SITE-SPECIFIC PHOSPHORUS AND POTASSIUM FERTILIZATION OF ALFALFA: FERTILIZER USAGE AND SAMPLING DENSITY COMPARISON

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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 farmers' fertilization practices and crop nutritional status. These areas have limited to no studies regarding nutrient SSM, and variable rate (VR) fertilizer application has not been commonly used by farmers in either area. 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 compare three soil sampling densities (A = 1 sample/1.2 ha, B = 1 sample/2.4 ha and C = 1 sample/4.8 ha) in order to establish a pattern for future soil sampling for nutrient variability assessment in alfalfa fields in the High Desert and Intermountain regions, and to compare fertilizer usage and cost differences between uniform rate (UR) and VR application methods. Two hundred and four samples were collected in five alfalfa fields located in Lancaster and near Yreka, CA, based on a sampling grid density of 1 sample/1.2 ha. Most of the soil phosphorus (P) and potassium (K) variability and fertilizer savings due to VR occurred in the fields located in the Intermountain region. Overall, maps created based on sampling densities A and B were very similar. Total fertilizer savings due to VR application in all 5 fields (247.3 ha) combined was \$3,823. Although VR application resulted in the use of 12% more K fertilizer in a particular field of 36ha located in the Antelope Valley region, application rates on that field ranged from 56 to 280 kg ha^{-1}. This fact emphasizes that the more intensive soil sampling of the VR method allowed the identification of portions of fields where soil K would be overestimated with the UR method.

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

INTRODUCTION

The High Desert and Intermountain regions in California 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.

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 is 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 samples 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 of California, 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 literature (Ferguson and Herbert, 2002; Havlin et al., 1999) indicates that the ideal grid sampling density for SSM is between 0.5 and 2 ha 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 2.4 and 4 ha 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 compare differences in 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/1.2 ha, B = 1 sample/2.4 ha and C = 1 sample/4.8 ha) in order to establish a pattern for future soil sampling in the High Desert and Intermountain Region.

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 (Fig. 1), with 1 soil sample collected for every 1.2 ha. Each sampling point was located with the use of a handheld GPS, and soil samples were collected at the depth of 0-15 cm, with 10 sub-samples randomly collected within a radius of approximately 3 m to the center of each sampling point (Fig. 1). The subsamples were mixed to achieve a representative composite sample for that point, and analyzed for phosphorus (Olsen-P) and potassium (Extractable K). A total of 204 soil samples were collected from 247 ha 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. Soil P and K levels were also assessed by the field average method, which represent the soil fertility of a field assessed with only one or three composite samples, according to a grower’s usual procedure.

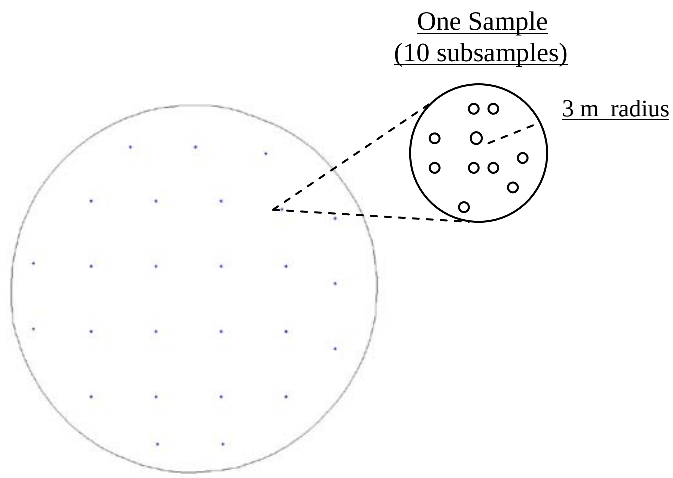

Fig. 1. Illustration of soil sampling grid and sampling points in a center pivot field of 50 ha.

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 to 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/1.2 ha).

The phosphorus and potassium recommendations, for both UR and VR methods, were calculated with formulas that attribute particular fertilizer rates to specific ranges of soil P and K (Table 1). These formulas were created based on information adapted from Meyer *et al* in Irrigated Alfalfa Management (Summers and Putnam, 2008). Potash and phosphate prices used on this study were provided by a fertilizer dealer located in the Intermountain Region, and were quoted in March of 2009 as \$0.68/kg for 11-52-0 and \$0.93/kg for 0-0-60.

Table 1. Recommendation rates of mono-ammonium phosphate (left) and muriate of potash (right) 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 (kg ha^{-1})
0-2	385
2-4	300
4-6	260
6-8	175
8-10	130
10-12	85
12-15	40
>15	0

Soil K (ppm)	0-0-60 (kg ha^{-1})
0-20	745
20-40	560
40-60	375
60-80	280
80-100	185
>100	0

Sampling Density Comparison

Sampling grid densities of one sample per 2.4 ha (B) and one sample per 4.8 ha (C) were created by reducing the number of sampling points from the original grid of one sample per 1.2 ha (A). Fig. 2 illustrates sampling densities A, B and C for a 56 ha field located in the Intermountain Region.

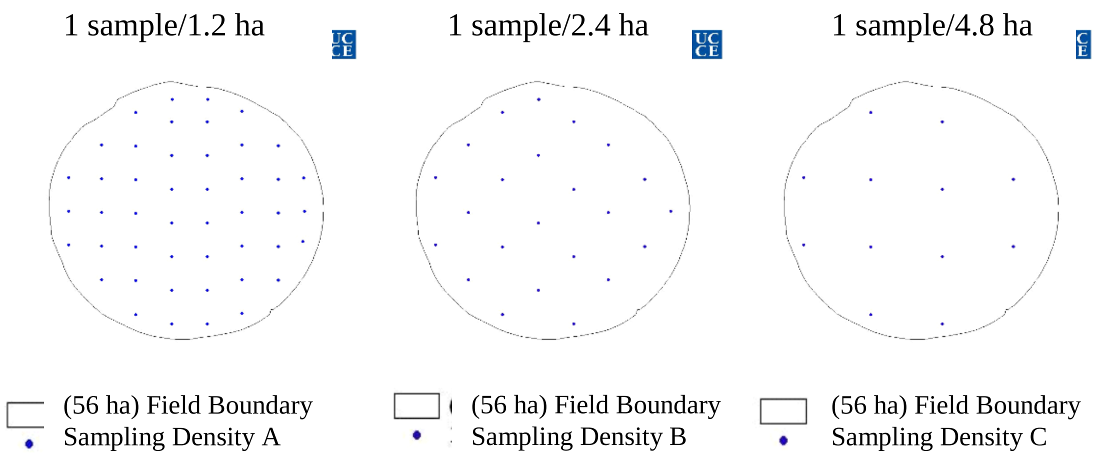

Fig. 2. Soil sampling densities A, B and C were compared in this study.

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 in Table 2. To emphasize differences in soil P and K variability, the nutrient ranges in this reference were subdivided into more classes to create a more detailed legend, as observed in 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

Figures 3 and 4 summarize differences in soil P and K due to the different sampling methods: grid sampling and field average. Field average values represent the soil fertility of a specific field assessed with only one or three composite soil samples, according to a grower's usual procedure. Grid sampling values show the range of soil fertility identified within each field.

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 field average method, while with the grid sampling 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.

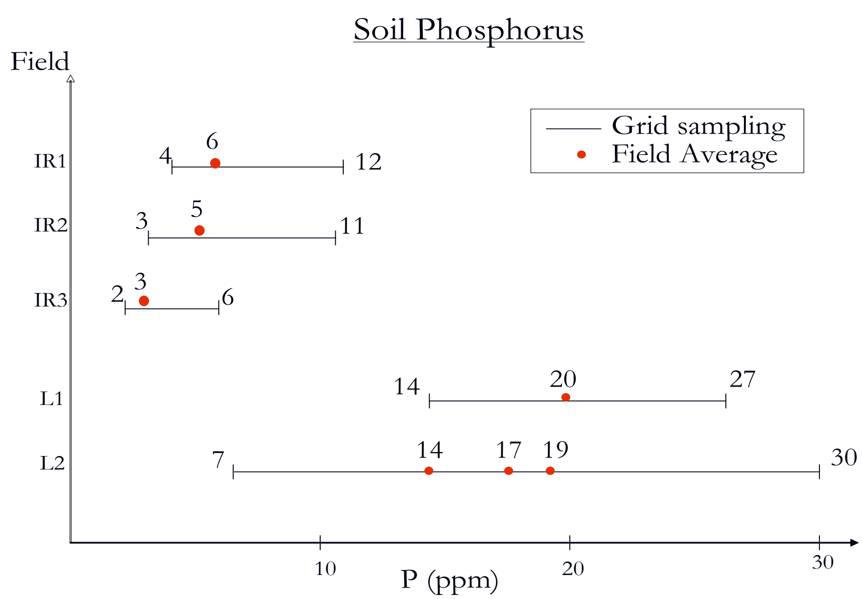

Fig. 3. Soil Phosphorus Assessment by the Grid Sampling and Field Average Methods.

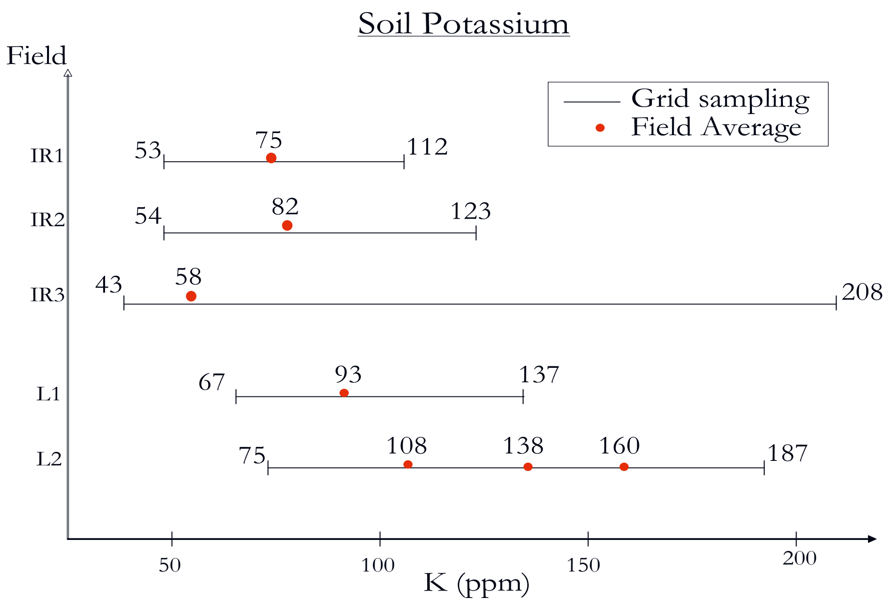

Fig. 4. Soil Potassium Assessment by the Grid Sampling and Field Average Methods.

As would be expected, differences in 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 3,783 kg ($3,538) of muriate of potash (0-0-60) and 2,377 kg ($1,621) of mono-ammonium phosphate (11-52-0), as observed in Table 5. Although potash fertilizer usage on field IR2 was greater with the VR method, rates varied from 0 to 370 kg ha^{-1} (Fig. 5). In addition, phosphate fertilizer rates on that field varied from 90 to 300 kg ha^{-1} with the VR method, where the UR recommendation was 260 kg ha^{-1}. 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 (Figs. 7 to 11).

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 32 ha of that field (95 ha) 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.

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

Intermountain Region Fields

Fertilizer Type	*Field (ha)*	Uniform Rate (UR)	Variable Rate (VR)		Cost Summary (U$)
		Application Method			
		kg			
Potash[†]	IR1 (56)	15,697	13,654		
Potash	IR2 (34)	6,407	6,833	*Potash*	Potash
Potash	IR3 (26)	9,706	7,538	*Difference* [†††]	balance
	Subtotal	31,810	28,026	***3,783***	**3,538**
Phosphate[††]	IR1 (56)	14,441	12,655		
Phosphate	IR2 (34)	8,823	8,455	Phosphate	Phosphate
Phosphate	IR3 (26)	7,870	7,647	*Difference*	balance
	Subtotal	31,134	28,757	***2,377***	**1,621**
				P and K Balance ($)	**5,159**

[†]Potash = 0-0-60 (U$0.93/kg); [††]Phosphate = 11-52-0 (U$0.68/kg); [†††] 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 (ha)*	Uniform Rate (UR)	Variable Rate (VR)		Cost Summary (U$)
		Application Method			
		kg			
Potash [†]	L1 (36)	6,786	5,635	*Potash*	Potash
Potash	L2 (95)	0	2,750	*Difference* [†††]	balance
	Subtotal	6,786	8,384	***-1,598***	**-1,494**
Phosphate [††]	L1 (36)	0	0	Phosphate	Phosphate
Phosphate	L2 (95)	1,059	1,469	*Difference*	balance
	Subtotal	1,059	1,469	***-410***	**-280**
				P and K Balance ($)	**-1,774**

[†]Potash = 0-0-60 (U$0.93/kg); [††]Phosphate = 11-52-0 (U$0.68/kg); [†††] Difference = UR minus VR

While the UR potash fertilizer recommendation on field L1 was 190 kg ha^{-1} for the entire field, the VR recommendation varied from 0 to 280 kg ha^{-1}, better matching the soil fertility of that field (Fig. 8).

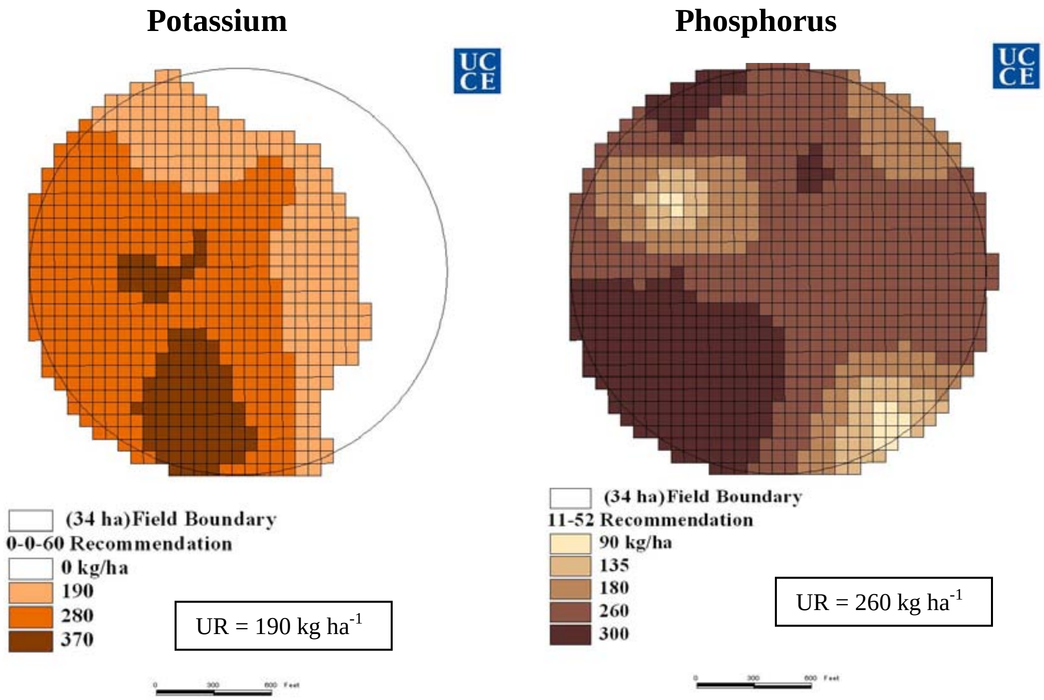

Fig. 5. Potash and phosphate fertilizer recommendation maps for field IR2, located in the Intermountain Region. The uniform rate (UR) recommendation values are shown in the box under each map.

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, 6,160 kg ($5,159) of fertilizers were saved on 114 ha 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 the superiority of maps created with sampling grid B to sampling group C. Fig. 6 illustrates soil P maps of field L2 created with sampling densities A, B and C.

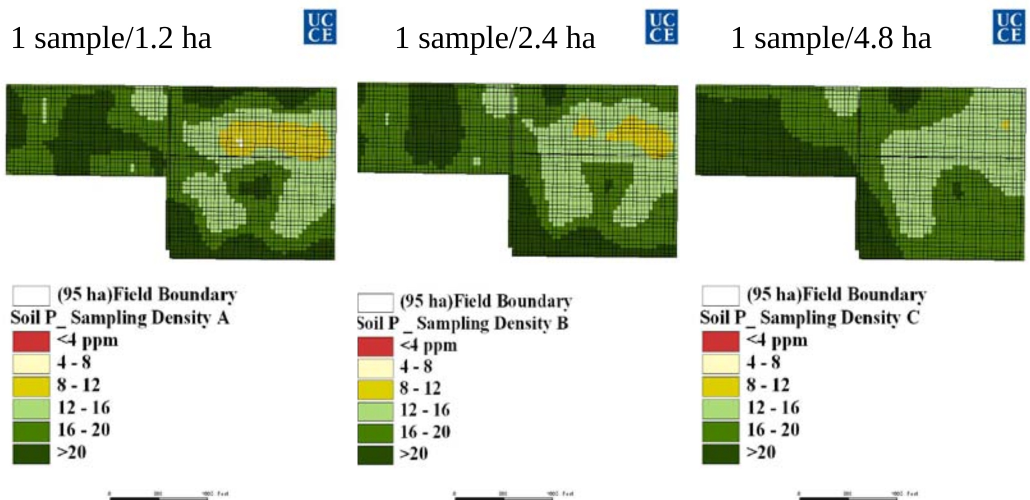

Fig. 6. Soil phosphorus maps created with sampling densities A, B and C.

CONCLUSIONS

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. 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 ($5,159). Grid sampling identified areas of the field with adequate nutrient levels in an overall deficient field resulting in specific areas that did not need fertilizer and thus a reduction in fertilizer application compared to a UR fertilizer application. 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/1.2 ha were similar to maps creating using 1 sample/2.4 ha. This suggests that sampling every 2.4 ha 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 (field average) 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

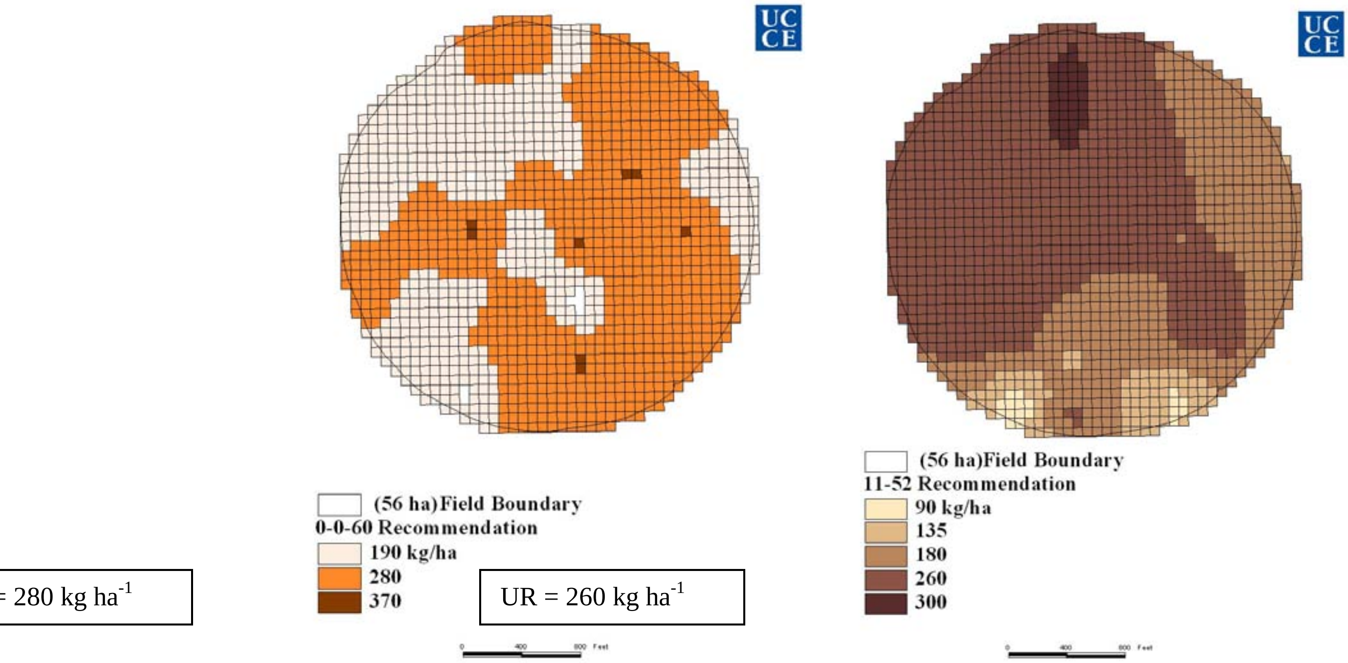

Fig. 7. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR1. The uniform rate (UR) recommendation values are shown in the box under each map.

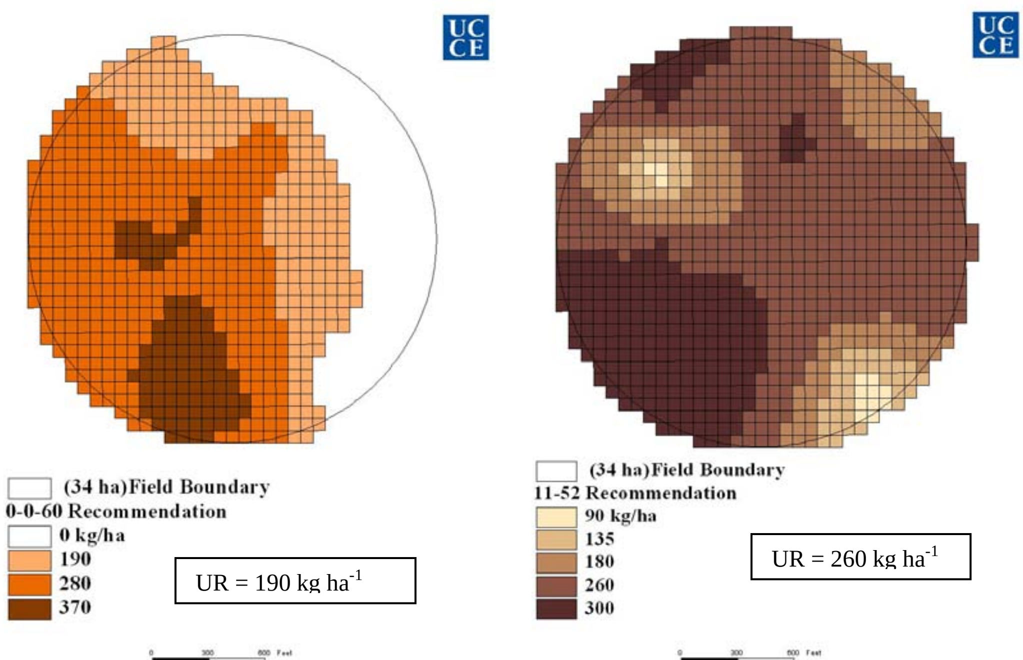

Fig. 8. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR2. The uniform rate (UR) recommendation values are shown in the box under each map.

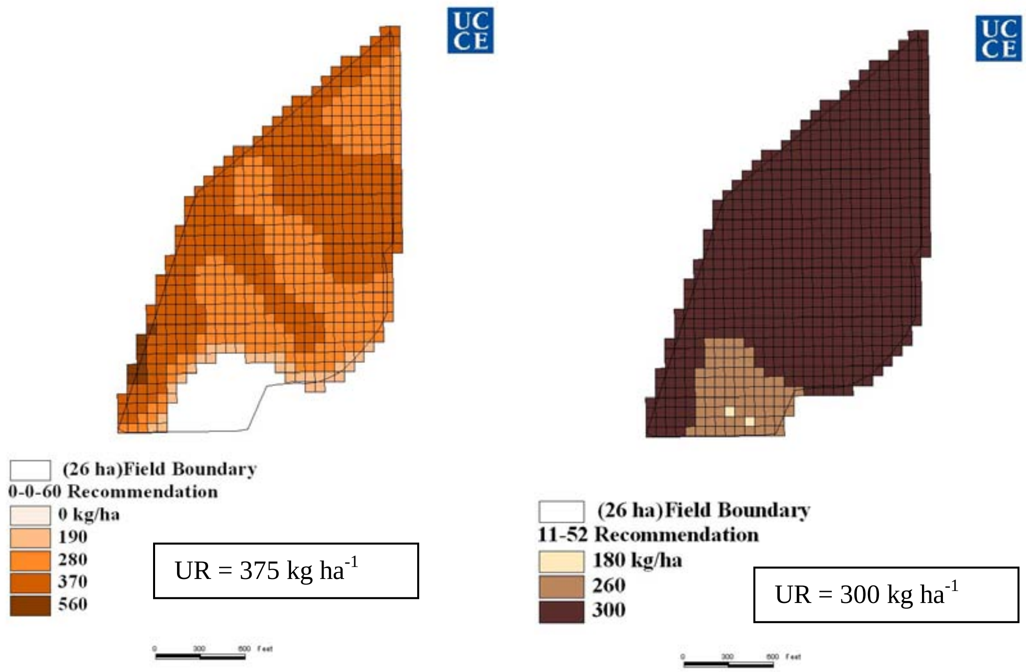

Fig. 9. Recommendation maps of potash (left) and phosphate fertilizer (right) for field IR3. The uniform rate (UR) recommendation values are shown in the box under each map.

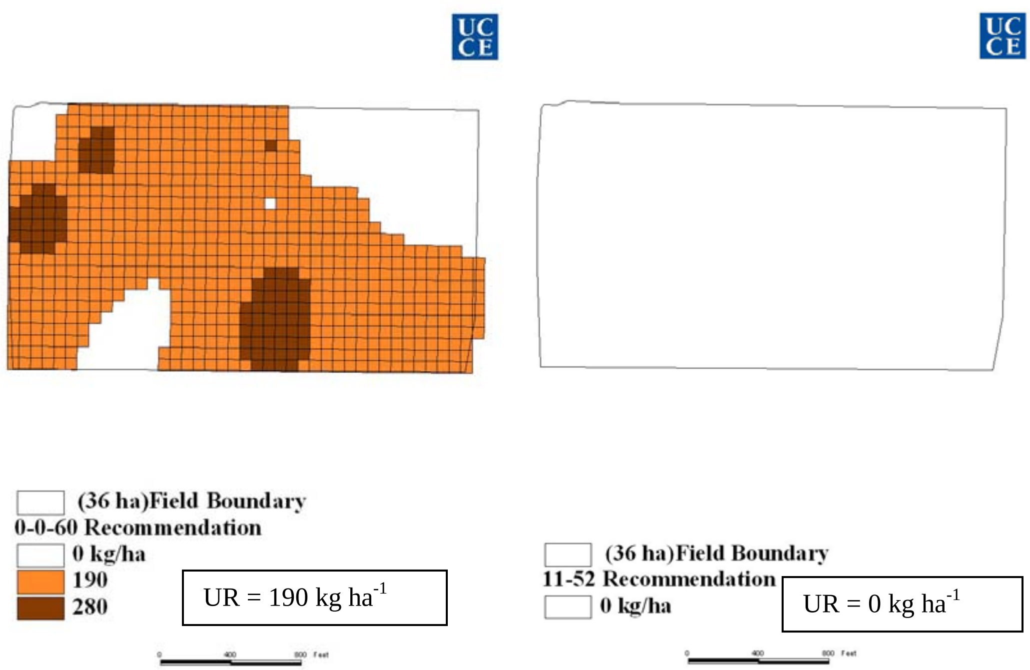

Fig. 10. Recommendation maps of potash (left) and phosphate fertilizer (right) for field L1. The uniform rate (UR) recommendation values are shown in the box under each map.

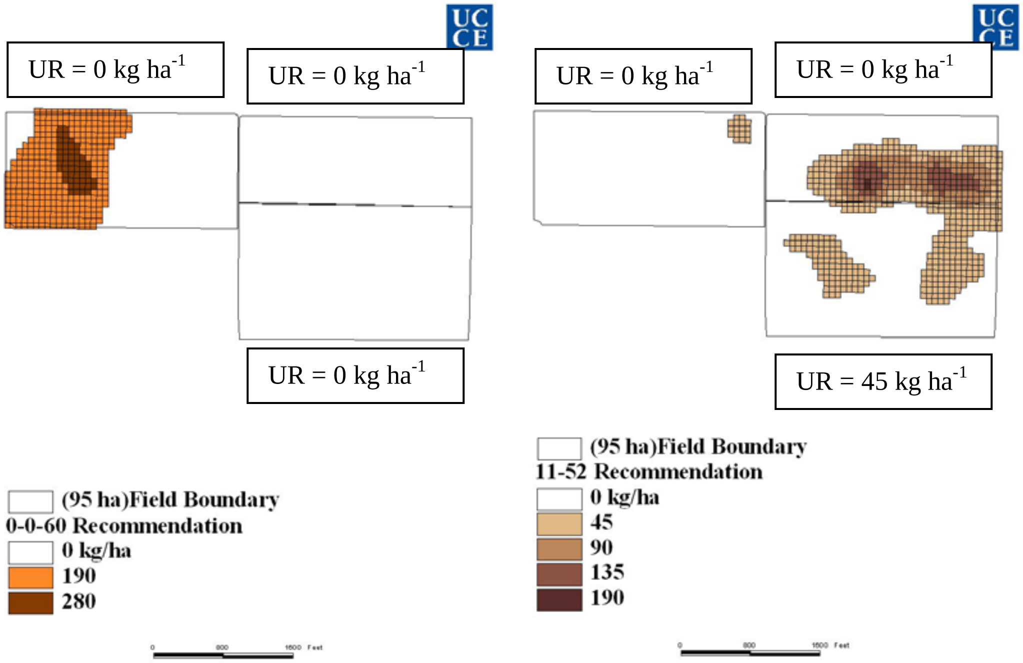

Fig. 11. Recommendation maps of potash (left) and phosphate fertilizer (right) for field L2. The uniform rate (UR) recommendation values (three for this field) are shown in the box by each map.