

## **TITLE: INCREASING CROP PRODUCTION EFFICIENCY THROUGH SITE-SPECIFIC FARMING: Final Report**

**Account #: ARF7125**

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### **INTRODUCTION**

Traditional farming practices ignore the inherent spatial variability found in most farm fields. Managing fields uniformly has led to over fertilization in areas with high residual nutrients and unnecessary applications of insecticides and herbicides in areas not affected by insects and weeds (Mulla and Schepers, 1997; Wollenhaupt et al., 1994). The extensive variability in soil properties (texture, depth, slope, and aspect) and crop productivity (Mulla and Schepers, 1997), coupled with concerns about water and soil quality, and narrow profit margins (Wollenhaupt et al., 1994) justify farming based on the needs of specific areas within a field. Site-specific farming (SSF) has the potential to increase efficiency in farm decision-making, improve profit margins, and reduce environmental pollution. Furthermore, SSF has the potential to reduce insecticide and herbicide resistance that may develop when whole fields are frequently and uniformly sprayed. Evaluation and implementation of SSF has been made possible by advancements in remote sensing, global positioning systems (GPS), geographical information systems (GIS), variable rate technology (VRT), and grain yield monitors. These technologies made it possible to identify and treat specific areas within a field differently from others. SSF has the potential to revolutionize crop production by increasing profit margins through improved efficiency in the management of field variability.

Despite the advancement in technology and the potential of SSF, adoption of SSF is lagging primarily because it has not proven to be more profitable than traditional farming practices (Lowenberg-DeBoer and Swinton, 1997, Lowenberg-DeBoer and Boehlje, 1996). A review of economic analyses shows that SSF was profitable only in some situations (Lowenberg-DeBoer and Swinton, 1997). However, all of these studies provided partial budgets based on inadequate input and output information and therefore cannot be reliably used to evaluate the viability of SSF. As illustrated in recent precision agriculture conferences such as Robert et al. (1996, 1998), early research on SSF has been dominated by the development and evaluation of instrumentation and VRT of fertilizers. Likewise studies on economic returns to SSF have been based on fertilizer or single factor responses. Fertilizer alone or single factors, however, have not explained all the observed spatial and temporal variation in grain yields (Mulla and Schepers, 1997; Everett and Pierce, 1996; Braum et al., 1998; Solohub et al., 1996). To successfully evaluate and implement SSF, more information on factors affecting variability of grain yields is required.

The observed spatial and temporal variation (season to season) in crop growth is the result of the interactions between soil factors (texture, fertility, depth, slope, aspect) and biological (pests) factors experienced during a growing season (Mulla and Schepers, 1997; Braum et al., 1998; Machado et al., 2000). The implementation and adoption of SSF will be successful when soil and biological factors, limiting grain yield and profitability, can be identified and managed at different locations and for different plant growth stages in integrated systems.

### **OBJECTIVES:**

1. Identify soil and biological factors that influence the spatial and temporal variability in crop yields of agricultural fields in eastern Oregon.
2. Use information obtained in objective 1 to increase crop production efficiency by applying inputs based on the requirements of specific areas in a field.

### **OBJECTIVE 1**

#### **Factors influencing grain yield**

It was initially planned that this work will be carried out at Mr. John McElheran's farm. Work on this farm did not begin last year due to some logistical problems and lack of equipment needed to characterize the site. Work was, however, initiated at the CBARC, Sherman Experiment Station, Moro where all the equipment was available. After equipment was acquired, some work was initiated at Mr. McElheran's farm.

### **MATERIALS AND METHODS**

To identify soil and biological factors influencing wheat yields, a 28-acre field at CBARC, Moro, was first characterized. Using a Giddings® probe (Giddings Machine Co. Inc. Fort Collins, CO), soil was sampled at one-foot intervals to a depth of 5ft or to restricting layer at 126 geo-referenced locations (DGPS) on a 100 ft grid (Fig. 1). The soil was analyzed for nitrogen (N), phosphorus (P), potassium (K), sulfur (S), soil organic matter (SOM), and acidity (pH) at the Kuo Testing Laboratories, Othello, WA to obtain baseline information. The soil probe was set to drill as deep as 5 ft and we assume that the soil is more than 5ft deep in areas where the probe reached 5 ft without going through a restrictive layer. Depth to restrictive zone or bedrock was recorded during soil sampling. Soft white spring wheat (Jefferson) was grown (2003) to determine the effects of soil characteristics on grain yield. About 30, 45, and 26 lb/acre of N, P, and S, respectively were applied before seeding. Wheat was seeded in April at a seeding rate of 90 lbs/acre. The crop was harvested at each DGPS location to determine grain yield and analyzed to determine how grain yield was influenced by site characteristics. Both traditional and spatial analyses were used to interpret data.

#### **Data analysis**

The associations of grain yields with the measured soil characteristics at the DGPS locations were determined by correlations, factor analysis, and multiple regressions. Simple linear correlations were used to find relationships between measured characteristics and grain yield. Factor analysis is a procedure used to group factors that are correlated or that co-vary. The variables we measured are assumed to be functions of some underlying common factors. Factor analysis was used to identify the common factors (Davis, 1986; Khattree and Naik, 2000). The

identified factors that are assumed to be independent were then subjected to multiple regression analysis to determine how they influenced grain yields across the whole field (Mallarino et al., 1996; Machado et al, 2000). The regression model used is represented by the equation:  $Y = b_0 + b_1F_1 + b_2F_2 + \dots + b_nF_n + \varepsilon$ , where  $b_0$  to  $b_n$  are coefficients and  $F_1$  to  $F_n$  are the common factors, and  $\varepsilon$  is residual error. These analyses were done by SAS procedures (SAS Institute Inc.).

## RESULTS AND DISCUSSION

The site slopes from the south to nearly all directions and the slope ranges from 0.03 to 5% (Figure 2). Depth to restricting zone or bedrock was recorded during soil sampling and is shown in Figure 3. The site is shallow (0.5 – 3ft) towards the west and 4 to >5ft deep towards the east. The spatial distribution of N, P, K, S, SOM, and pH is shown in figure 4, 5, 6, 7, 8, and 9, respectively.

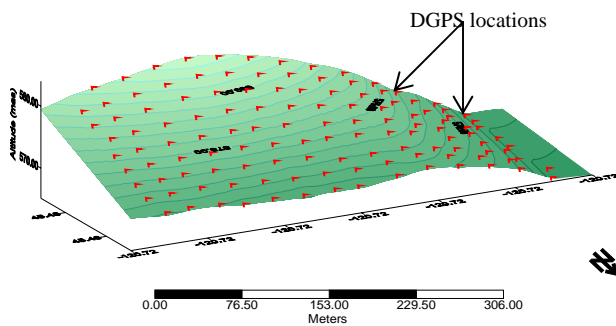


Fig. 1. Experimental site at CBARC, Moro showing 100-ft DGPS grid locations (red flags) that were sampled.

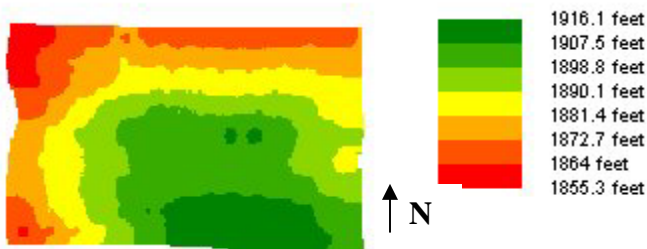


Figure 2. Elevation (feet above sea level ) of the experiment site at CBARC, Moro, 2002

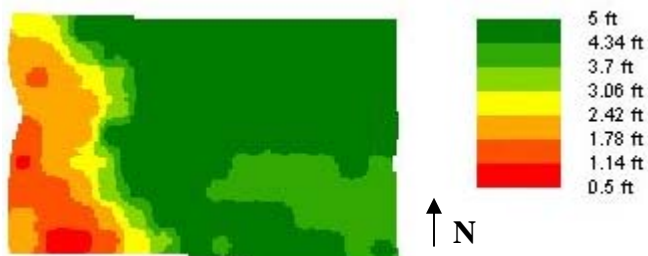


Figure 3. Depth to restricting layer or bedrock of the experiment site at CBARC, Moro, 2002.

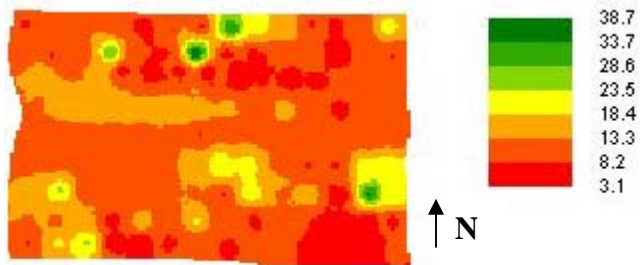


Figure 4. Spatial distribution of inorganic nitrogen (N) (lbs/a) in the 5-foot soil profile or to restricting layer at CBARC, Moro, 2002.

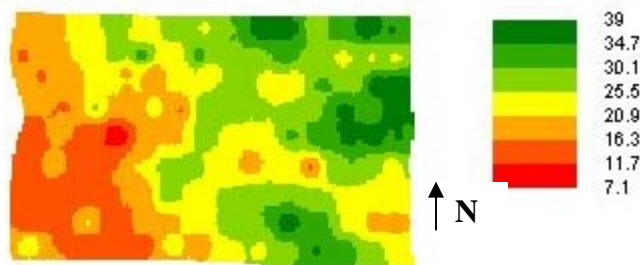


Figure 5. Spatial distribution of phosphorus (P) (ppm) in the top foot of the experiment site at CBARC, Moro, 2002.

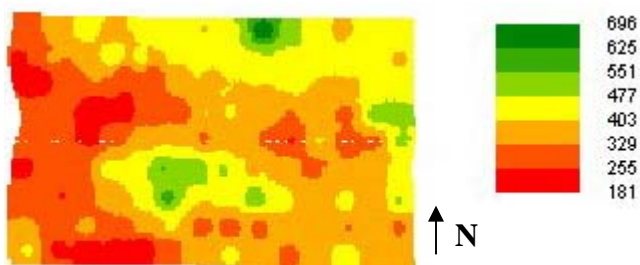


Figure 6. Spatial distribution of potassium (K) (ppm) in the top foot of the experiment site at CBARC, Moro, 2002.

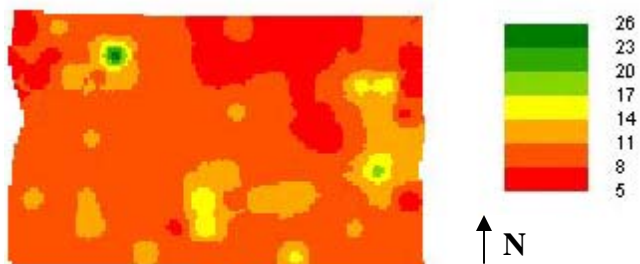


Figure 7. Spatial distribution of sulfur (S) (ppm) in the top 2 feet of the experiment site at CBARC, Moro, 2002.

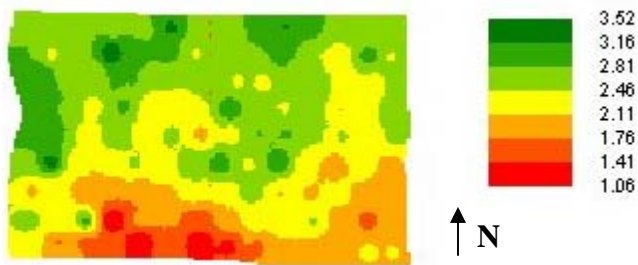


Figure 8. Spatial distribution of soil organic matter (SOM) (%) in the top foot of the experiment site at CBARC, Moro, 2002.

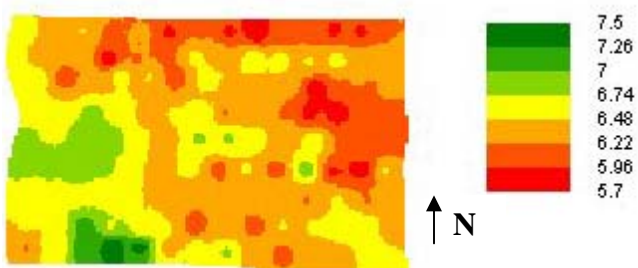


Figure 9. Spatial distribution of soil pH in the top foot of the experiment site at CBARC, Moro, 2002.

These results show that there is considerable variation in each of the measured characteristics in this field. Ignoring this variability often results in poor and inefficient farming. Information from these characteristics should be used to improve input efficiency and profit margins. Only factors that significantly influence yield should be considered for SSF.

#### *Factors influencing grain yield of soft white spring wheat*

**Factor analysis.** Factor analyses outputs for the north-south (NS) aspect and east-west (EW) aspects are shown in Tables 1 and 2, respectively. The numbers in this table represent rotated components of measured variables. Large loadings (in boldface) indicate high correlations between the variables and the common factor. The signs of the loadings indicate how the variables vary with the common factors. Using the signs of the loadings and the magnitude of dummy variables used for the variables in the analysis, it is possible to describe the relationships of the common factors and the variables. Multiple regression equations that show the relationship of selected factors to wheat grain yield are shown in Table 3. Correlations are shown in Table 4.

#### *North-South Aspect*

The spatial distribution of grain yield is shown in figure 10. Four common factors that influence grain yield were identified when the site was viewed (analyzed) from a north-south aspect. Factor 1 receives high loadings from soil depth, N, P, K, and soil pH. This factor describes depth effects. Soil depth was positively and significantly correlated with grain yield (Table 1, fig. 10). There is a great deal of similarities between maps of soil depth (Fig. 3) and grain yield (Fig. 10). Depth influenced the spatial distribution of N, P, and K and the levels of these nutrients

increased with depth (Table 4). Soil pH was lower in the deeper parts of the site (Table 4;  $r = -0.48$ ). The north-south aspect, SOM, and soil pH, respectively, assign large loadings of 0.86, -0.77, and 0.37 to factor 2 (Table 1). This factor describes the north-south aspect which influenced SOM and soil pH. SOM was higher in the north facing slope than in the south facing slope (Table 1 and 4) and the opposite was true for soil pH (Table 1 and 4). Factor 3 receives large loadings from soil depth, grain protein, N, and OM (Table 1). This factor describes grain protein (Fig. 11) and indicates that grain protein was high in areas with high SOM and N and in shallow areas. Factor 4 receives high loadings from S and pH (Table 1) and based on the signs of the loadings it appears that S levels were high in areas of low pH (Table 1 and 4). This is in contrast to the well established fact that S availability increases with increase in pH. The total amount of S was calculated as the sum of S in the first 2 ft so, using this method, shallow areas had lower S levels than deeper areas. In this site pH was high in shallow areas (< 1 ft) where S was low and hence the negative correlation of S and pH observed in this study.

The four factors identified through the north-south aspect analysis only explained 34% of the variations in grain yield (Table 3). Out of these factors, only factor 1, soil depth, significantly influenced grain yield. Yield was also influenced by aspect (factor 2) and S (factor 4) although this was not significant (Table 3). Factor 3 was omitted from the equation because it describes grain protein that is influenced by grain yield. There are many other factors that were not considered in this experiment like soil texture, plant stand, and pests, that influenced grain yield of spring wheat. Plant stands were noticeably low in some areas and gopher (pest) damage was severe in other areas.

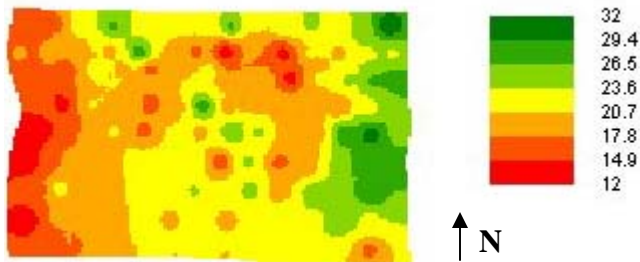


Fig. 10. Spatial distribution of grain yield (bushels/acre) of spring wheat at CBARC, Moro in 2003

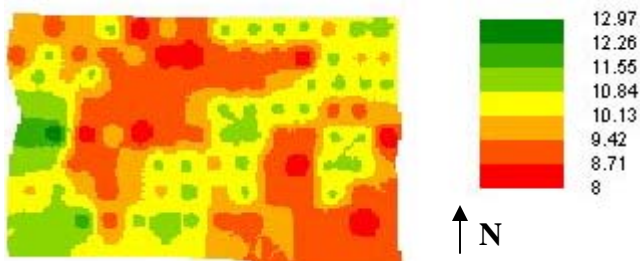


Fig. 11. Spatial distribution of grain protein (%) of spring wheat at CBARC, Moro in 2003

### *East-West Aspect*

When analyzed in an east-west aspect, four factors that influenced grain yield were identified (Table 2). Factor 1 receives high loadings from aspect, soil depth, P, K, and soil pH. Factor 1 appears to describe the effect of soil depth. Based on the signs of the loadings, the site was deeper in the east and shallower in the west. The levels of P and K were high in deeper soil (Table 4). Soil pH was lower in deep areas and higher in shallow areas (Table 4). Grain protein, soil depth and SOM, respectively, assign large loadings of 0.83, -0.26, and 0.71 to factor 2. Factor 2 appears to describe grain protein which was high in areas with high SOM and low in deep areas. This factor does not influence grain yield and was omitted in the regression equation (Table 3). Factor 3 receives large loadings from soil depth, N, and K. This factor appears to describe N and K effects that were higher in areas where the soil was deep. Factor 4 receives high loadings from S, SOM, and pH and appears to be describing S effects. The loadings indicate that high S levels were found in areas with low SOM and low pH. The relationship between S and pH has already been discussed above.

Factor 1 (depth), factor 3 (N), and factor 4 (S) explained only 30% of the variation in grain yield (Table 3). As in the north-south aspect analysis, soil depth had a significant and greater effect on grain yield than N and S (Table 3). Soil N's effect on grain yield was not significant (Table 3). Although S significantly influenced grain yields, its effect (coefficient) was much smaller compared to the effect (coefficient) of depth on grain yield (Table 3). Other factors not considered in this analysis like plant stand and pests may have influenced the spatial variability of grain yield.

### **CONCLUSIONS**

Based on correlations and factor analyses in the north-south and east-west orientations, soil depth was the major factor that influenced grain yield of spring wheat in this field in 2003. The availability of N, P, and K was depended on depth and the levels of these nutrients increased with increasing depth. Although not measured in this experiment, soil depth influences the availability of soil moisture that is essential for plant growth and yield. The north-south slope aspect appears to influence yield. Higher yields were obtained from the north-slope than from the south-slope. Soils in the north-slope were high in SOM that is known to increase the water holding capacity of the soils. Furthermore, the north-slope is usually cooler and is less prone to drought than the south-slope. East-west aspect analysis revealed that N and S also influenced grain yield although their effects were not as great. Information on soil depth, aspect, N, and S can be used to improve the efficiency of input management in this field.

Table 1. Rotated factor pattern of variables in the whole field at CBARC, Moro, 2003: North-South aspect

| Variable              | Factor 1     | Factor 2     | Factor 3     | Factor 4     |
|-----------------------|--------------|--------------|--------------|--------------|
| North-South Aspect    | -0.18        | <b>0.86</b>  | 0.15         | 0.10         |
| Soil depth            | <b>0.85</b>  | -0.03        | <b>-0.29</b> | -0.04        |
| Grain protein         | 0.03         | -0.07        | <b>0.93</b>  | 0.03         |
| Nitrogen (5ft)        | <b>0.52</b>  | -0.09        | <b>0.26</b>  | 0.05         |
| Phosphorus (1 ft)     | <b>0.82</b>  | -0.19        | -0.04        | 0.06         |
| Potassium (1 ft)      | <b>0.80</b>  | 0.01         | 0.14         | -0.05        |
| Sulfur (2 ft)         | -0.02        | 0.17         | 0.04         | <b>0.94</b>  |
| Organic matter (1 ft) | 0.03         | <b>-0.77</b> | <b>0.34</b>  | -0.04        |
| pH (1 ft)             | <b>-0.61</b> | <b>0.37</b>  | 0.03         | <b>-0.49</b> |

Table 2. Rotated factor pattern of variables in the whole field at CBARC, Moro, 2003: East-West aspect

| Variable              | Factor 1     | Factor 2     | Factor 3    | Factor 4     |
|-----------------------|--------------|--------------|-------------|--------------|
| East-West Aspect      | <b>-0.83</b> | -0.01        | 0.24        | 0.05         |
| Soil depth            | <b>0.76</b>  | <b>-0.26</b> | <b>0.39</b> | -0.10        |
| Grain protein         | 0.01         | <b>0.83</b>  | -0.09       | 0.13         |
| Nitrogen (5ft)        | 0.14         | 0.09         | <b>0.86</b> | 0.09         |
| Phosphorus (1 ft)     | <b>0.87</b>  | 0.08         | 0.16        | 0.00         |
| Potassium (1 ft)      | <b>0.62</b>  | 0.10         | <b>0.40</b> | -0.05        |
| Sulfur (2 ft)         | -0.02        | -0.05        | 0.05        | <b>0.95</b>  |
| Organic matter (1 ft) | 0.07         | <b>0.71</b>  | 0.24        | <b>-0.20</b> |
| pH (1 ft)             | <b>-0.68</b> | -0.18        | -0.17       | <b>-0.39</b> |

Table 3. Regression equations of common factors affecting grain yields of spring wheat within the field..

| Aspect      | Regression model                                   | R <sup>2</sup> | Pr > F  |
|-------------|--|----------------|---------|
| North-South | $Y = 20.86 + 2.25F_1^{****} + 0.56F_2 + 0.57F_4$   | 0.34           | <0.0001 |
| East-West   | $Y = 20.86 + 2.01F_1^{****} + 0.63F_3 + 0.71F_4^*$ | 0.30           | <0.0001 |

\*, \*\*, \*\*\*, \*\*\*\* significant at 0.10, 0.05, 0.01, and 0.0001 levels of probability, respectively.



Table 4. Correlations of grain yield and grain protein with soil chemical and physical characteristics in a field at CBARC, Moro, 2003

|       | †NSA    | EWA     | Depth   | EC      | Yd      | Gp     | Ntot    | P1      | K1      | Stot   | OM1   |
|-------|---------|---------|---------|---------|---------|--------|---------|---------|---------|--------|-------|
| NSA   | 1.00    |         |         |         |         |        |         |         |         |        |       |
| EWA   | ‡0.02   | 1.00    |         |         |         |        |         |         |         |        |       |
| Depth | -0.21*  | -0.49** | 1.00    |         |         |        |         |         |         |        |       |
| EC    | 0.22*   | 0.21*   | -0.49** | 1.00    |         |        |         |         |         |        |       |
| Yd    | 0.00    | -0.34** | 0.47**  | -0.37** | 1.00    |        |         |         |         |        |       |
| Gp    | 0.01    | -0.05   | -0.20*  | 0.08    | 0.16    | 1.00   |         |         |         |        |       |
| Ntot  | -0.21*  | -0.08   | 0.34**  | -0.16   | 0.27**  | 0.12   | 1.00    |         |         |        |       |
| P1    | -0.27** | -0.62** | 0.63**  | -0.35** | 0.51**  | 0.04   | 0.29**  | 1.00    |         |        |       |
| K1    | -0.13   | -0.32** | 0.56**  | -0.30** | 0.34**  | 0.08   | 0.27**  | 0.54**  | 1.00    |        |       |
| Stot  | 0.22*   | 0.05    | -0.05   | -0.11   | 0.13    | 0.02   | 0.07    | -0.01   | 0.01    | 1.00   |       |
| OM1   | -0.44** | 0.01    | 0.01    | 0.00    | -0.14   | 0.25** | 0.12    | 0.15    | 0.16    | -0.10  | 1.00  |
| pH1   | 0.34**  | 0.38**  | -0.48** | 0.46**  | -0.36** | -0.10  | -0.25** | -0.59** | -0.39** | -0.24* | -0.18 |

† NSA-north-south aspect, EW-east-west aspect, Yd-grain yield, Gp-grain protein, Ntot-total nitrogen in the whole profile (5 ft), P1-phosphorus in the 1<sup>st</sup> foot of soil, K1-potassium in the 1<sup>st</sup> foot of soil, Stot-sulfur in the top 2 ft of soil, OM1-organic matter in the 1<sup>st</sup> foot of soil, pH-degree of acidity in the 1<sup>st</sup> foot of soil.

‡ \*,\*\* significant at the 0.05 and 0.01, probability level, respectively

## OBJECTIVE 2

### SITE-SPECIFIC FARMING (SSF)

The efficiency of crop production in eastern Oregon can be improved by SSF, the practice of managing different areas in a field based on the need of those areas. Information obtained in objective 1 indicates that grain yield is influenced largely by soil depth and to some extent by aspect, N, and S. With this information management zones can be demarcated and managed based on specific needs of those zones. Alternatively long-term information from yield monitors can be used to demarcate management zones. Due to lack of resources and short duration of the grant, the actual demarcation of fields into management zones and managing crop growth in those zones could not be done. I am in the process of seeking additional funding to continue this work in collaboration with Dr. Dan Long, the new USDA-ARS leader at the Columbia Plateau Conservation Research Center, Pendleton. In the meantime however, the information obtained in objective 1 can be theoretically used to demarcate management zones and compare profitability of traditional farming practices (TF) to SSF.

### MANAGEMENT ZONES

Using information obtained under objective 1, the field can be demarcated into management zones based on soil depth, north-south aspect, N, and S. Management zones can be demarcated by simply producing the a map of the spatial distribution of the factor in question (Fig. 2-9). These maps can be overlaid on top of each other to form management zones for a combination of two or more factors. In this exercise the profitability of SSF will be compared on single factors and a combination of factors. Soil depth was the most influential factor on grain yield and based on this factor only two management zones can be demarcated (Fig. 12).

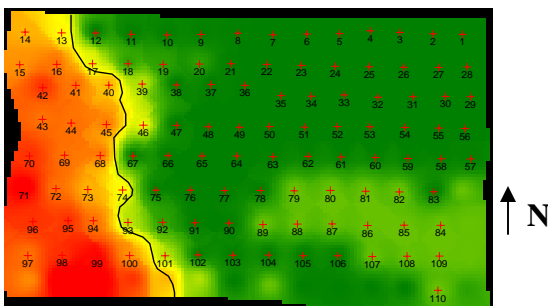


Fig. 12. Management zones based on soil depth. The red area represents shallow soil (1-3 ft) and the green areas represent deep soil (3->5ft).

Despite uniform fertilizer and seeding rates, grain yields in this field closely followed trends in soil depth (Fig 3). Grain yield varied from 11 to 22 bu/a in the shallow soil and from 15 to 32 bu/a in deep soil (Fig. 11). Efficient use of inputs can be achieved by determining the amount of inputs to be applied based on the requirements or yield potential of specific areas in the field. For illustration purposes only seeding rate and N will be applied based on the requirements and yield potential of the shallow and deep areas. Shallow areas will not hold enough moisture to support the same plant population as in deep areas. Similarly, a lower plant population does not require the same amount of nutrients compared to a higher population in deep areas. Therefore, a lower seeding rate and lower fertilizer rates should be used in shallow areas than in deep areas. A

higher seeding rate and fertilizer rate will increase competition for water resulting in crop failures particularly in drought years. In TF the seeding rate was 90 lb/acre throughout the whole field. Under SSF, the seeding rate would be 90 lb/acre in deep areas and 45 lb/acre in shallow areas. Because it was a re-crop situation and the soil was dry only about 30 bu/acre of grain yield was expected in 2003 on this site. To achieve this yield only 30 lb N/acre was required. Under SSF the difference of this amount and soil analysis results would have been applied in areas with deeper soil and based on soil analysis, no fertilizer would have been applied in the shallow areas.

### Comparison of Profitability between TF and SSF

The spatial distribution of net returns of spring wheat grown at a uniform seeding rate under TF and at variable rates under SSF are shown in figures 13 and 14, respectively. This economic analysis does not include other variable and fixed costs and government payments.

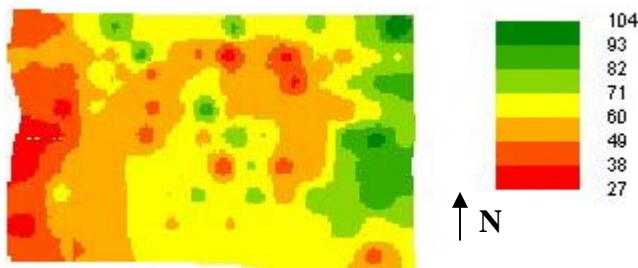


Fig. 13. Net profit (\$/acre) of spring wheat under Traditional Farming at a uniform seeding rate (90 lb/acre) at CBARC, Moro, 2003

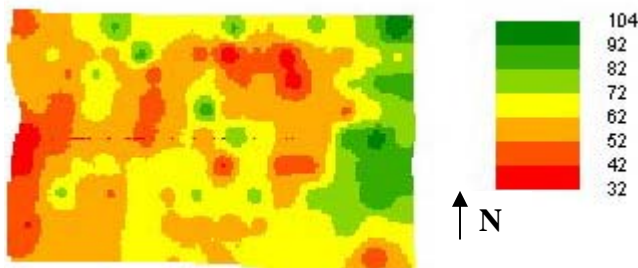


Fig. 14. Net profit (\$/acre) of spring wheat under Site Specific Farming at variable seeding rate (45 and 90 lb/acre) at CBARC, Moro, 2003



Fig. 15. Increase in net profit (\$/acre) of spring wheat under Site Specific Farming compared to Traditional Farming at CBARC, Moro, 2003

The difference between these two maps or the increase in net profit under SSF is shown in figure 15. Net returns are higher under SSF than TF particularly under the shallow areas where lower

seeding rates were used. On average SSF increased net returns by \$1.96/acre when seeding rates were varied according to yield potential of shallow and deep areas.

The spatial distributions of net returns of spring wheat when N was applied at a uniform rate under TF and at varying rates under SSF are shown in figure 16 and 17, respectively. The highest net returns were obtained in the deeper areas of the field in both TF and SSF. However, SSF had higher net returns in the shallow areas than TF. On average, varying N rates based on the requirements of

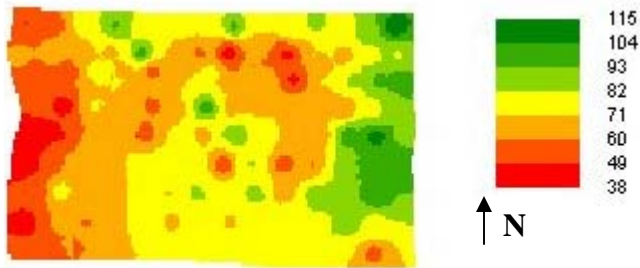


Fig. 16. Net profit (\$/acre) of spring wheat under Traditional Farming at a uniform N rate at CBARC, Moro, 2003

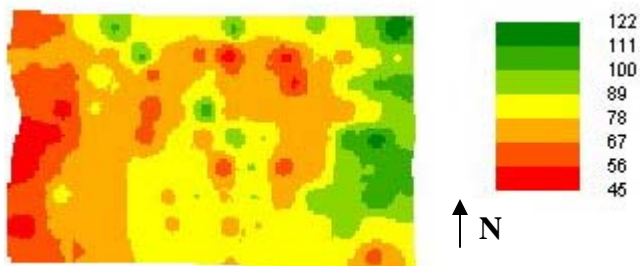


Fig. 17. Net profit (\$/acre) of spring wheat under Site Specific Farming at variable N at CBARC, Moro, 2003

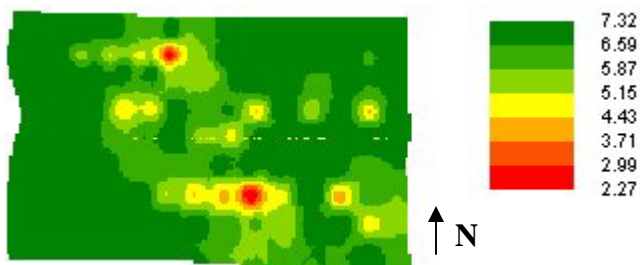


Fig. 18. Increase in net profit (\$/acre) of spring wheat under Site Specific Farming compared to Traditional Farming at CBARC, Moro, 2003

shallow and deeper areas increased net returns by \$6.62/acre (Fig. 18). Varying both seeding rates and N rates resulted in an increase in net profit of \$8.58/acre. This number is close to numbers reported by Kent Madison, an Oregon grower, who estimates a \$10 per acre increase in returns through soil mapping and precision fertilizer application on his wheat fields. In

Washington wheat farms, an increase of \$3.39 to \$14.80 more per acre return has been observed with SSF<sup>1</sup>. The profit margin could be further increased if insecticides and herbicides were spot applied only to affected areas and if inputs were varied according to aspect. In the majority of fields in eastern Oregon which are hilly, slope and aspect influence plant growth and grain yield. North-facing slopes are usually drier and warmer than south facing slopes and consequently produce higher yields than south facing slopes. Under such situations farming the two slopes uniformly is inefficient use of inputs.

### **PRACTICAL IMPLICATION OF THE RESULTS TO SSF**

Theoretically SSF can be practiced using information from soil physical, chemical, and hydrological factors and the results from this study indicate that there is a potential for increasing profit margins through SSF. In reality, this may not be the case. The main obstacle to the adoption of SSF is the cost of acquiring information on factors influencing grain yield. Information on soil factors discussed in this report was obtained through grid sampling. It cost \$32 per sample (discounted fee) to analyze each of the 126 grid locations (\$4,032.00). Add labor, equipment and analysis and the costs add up to about \$8,000.00 for the 28 acres we worked on (about \$280/acre). At these costs no grower can afford to practice SSF. However, cheaper, faster, and indirect methods to characterize fields are being developed.

One of the methods to characterize the field is electrical conductivity (EC). This is a non-invasive, non-destructive sampling method. The method tested in this study utilizes the principle of electromagnetic induction (EM). The instrument's transmitting coil induces an electrical current in the soil. The magnetic field created is strongest in the top 15 inches of the soil and has an effective sensing depth of about 5ft. The induced current creates secondary currents in the field that are sensed by a receiving coil. The relationship between the primary and the secondary currents is related to the electrical properties (EC) of the soil. When properly calibrated, the instrument can be used to measure soil depth and soil texture (Williams and Hoey, 1987). Sand, silt, and clay have low, medium, and high EC, respectively. The instrument can also measure soil water and crop productivity. The instrument is light weight and can be suspended (Fig 19) or mounted on a non-metallic cart (Fig 20). To take soil measurements, the EM meter was dragged (on the cart) across the field at 100 ft-intervals. The readings obtained were then processed with mapping software to produce an EC map (Fig 21). The EC readings (Fig 21) are significantly correlated with depth (Table 4,  $r=-0.49$ ). The EC map closely resembles the depth map (Fig 3) suggesting that soil depth in this field can be quickly mapped relatively cheaper by EC than by manual soil probing. Furthermore the EC map has more resolution than our 100-ft grid soil cores and is probably more accurate than our map. It took about one and half days to sample the soil for depth and only 45 minutes to conduct EC measurements. As with the depth map, the EC map was significantly correlated to grain yields (Table 4,  $r=-0.32$ ). EC can therefore be used effectively to demarcate management zones.

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<sup>1</sup> [http://www.oda.state.or.us/Information/sow/Precision\\_Ag.html](http://www.oda.state.or.us/Information/sow/Precision_Ag.html)



Fig 19. EM38® electrical conductivity meter suspended a few inches above ground during a measurement



Fig 20. EM38® electrical conductivity meter mounted on a non-metallic cart to leave a few inches above ground. The height of the meter above the soil surface can be adjusted.

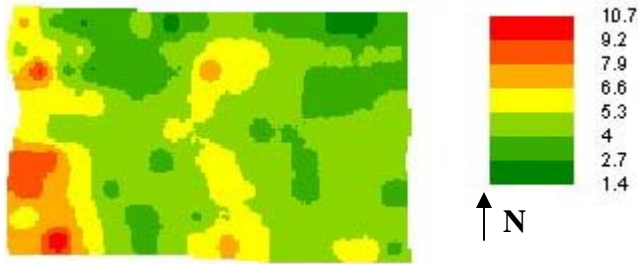


Fig. 21. Electrical conductivity (mS/m) map of the CBARC, Moro field, 2002.

Yield maps, generated by yield monitors, can be effectively used to demarcate management zones at lower cost than EC maps. Although yield monitors were expensive the time they were introduced, their prices have gone down considerably. More and more growers are now using yield monitors on a routine basis. Yield maps, taken over a number of seasons, can provide precise information on demarcating management zones. Maps below show yield monitor data in 2001 (Fig 22) and 2002 (Fig 23) from the Paulson field at John McElheran's farm, Wasco County. It is clear from Fig. 22 that there is tremendous grain yield variability in this field. Although slightly different, grain yield variability was remarkably similar in the following year (Fig 23). Based on the information obtained in 2001 and 2002, this field can be demarcated into two major management zones consisting of areas with low yield potential (red to yellow) and areas with high yield potential (green to purple). These areas can be sampled the usual way

separately and only two soil samples will be sent for analysis instead of hundreds when grid sampling is done. Inputs (fertilizer and seeding rates etc) would then be applied accordingly.

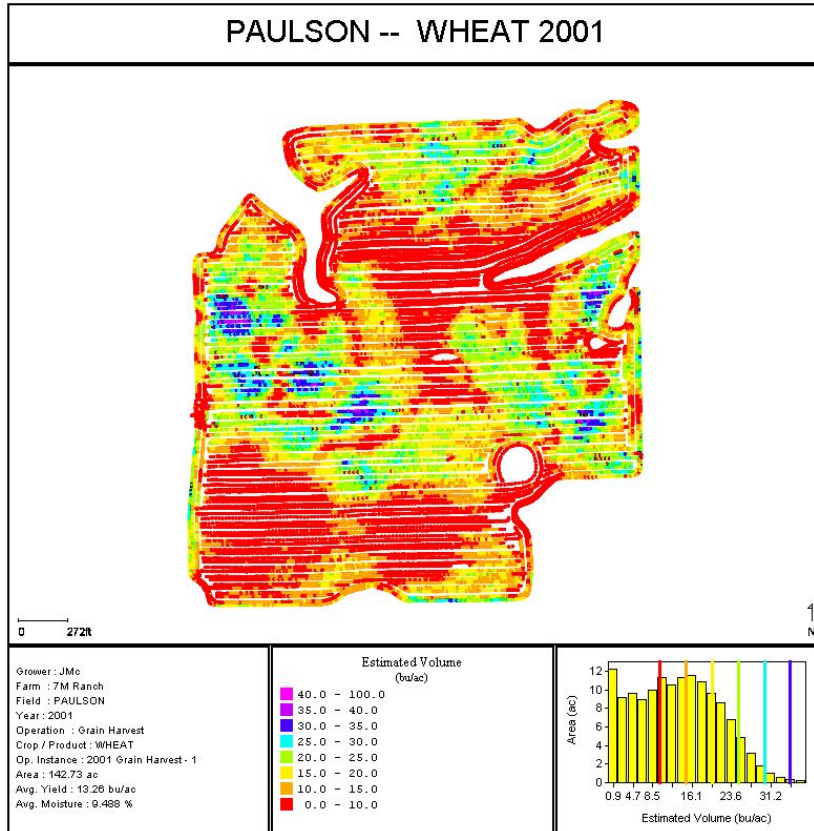


Fig. 22. Wheat yield map of the Paulson field at McElheran's farm in Wasco County, 2001

It may be necessary to demarcate management zones every year as grain yield variability changes from year to year (Fig 22, 23). For instance, high grain yields were produced in the upper most area in 2001 (Fig. 22) but in 2002 (Fig. 23) this area produced low grain yields due to cheatgrass (weed) infestation.

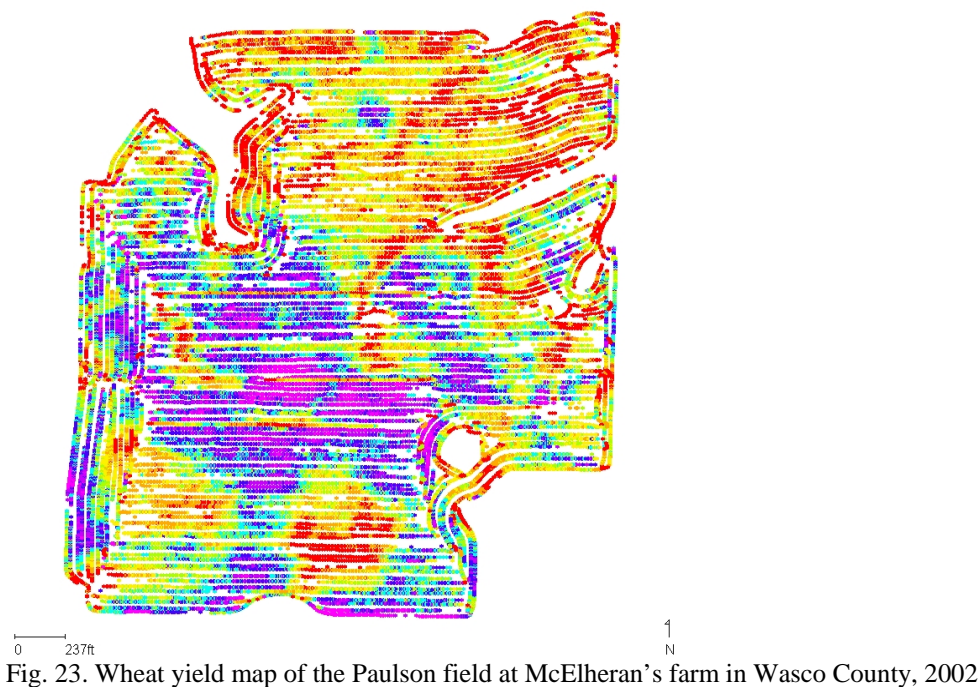


Fig. 23. Wheat yield map of the Paulson field at McElheran's farm in Wasco County, 2002

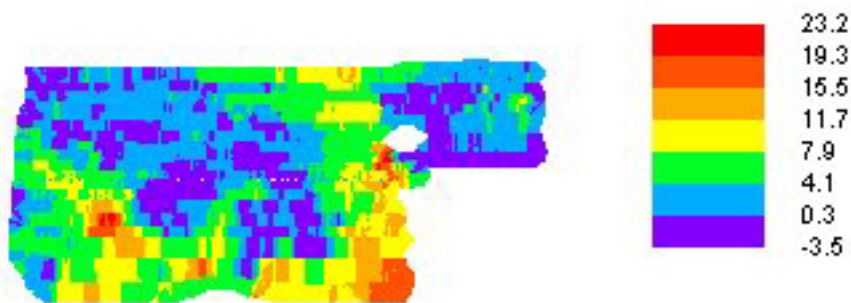


Fig. 24. EC map (mS/m) of the southern (lower) half of the Paulson field at McElheran's farm in Wasco County, 2003

An attempt to map EC on this field in the fall of 2003 is shown in Fig 24. The storage of our data logger got full halfway through the measurements and we lost data from the other half. However, the bottom half of the field we mapped (Fig. 24) was strikingly similar to yield data in both years suggesting that EC can effectively be used to demarcate management zones based on yield potential of this field. The low yielding areas in this field appear to be shallow.

Care should be taken when using information from EC measurements for SSF. Soil EC measurements can be a manifestation of many soil factors that include depth, texture, salinity, and moisture. It is therefore important to calibrate the EC readings with the property under investigation. The following example illustrates the point. Seed yield map of Fine Fescue in the Circle field at Mr. MacElheran's farm is shown in figure 25. The EC readings of the same field, we took a year later, is mapped in figure 26. These two maps do not seem to correlate very well. The EC map was taken when the field was moist and the map is probably reflecting soil moisture



status at that time coupled with soil texture and depth. To avoid moisture interference, EC readings should be done after harvest before the fall when soil is fairly dry.

Nevertheless, information obtained from yield maps is valuable for fertilizer management. Areas that were low yielding may have high residual nutrients and may require reduced fertilizer rates in the following season. Similarly these areas may require reduced plant stands. Decisions on whether to increase or reduce fertilizer and seeding rates need to be made every year based on yield monitor data.

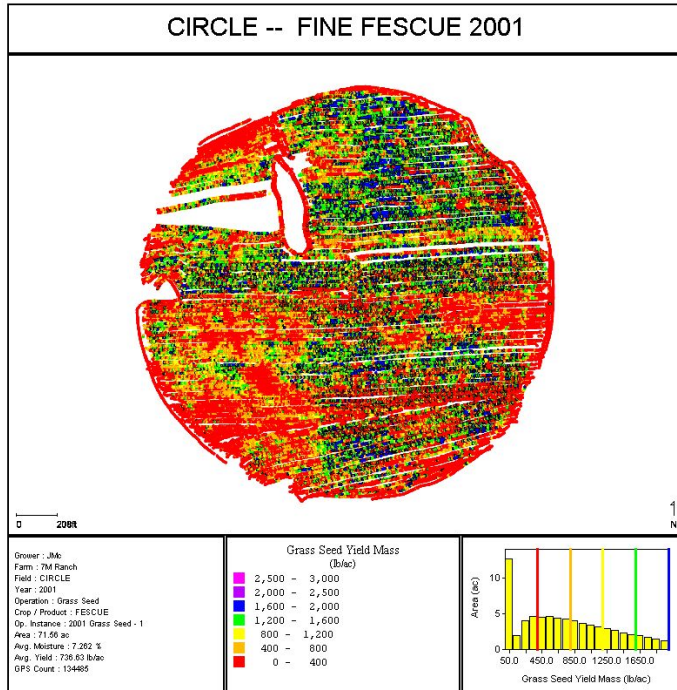


Fig 25. Fine Fescue seed map yield of the Circle field at McElheran’s farm in Wasco County, 2001

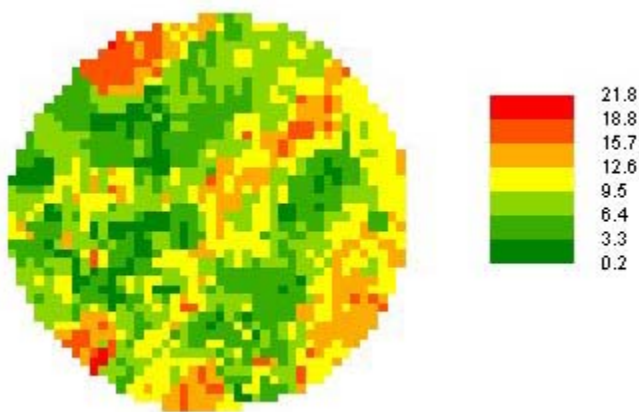


Fig 26. EC map (mS/m) of the Circle field at McElheran’s farm in Wasco County, 2002

## **CONCLUSIONS**

Farm profits in eastern Oregon are decreasing because of low and stagnant wheat prices and ever increasing input costs. Managing inputs more efficiently is one way to increase profit margins. Site-specific farming provides this opportunity. There is considerable variation in wheat yields (5 to 40 bu/acre) within fields in eastern Oregon (Fig 3, 22, 23, and 25). Despite the variation in grain yields, uniform fertilizer and herbicides continue to be applied to whole fields leading to over-fertilization in areas that do not need fertilizer and inefficient use of inputs. Varying amounts of inputs should be applied to specific areas in a field based on yield potential. To this end, factors influencing grain yield must first be identified. Many factors influence the spatial variability of crop yields. In dryland agriculture soil depth has considerable effects on grain yield because of its influence on soil available moisture. Where ever possible shallow and deep areas should be managed differently. More inputs (fertilizer, seeding rates) should be applied in deeper areas than in shallower areas. EC and yield monitor maps are so far the cheapest way to obtain information about yield potential of different areas in a field. Therefore management zones can easily be demarcated with information from EC and yield monitors. Growers are encouraged to invest in yield monitors for a start. Yield maps of fields from year to year can provide useful information for demarcating management zones.

Other factors that influence yield in many eastern Oregon include slope and aspect. For example, north-facing slopes are usually drier and warmer than south facing slopes and consequently produce higher yields than south facing slopes in dry years. Under such situations farming the two slopes uniformly is inefficient use of inputs. It is even easier to demarcate management zones based on slope and aspect by visual assessments.

Once the management zones are demarcated, inputs can be applied accordingly. Applying variable rates of inputs can be achieved by simply calibrating the drill or fertilizer applicator for a given management zone. Furthermore, variable rate applicators are becoming affordable and farmers are encouraged to invest in this equipment to save time on calibrations.

Given the stagnant wheat prices, SSF offers the potential to increase profit margins and we recommend all growers to adopt this practice. Our results show that a profit of about \$9.00/acre is possible when only seeding rates and N rates were varied based on soil depth. The profit margin could be further increased if insecticides and herbicides were spot applied only to affected areas. By applying fertilizers in the right amounts where they are needed, over fertilization that increases the potential for leaching and ground water pollution, is reduced. Furthermore, SSF has the potential to reduce insecticide and herbicide resistance that may develop when whole fields are frequently and uniformly sprayed.

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## REFERENCES

- Braum, S. M., P. Hinds, G.L. Maltzer, J. Bell, D. Mulla, and P.C. Robert. 1998. Terrain attributes and soil nitrogen: Spatial effects on corn grain yield responses to nitrogen fertilization for a northern, glaciated landscape. *In* Robert, P.C., et al. (ed.) 4<sup>th</sup> International Conference on Precision Agriculture. ASA, CSSA, SSSA, Madison, WI.
- Davis J.C. 1986. *Statistics and Data Analysis in Geology*. 2<sup>nd</sup> ed. Kansas Geological Survey, John Wiley and Sons, New York.
- Everett, M. W., and F. J. Pierce. 1996. Variability of corn grain yield and soil profile nitrates in relation to site-specific N management. *In* Robert, P.C., et al. (ed.) 3<sup>th</sup> International Conference on Precision Agriculture. ASA, CSSA, SSSA, Madison, WI.
- Lowenberg-DeBoer, J and M. Boehlje. 1996. Revolution, evolution or dead-end: economic perspectives on precision agriculture. *In* Robert, P.C., et al. (ed.) 3<sup>th</sup> International Conference on Precision Agriculture. ASA, CSSA, SSSA, Madison, WI.
- Lowenberg-DeBoer, J and S.M Swinton. 1997. Economics of site-specific management in agronomic crops. p. 369-396. *In* The State of Site-Specific Management for Agriculture. ASA, CSSA, SSSA, Madison, WI.
- Khattree, R., and D.N. Naik. 2000. *Multivariate Data Reduction and Discrimination with SAS Software*. SAS Institute Inc., Cary, NC.
- Machado, S., E.D. Bynum, Jr., T.L. Archer, R.J. Lascano, L.T. Wilson, J. Bodosvsky, E. Segarra, K. Bronson, D.M. Nesmith, and W. Xu. 2000. Spatial and Temporal Variability of Corn Grain yield: Site-Specific Relationships of Biotic and Abiotic Factors.. *Precision Agriculture* 2, 343-360.
- Mallarino, A.P., P.N. Hinz, E.S. Oyarzabal. 1996. Multivariate analysis as a tool for interpreting relationships between site variables and crop yields. p. 151-158. *In* P.C. Robert, R.H. Rust, and W.E. Larson (ed.) *Proceedings of the Third International Conference on Precision Agriculture*, ASA, CSSA, SSSA, Madison, WI.
- Mulla, D.J., and J.S. Schepers. 1997. Key processes for site-specific soil and crop management. p. 1- 18. *In* F.J. Pierce and E.J. Sadler (ed.) *The State of Site-Specific Management for Agriculture*. ASA, CSSA, SSSA, Madison, WI.
- Robert, P.C., R.H. Rust, and W.E. Larson. (ed.) 1996. *Proc. Int. Precision Agriculture Conf.*, 3<sup>rd</sup>, Minneapolis, Minnesota. 23-26 June. 1996. ASA, CSSA, SSSA, Madison, WI.
- Robert, P.C., R.H. Rust, and W.E. Larson. (ed.) 1998. *Proc. Int. Precision Agriculture Conf.*, 3<sup>rd</sup>, Minneapolis, Minnesota. 19-22 Jun. 1998. ASA, CSSA, SSSA, Madison, WI.
- Solohub, M.P. C. van Kessel, and D.J. Pennock. 1996. The feasibility of factor rate N fertilization in Saskatchewan. *In* Robert, P.C., et al. (ed.) 3<sup>th</sup> International Conference on Precision Agriculture. ASA, CSSA, SSSA, Madison, WI.
- Williams, B., and D. Hoey. 1987. The use of electromagnetic induction to detect the spatial variability of the salt and clay content of soils. *Aust. J. Soil Res.* 25, 21-27.
- Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. 1994. Mapping soil test phosphorous and potassium for factor-rate fertilizer application. *J. Prod. Agric.* 7:441-448.