate and management practices like land leveling, fertilization, tillage and crop rotation (Jenny, 1941). Therefore, soil fertility variability are expected to be regional, and it is essential to understand how to assess soil nutrients spatial variability in order to provide growers with applicable local information for SSM.

Soil grid sampling assumes that the areas sampled can predict unsampled areas, and it should be considered when the location of variation is unknown and when future management can address the spatial variability. Although grid sampling is more costly and time consuming than field composite or stratified/zone sampling (due to a considerably higher number of soil sampling and analysis), it can be a superior method to assess soil fertility if an adequate grid density is used. Elevation and topography maps, yield maps, soils type maps, electrical conductivity maps, aerial imageries and grower's knowledge of the field are valuable information to identify soils and crop differences throughout the field and could be used to direct soil sampling locations for different types of assessment. This method is called stratified or zone composite sampling, and fewer samples are used by assuming that soil properties are homogeneous inside the delineated zones. However, there is no guarantee that this technique can adequately predict soil fertility. For example, soil electrical conductivity can be closely related to soil K, since it has a high correlation with soil salinity and soil texture, however, it may not be useful for predicting P. Similarly, the USDA soil survey maps have useful information for assessing general soil characteristics, however the accuracy of those maps may not be satisfactory for making management decisions on agricultural fields (different scales). Therefore, grid sampling is a better and more accurate option to assess soil fertility (except for nitrogen) for the first time, and the maps developed could be used in following years to direct the next soil sampling, together with any other type of pertinent data.

Knowing the costs involved in using UR versus VR fertilizer application is basic information needed to decide whether or not SSM is cost-effective. It is expected that the benefits from fertilizer relocation justify the investment associated with higher number of soil analysis and labor. However, there are no studies conducted in the High Desert or Intermountain areas, both of which generally have more variable soil conditions than many other agricultural areas. Regional assistance in recommendation and implementation of SSM can provide growers with basic information to improve yield potential and achieve input optimization. Therefore, it is essential to understand how soil P and K vary throughout alfalfa fields, methods to identify soil nutrient variability, and the economic and agronomic impacts of adopting VR fertilization. Some research (Ferguson and Herbert, 2002) indicates that the ideal grid sampling density for SSM is between 1 and 2.5 acres per sample**,** however, sampling costs could be significantly reduced if fewer samples could be used to identify soil nutrient spatial variability. However, other studies used lower sampling grid densities: between 6 and 10 acres per sample (Menegatti et al, 2004).

In order to establish a pattern for future soil sampling and reduce costs with soil analysis, we hope to identify an optimum number of samples necessary to identify soil fertility spatial variability in selected alfalfa fields in the High Desert and Intermountain Region. Also, we will be comparing the differences of fertilizer use and costs between uniform rate and variable rate phosphorous and potassium fertilization, which will be supportive information for other farmers in these two areas.

Objectives

To explore the potential benefits of Variable Rate fertilizer application for the High Desert and Intermountain Region, a project was conducted with the following objectives:

- Assess P and K variability in alfalfa fields;
- Compare the difference in fertilizer usage and cost between Uniform Rate and Variable Rate application methods;
- Compare three soil sampling densities (A = 1 sample/3acres, B = 1 sample/6acres and C = 1 sample/12acres) in order to establish a pattern for future soil sampling in the High Desert and Intermountain Region. Fewer samples would obviously save money, but would they adequately reflect the variability in a field?

MATERIALS AND METHODS

Five alfalfa fields located in the High Desert, near Lancaster, CA and in the Intermountain Region, near Yreka, CA, were sampled in a grid pattern (Figure 1), with 1 soil sample collected for every 3 acres. Each sampling point was located with the use of a handheld GPS, and soil samples were collected at the depth of 0-6 inches, with 10 sub-samples randomly collected within a radius of approximately 10 ft to the center of each sampling point (Figure 1). The subsamples were mixed and composite a representative sample for that point, and analyzed for phosphorus (Olsen-P) and potassium (Extractable K). Overall, 204 soil samples were collected from 610 acres of alfalfa, and the respective P and K maps were created in a GIS (Geographic Information System) through the interpolation of the soil analysis results.

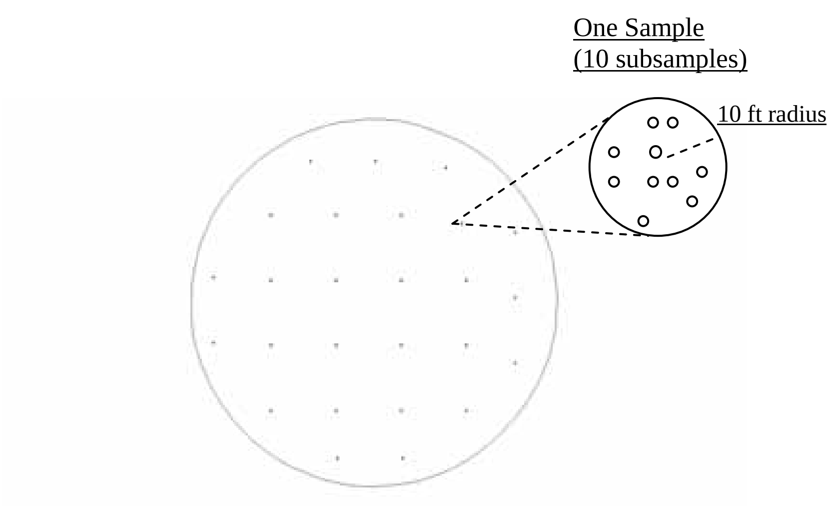

Figure 1. Illustration of soil sampling grid and sampling points in a center pivot field of 124 acres.

UR vs. VR Comparison: Fertilizer Usage

Differences in fertilizer use and costs between UR and VR application were calculated based on the differences between the grower's current nutrient management plan, herein referred as UR (one or three soil samples used for the entire field), and the VR method, which considered field variability assessed with grid sampling (1 sample/3 acres).

The phosphate and potash recommendations, for both UR and VR methods, were calculated based on a formula that attributes particular fertilize rates to specific ranges of soil P and K (Table 1). These formulas are used by a fertilizer dealer located in the Intermountain Region that provides VR application for his costumers. Potash and phosphate prices used on this study were provided by the same fertilizer dealer, and the prices quoted in March of 2009 were $0.42/Lb for 0-0-60 and $0.31/Lb for 11-52-0.

Table 1. Fertilizer recommendation (pounds of mono-ammonium phosphate or muriate of potash) assumed in this study, based on specific ranges of soil fertility, adapted from Meyer *et al* in Irrigated Alfalfa Management (Summers and Putnam, 2008).

Soil P (ppm)	11-52-0 (lbs/A)
0-2	345
2-4	270
4-6	230
6-8	155
8-10	115
10-12	77
12-15	38
>15	0

Soil K (ppm)	0-0-60 (lbs/A)
0-20	667
20-40	500
40-60	333
60-80	250
80-100	167
>100	0

Sampling Density Comparison

Sampling grid densities of 6 acres (B) and 12 acres (C) per sample were created by reducing the number of sampling points from the original grid of 3 acres per sample (A). Figure 2 illustrates sampling densities A, B and C for a 138.3 acres field located in the Intermountain Region.

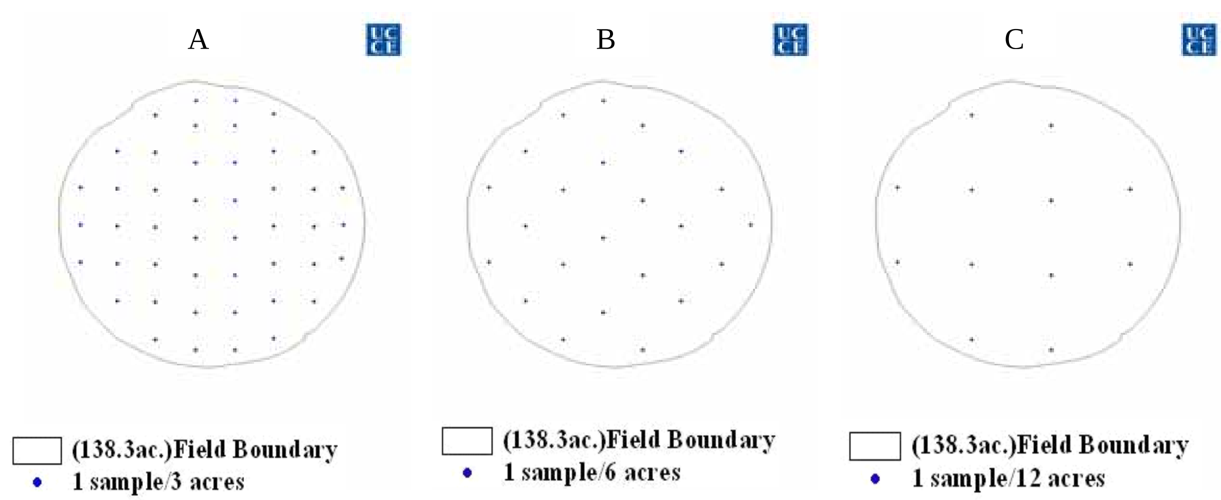

Figure 2. Soil sampling densities A, B and C were compared on this study.

A percentage value was calculated to quantify the similarity of maps created with sampling grids B and C to maps created with sampling grid A. To calculate the percentage, the numerator was the area the maps created with sampling grids B or C had in common with maps created using sampling grid A for a given nutrient range. The denominator was the total area of that nutrient range on maps created with sampling grid A. The more they had in common the higher the percentage.

The legends used for the P and K maps of this study were developed based on a guideline for interpreting soil results adapted from the Integrated Alfalfa Management book (Summers and Putnam, 2008), which can be observed on Table 2. To emphasize differences in soil P and K variability, the nutrient ranges in this reference were subdivided in more classes in order to create a more detailed legend, as observed on Table 3.

Table 2. Interpretation of soil tests results for alfalfa production, adapted from Meyer *et al* in Irrigated Alfalfa Management (Summers and Putnam, 2008).

	Soil Value (ppm)			
Nutrient	Deficient	Marginal	Adequate	High
Phosphorus	<5	5-10	10-20	>20
Potassium	<40	40-80	80-125	>125

Table 3. Nutrient levels derived from Table 2 and used for the phosphorus and potassium legends of the fertility maps developed in this study.

Nutrient	Soil Value (ppm)					
Phosphorus	<4	4-8	8-12	12-16	16-20	>20
Potassium	<40	40-60	60-80	80-100	100-125	>125

RESULTS AND DISCUSSION

Soil Fertility and Fertilizer Usage Comparison

Table 4 summarizes differences in soil fertility assessment due to the different sampling methods: conventional (UR) and grid sampling (VR). Values under the UR column represent the soil fertility of a specific field assessed with only one or three composite soil samples, according to a grower's usual procedure. Values under the VR column show the lowest and the highest fertility values for a specific field, with the fertility range (difference between lowest and highest value) of that field shown in parenthesis.

It is important to emphasize that the fertility of a field is better assessed by the grid sampling method due to many more soil samples collected compared to the conventional (UR) method. Field IR3 for example had soil K value of 58 ppm with the UR method, while with the VR method K values ranged from 43 to 208 ppm. This is a clear example of the degree soil fertility varies throughout the field, and that sampling in a grid can identify such variability.

Table 4. Soil Fertility Assessment by the Uniform Rate (UR) and Variable Rate (VR) Methods.

	Soil Fertility (ppm)					
	UR	VR (range)	UR	VR (range)	UR	VR (range)
	Intermountain Region Fields					
	--------------- IR1 ---------------		--------------- IR2 ---------------		--------------- IR3 ---------------	
P	5.8	4 - 12 (8)	5	3 - 11 (8)	3	2 - 6 (4)
K	75	53 - 112 (59)	82	54 - 123 (69)	58	43 - 208 (165)
	High Desert Fields					
	------------------ L1 ----------------		--------------- L2 ----------------		----------	
P	20	14 - 27 (13)	19,14,17	7 - 30 (23)	---	---
K	93	67 - 137 (70)	108, 160,138	75 - 187 (112)	---	---

As it would be expected, differences of fertilizer usage between the UR and the VR methods varied according to each field, their location (Intermountain Region or High Desert) and fertilizer type (potash or phosphate). Overall, fertilizer rates due to the VR method significantly varied on every field located in the Intermountain Region, and resulted in savings of 8,334 lbs ($3,542) of muriate of potash (0-0-60) and 5,236 lbs ($1,623) of mono-ammonium phosphate (11-52-0), as observed on Table 5. Although potash fertilizer usage on field IR2 was greater with the VR method, rates varied from 0 to 330 lbs/A (Figure 3). In addition, phosphate fertilizer rates on that field varied from 80 to 270 lbs/A with the VR method. This significant fertilizer relocation inside of field IR2 would optimize fertilizer usage by avoiding over and under-fertilization in different portions of the field. Fertilizer recommendation maps with UR values for all fields of this study can be observed in the appendix (Figures 5 to 9).

Table 5. Fertilizer usage and cost summary for the Intermountain Region fields, located in Siskiyou County, CA.

Intermountain Region Fields

		Application Method			
Fertilizer Type	*Field (acres)*	**Uniform Rate (UR)**	**Variable Rate (VR)**		**Cost Summary (U$)**
		---------- lbs ----------			
Potash[†]	IR1 (134)	34,575	30,076		
Potash	IR2 (84)	14,112	15,052	*Potash*	Potash
Potash	IR3 (64)	21,379	16,604	*Difference* [†††]	balance
	Subtotal	*70,066*	*61,732*	***8,334***	**3,542**
Phosphate[††]	IR1 (134)	31,809	27,874		
Phosphate	IR2 (84)	19,435	18,624	Phosphate	Phosphate
Phosphate	IR3 (64)	17,334	16,844	*Difference*	balance
	Subtotal	*68,578*	*63,342*	***5,236***	**1,623**
				P and K Balance ($)	**5,165**

[†]Potash = 0-0-60 (U$0.42/lb); [††]Phosphate = 11-52-0 (U$0.31/lb); [†††] Difference = UR minus VR

Table 6. Fertilizer usage and cost summary for the High Desert fields, located in Los Angeles County, CA.

High Desert Fields

Fertilizer Type	Field (acres)	Application Method: Uniform Rate (UR)	Application Method: Variable Rate (VR)		Cost Summary (U$)
		---------- lbs ----------			
Potash †	L1 (90)	14,980	12,438	*Potash*	Potash
Potash	L2 (234)	0	6,070	*Difference †††*	balance
	Subtotal	*14,980*	*18,508*	***-3,528***	**-1,499**
Phosphate ††	L1 (90)	0	0	Phosphate	Phosphate
Phosphate	L2 (234)	2,337	3,243	*Difference*	balance
	Subtotal	*2,337*	*3,243*	***-906***	**-281**
				P and K Balance ($)	**-1,780**

†Potash = 0-0-60 (U$0.42/lb); ††Phosphate = 11-52-0 (U$0.31/lb); ††† Difference = UR minus VR

For the High Desert fields (Table 6), fertilizer usage comparison between the UR and the VR methods varied according to each field. Although potash and phosphate fertilizer usage was greater with the VR method on field L2, that method was able to identify approximately 80 acres of that field (234 acres) that would not have received fertilizer with the UR method and that would be under-fertilized with either potash or phosphate, likely resulting in a yield reduction.

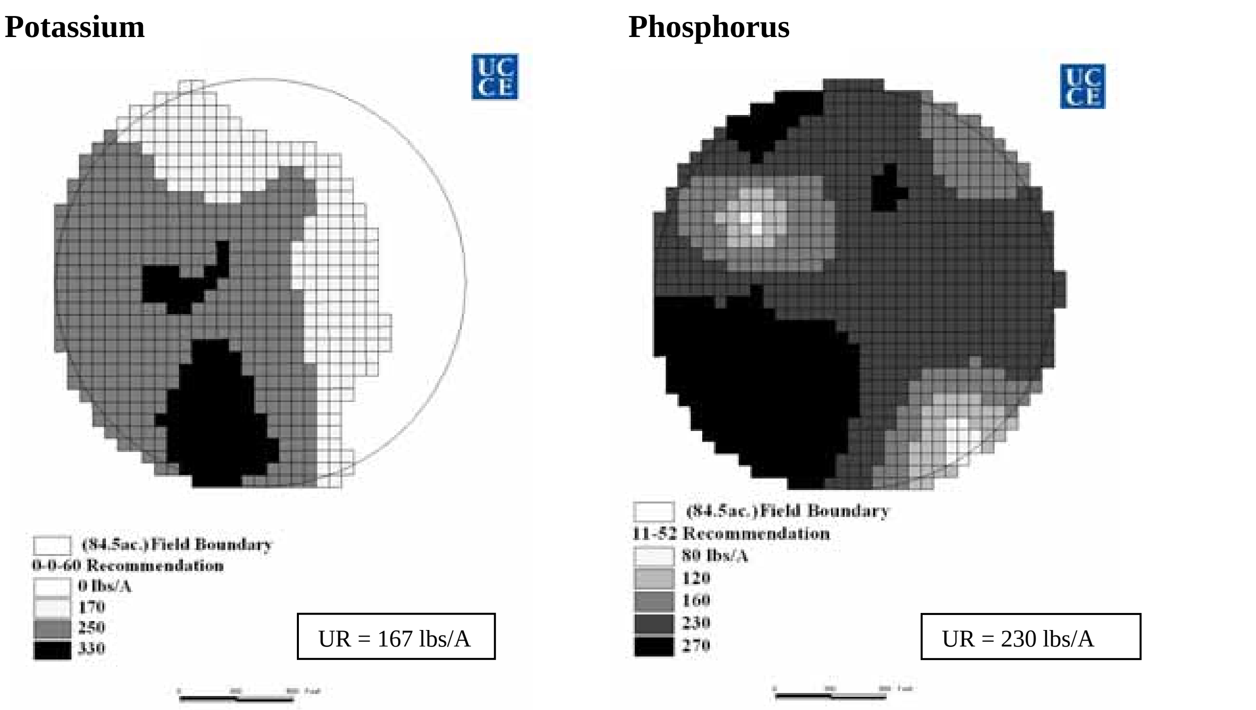

Figure 3. Potash and phosphate fertilizer recommendation maps for field IR2, located in the Intermountain Region. The uniform rate (UR) recommendation values are shown in the box under each map.

While the UR potash fertilizer recommendation on field L1 was 167 lbs/A for the entire field, the VR recommendation varied from 0 to 250 lbs/A, better matching the soil fertility of that field.

In summary, the opportunities observed in this study with VR applications of potash and phosphate fertilizers could be summarized as follows:

- Potential fertilizer savings by avoiding over-fertilization. Overall, 13,570 tons ($5,165) of fertilizers were saved on 282 acres of the Intermountain Region fields due to VR application. In addition, hay with high K content can lead to "milk fever", which could be avoided by reducing or eliminating potash applications in areas of the field with adequate K levels;
- Yield increases in portions of the fields by avoiding under-fertilization and improving crop nutritional status. In most of the fields evaluated a considerable amount of fertilizer was relocated to deficient areas of the field from areas with adequate or high fertility levels.

Sampling Density Comparison

Table 7 summarizes the similarity of maps created with sampling grids B and C to maps created with sampling grid A. Numbers 1 and 2 in front of sampling grids B and C (on Table 7) represent different sampling locations for the same sampling density B or C.

Table 7. Sampling density similarity to sampling grid A for each field and soil nutrient (P and K).

	Field (Nutrient)									
Sampling Grid	IR1 (P)	IR1(K)	IR2 (P)	IR2 (K)	IR3 (P)	IR3 (K)	L1 (P)	L1 (K)	L2 (P)	L2 (K)
	%									
B1[†]	92.2	67.3	81.8	81.0	94.2	61.2	65.5	66.3	72.2	93.1
B2	89.4	74.3	85.3	76.8	89.7	54.0	75.5	70.0	69.9	93.3
C1	86.0	55.7	73.6	72.6	86.8	48.0	36.4	67.1	54.2	81.0
C2	91.2	67.6	77.0	71.0	88.9	48.0	68.5	65.6	53.7	78.8

[†]The numbers 1 and 2 represent different sampling locations for the same sampling density B or C.

Overall, maps created with sampling grid B were more similar to A than C. Although the similarity values (Table 7) for maps created with sampling grid B are sometimes slightly greater or even smaller than sampling grid C, through a visual comparison we were able to assure a superiority of maps created with sampling grid B to C. Figure 4 illustrates soil P maps of field L2 created with sampling densities A, B and C.

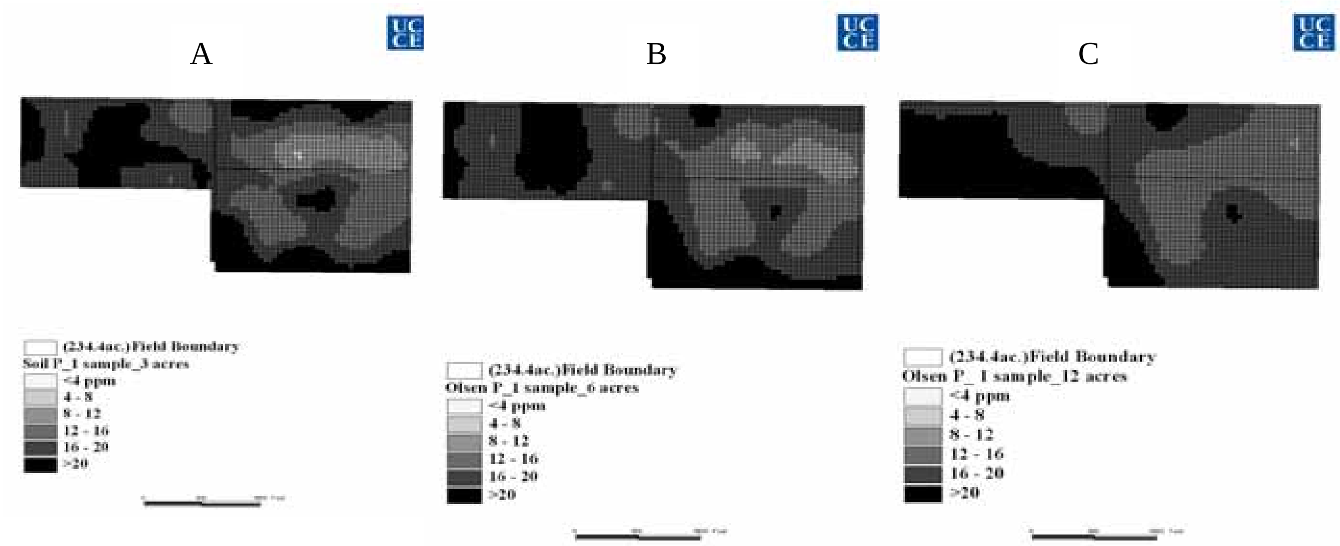

Figure 4. Soil phosphorus maps created with sampling densities A, B and C.

Costs Involved in Adopting SSM Fertilization

The costs associated with using nutrient SSM could vary significantly depending on the degree of involvement that the grower or crop consultant is willing to commit. One could work with a fertilizer dealer to decide about the sampling grid density and the fertilization method and the grower would not have to acquire any additional equipment. Or, the grower could make the decisions and do most of the work himself, which would require equipment acquisition and an understanding of how the technology works. A third option would be to assign someone on the farm to learn how to use a GPS and to receive basic training about collecting the soil samples and then put the crop consultant or fertilizer dealer in charge of the rest of the work.

To collect the samples in a grid pattern, one would need a simple GPS unit that could cost as low as $200. In order to create sampling grids, generate fertility and recommendation maps and the application file, it is necessary to use GIS software priced as low as $1,000. Some companies can provide assistance through the internet by creating the sampling grid and processing the fertility maps and generating application files. The actual VR application of the fertilizer depends on the installation of a set of equipment that could cost approximately $6,000, where the controller is the main component.

In general, we believe that growers should use this technique with the assistance of fertilizer dealers, consultants, PCAs and/or farm advisors familiar with SSM technology. Site-Specific Management is somewhat complex for most growers, and can only produce trustworthy results when there is good "integration" of the use of geotechnology tools and agronomic practices.

Another factor to consider when deciding to adopt SSM is the additional cost associated with the greater number of soil analyses required for grid sampling. The average price for soil P and K analysis at three Western US Laboratories is approximately $17, where the lowest price is $11, and the highest is $21 per sample. For a 100 acres field for example, soil analysis using a sampling density of 1 sample/3 acres would cost $586.00 at the average soil analysis price. However, if the100 acres field was sampled at a sampling density of 1 sample/6 acres, and the samples analyzed for $11 (lab with lowest cost, which actually includes pH, CEC, S, Ca and Mg), the final price for the soil P and K analysis would be only $183.

CONCLUSIONS

Soil fertility variability and fertilizer usage varied between fields, location (Intermountain Region or High Desert) and fertilizer type (potash or phosphate). Fertilizer savings with VR applications only occurred in the fields located in the Intermountain Region ($5,165). The use of VR fertilization in the High Desert fields resulted in greater fertilizer usage, however, the application better matched soil fertility of those fields. This suggests that grid sampling and VR fertilizer application may result in higher fertilizer cost for fields with overall high fertility levels. The soil analysis used for a UR application may indicate that the average overall fertility level of the field is adequate, however, the intensive sampling used with variable rate applications may identify areas of the field that are deficient. Hence, the VR method could increase yield by increasing the fertility level of deficient areas that would otherwise be overlooked with a UR fertilizer application.

Most of the maps created using a sampling density of 1 sample/3 acres were similar to maps creating using 1 sample/6 acres. This suggests that sampling every 6 acres was sufficient for the majority the fields used in this study.

Although the same amount or even more fertilizer was used in some alfalfa fields with the VR method, application rates would still vary significantly within most of those fields if the VR system was used. Whether or not VR application results in an actual fertilizer savings is secondary, and depends on whether conventional sampling (UR) generally over or underestimates the fertility level. The important point is that with grid sampling the VR fertilizer application better matches the actual fertility needs of the field.

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APPENDIX

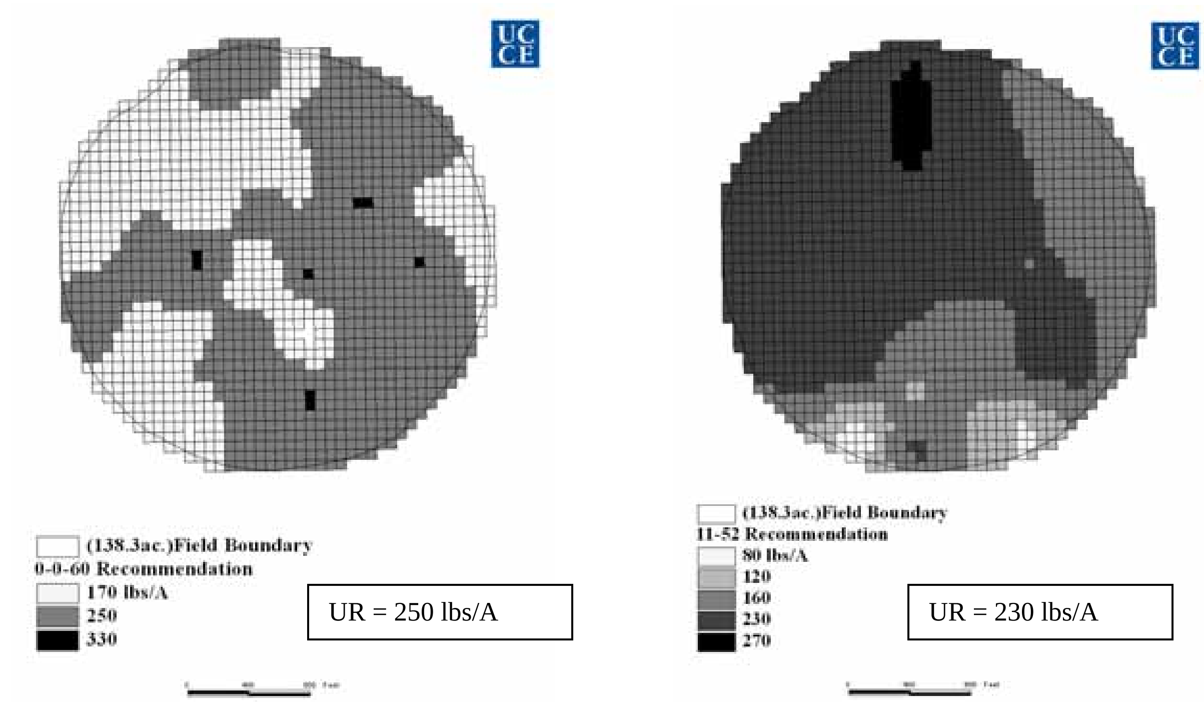

Figure 5. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR1. The uniform rate (UR) recommendation values are shown in the box under each map.

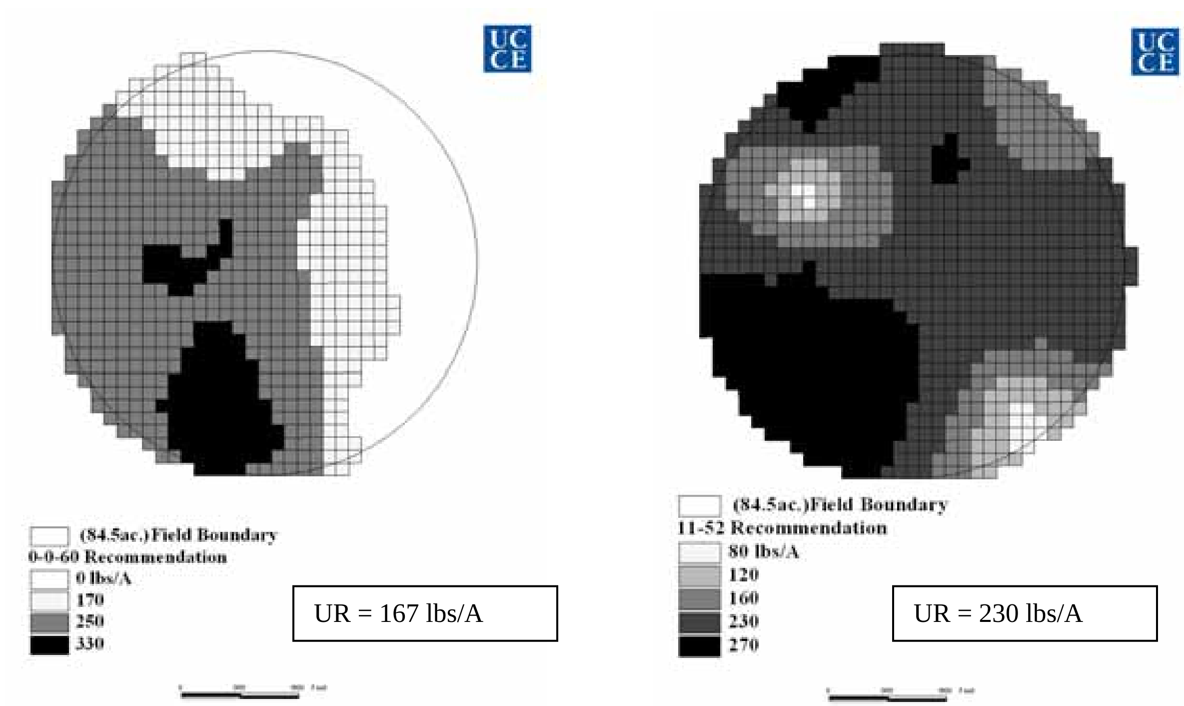

Figure 6. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR2. The uniform rate (UR) recommendation values are shown in the box under each map.

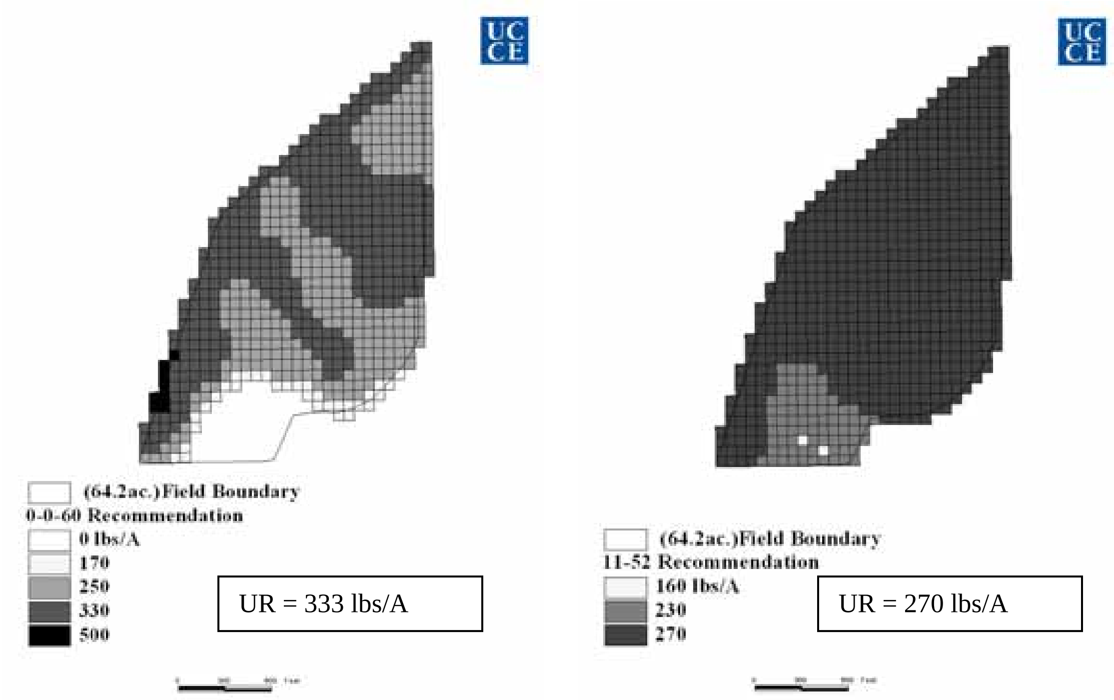

Figure 7. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR3. The uniform rate (UR) recommendation values are shown in the box under each map.

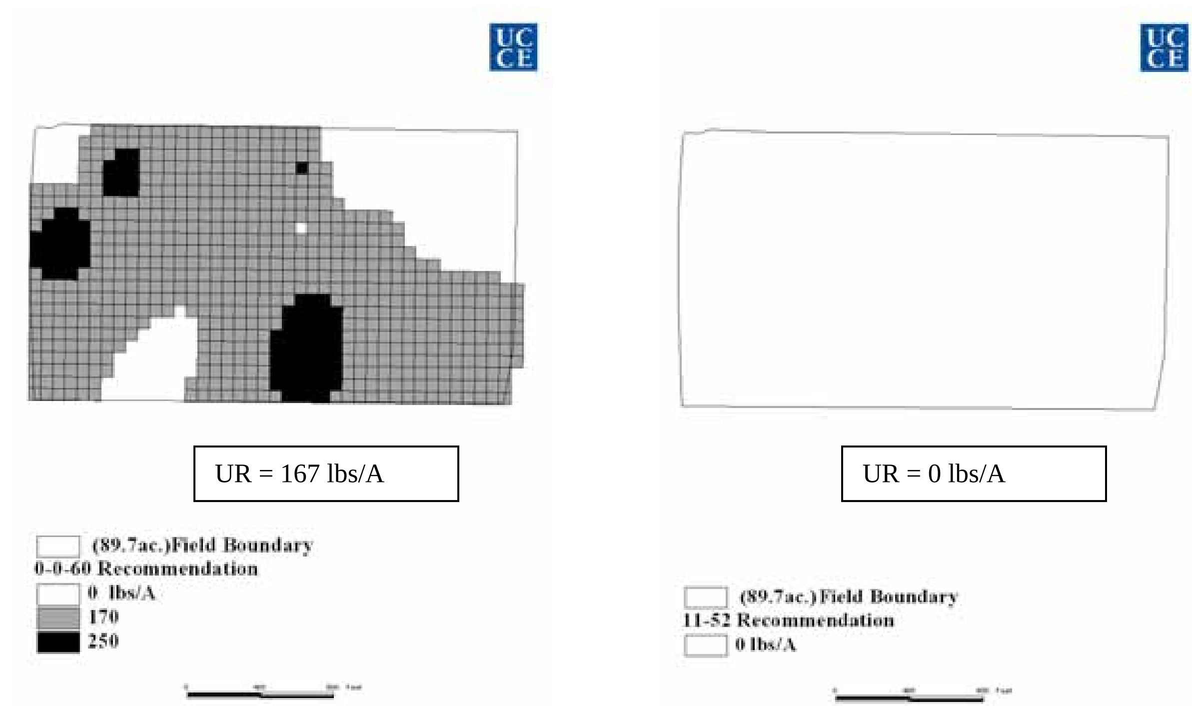

Figure 8. Recommendation maps of potash (left) and phosphate fertilizer (right) for field L1. The uniform rate (UR) recommendation values are shown in the box under each map.

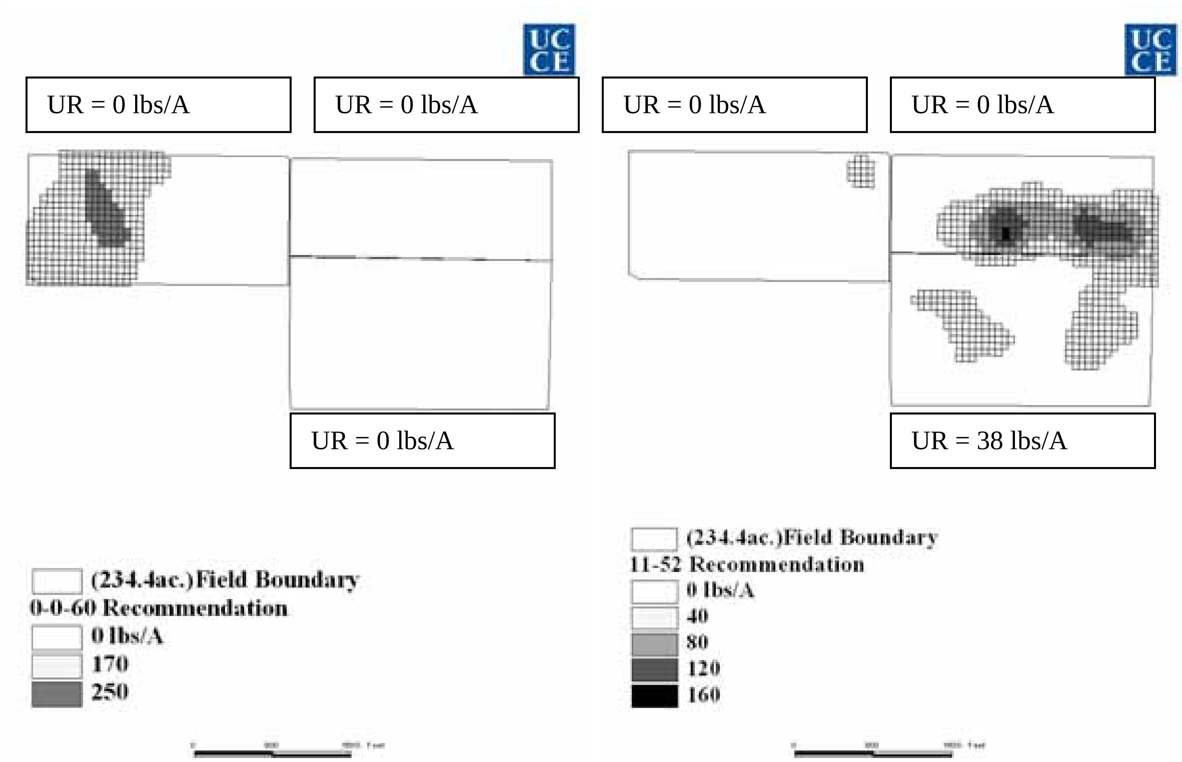

Figure 9. Recommendation maps of potash (left) and phosphate fertilizer (right) for field L2. The uniform rate (UR) recommendation values (three for this field) are shown in the box by each map.

Definition of terms*:*

Site-Specific Management (SSM): technique that identifies soil and crop spatial variability to better manage and optimize inputs;

Soil Spatial Variability: variation of soil properties within the field (e.g. soil fertility);

Soil Grid Sampling: soil sampling based on a grid pattern established for a field in order to identify spatial variability;

Soil Sampling Density: number of soil samples collected for a certain area (per acre basis);

*Variable Rate (VR) Fertilization***:** fertilization method that identifies soil fertility spatial variability and that applies fertilizers in different rates throughout the field in order to avoid over and/or under fertilization;

Uniform Rate (UR) Fertilization: conventional fertilization method that treats the entire field uniformly with respect to fertilizer application.