# Optimum Strategies for Mapping Management Zones Using Temporal Remote Sensing Information

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**Abstract**

Technological advances in variable rate application and global positioning systems (GPS) make site-specific management technically feasible. No longer do fertilizer and pesticides need to be applied uniformly across a field, they may be varied to match the soil productivity across the field. However, successful site-specific management depends on identifying management zones and the determining optimum input application rate for those zones Unfortunately, identifying management zones that are reasonably consistent from year to year has been the greatest problem to successful site-specific management. In this study we found that crop vigor measured with normalized difference vegetation index (NDVI) based on satellite (LANDSAT) remote sensing for two different years was successful for identifying management zones. Based on the NDVI, we divided a field near Shaunavon in southwestern Saskatchewan into two zones: zone 1 with low crop and vigor zone 2 with high crop vigor. The zones corresponded to differences in soils, particularly, soil moisture, but it would be too costly and impractical to try to delineate these zones from detailed soil sampling. Wheat yield and protein were more responsive to N in zone 1 than in zone 2. The optimal N fertilizer rate was 95 kg/ha for zone 1 and 75 kg/ha for zone 2. Satellite remote sensing is a cost-effective method to delineate management zones for site-specific management.

## Introduction

One way of describing the interaction between the organism and its environment is to consider it as a system influenced by three factors: controlled; uncontrolled and noise. Controlled variation comprises manipulation of inputs such as seed, nutrition, water or chemicals. These are adjusted by producers to increase the beneficial function of the plant. Uncontrolled variation describes measurable factors of known significance, such as incident radiation, temperature, rainfall or soil condition. A third source of variation, noise, is indeterminate. Fourth factor which may have influence in plant growth is temporal variation which reflect the interaction of spatial variation in soil condition with temporal variation of climate.

Site specific management accepts that variability occurs within agriculture fields spatially as well as temporally. Understanding the variability allows fields to be divided into relatively uniform units, which can be managed using techniques such as variable-rate fertilization or spraying. Information related to the in-field nutrient variation is a critical step, both in identifying the variability within the field and in providing appropriate fertilizer recommendations.

**Objectives**

The primary objective of this study was to analyze in-field spatial and temporal variability for better understanding of field productivity using remote sensing information. The secondary objective was to identify factors affecting field productivity, and to develop a methodology to minimize the effect of temporal variability by identifying management zones.

**Materials and Methods**

<u>Field Study</u>

The study site was near highway 13, 11 km NE of Shaunavon (NE10-09-18W3) covering 23 ha. (Figure 1) . Spring wheat (Triticum aesitivum L. ) were planted with uniform fertilization rate (40 kg of N/ha) before the start of the experimentation in 1997. The experiment area were planted with spring wheat during the four years of the experiment. At the start of the experiment in 1997, the study area was divided into 25 plots (plot number assigned east to west from 0 to 24 ). Each plot inside the study area (bounded by white polygon (Figure 1) with plot width 14.8 meters) received different amount of nitrogen fertilizer in 1997, 1998, and 1999, but in 2000 it was planted under uniform nitrogen fertilizer. The field topography was mapped using global positioning system(GPS) (Figure 1) .

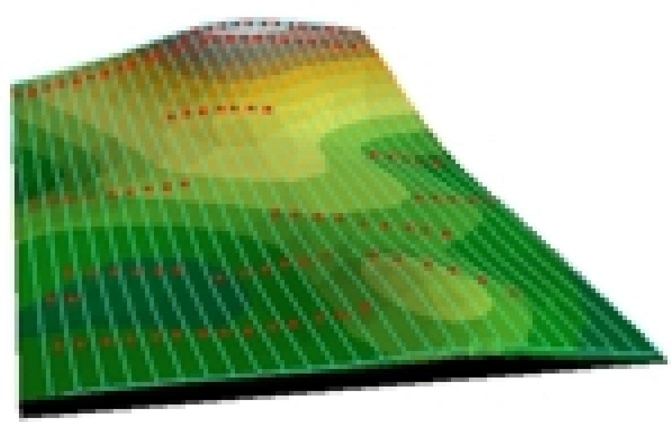


Figure 1. Topography and Sample location of the Study area

Maximum local relief is 29 meters and slopes ranging from 0 to 5 percent. Soils of the area consists of Amulet Association and Wymak Association developed in clay loam glacial till and silty loessial over till (Saskatchewan Soil Survey 1988). For most part, soils of the Amulet Association are expressed on shoulders and tops of the knolls, while soils of Wymark Association are expressed in the mid- and lower-slope positions. The calcareous soils on the tops of the knolls (Meinert 1996). During the experiment herbicides were applied as required.

Weather conditions and grain yield

Water and N are the primary factors determining stubble crop yields in the Canadian prairie (Campbell et al. 1997). The health of a crop gives a fairly reasonable about the availability of these limiting factors with the assumption that other factors influencing the crop conditions are under control. Hence, we have analyzed these factors in terms of their spatial as well as temporal variability. These variability were accounted for using the information extracted from satellite remote sensing and by analyzing soil samples collected each year. Soil moisture was determined gravimetrically 0-15, 15-30, 30-60, 60-90, 90 -120 cm increment and converted to volume and nitrate information were extracted from the soil samples collected during April-May before planting and yield information were collected using a plot combine representing all landscape position. These point observations were used to create surface covering the study area using Kriging interpolation (Goovaerts 1997). The cell size of the each surface created were matched to that of Landsat TM information. Weather data came from Environment Canada weather station at Shaunavon.

Management Zones, Crop Vigor, and Grain Yield

Normalized difference vegetation index (NDVI) were extracted using Landsat TM information of the growing season of the year 1996 (year before the start of the field experiment), 1997 first year of the experiment), 1999 (last year of the experiment) and year 2000 (year after the field experiment). The NDVI is the difference of near-infrared and visible red reflectance values normalized over total reflectance of the two channels (Lillesand and Kiefer 1994) as follows:

$$NDVI = \frac{ValueofInfraredBand - Valueof\ \mathrm{Re}dBand}{ValueofInfraredBand + Valueof\ \mathrm{Re}dBand} \quad (1)$$

To compare the temporal information, NDVI and grain yield information were normalized in order to remove difference in scale among the variables (Stevenson et al. 2001) as follows:

$$X_i = \frac{x_i - (\bar{x} - 2S.D.)}{4S.D.} \quad (2)$$

Where:

Xi = The transformed value.

xi = The observation i.

$\bar{x}$ = The mean of the observations.

S.D. = Standard Deviation

The temporal variation were analyzed by comparing management zones identified by the NDVI. The difference in management zones delineated using 1996 and 2000 information showed the variation before and after the variable rate fertilizer treatment, whereas difference between 1997, and 1999 showed the the temporal variability due to climate and treatment effects. Based on the average of 1996 and 2000 NDVI information, optimal management zones were delineated. Normalized grain yield of 1997, 1999 and 1999 inside each management zones were compared to validate the management zones. Least significant difference tests were used to Determine differences in means of normalized grain yield and normalized grain protein for the year and management zone effects.

Crop Response to N-fertilizer in each management zone

The magnitude of the yield and protein response to the fertilizer treatments were obtained by analyzing pooled data from the year 1997, 1998,1999 and 2000. Equations were fitted to represent the relationship between wheat yield or grain protein and N fertilizer applied. The equation fit to the yield-N supplied and protein-N used were used to derive the optimal N rate to produce maximum yield and grain protein. Separate N rate response curves were developed for the two management zones.

## Results and Discussion

Weather conditions and grain yield

Growing season precipitation are presented in the Table 1 along with maximum and average grain yield. Except for 1996, growing season precipitation during the study period were at about thirty years(1959-1987) average(172 mm) or above average. From the Table 1, it can also be seen that not only the amount of precipitation before or during the growing season that matters, but also the timing of in-season precipitation matching the important phenological events matters too. When overall precipitation (from harvesting of previous year crop to physiological maturity of current season crop) and grain yield of each year were compared, it was seen that overall cumulative high precipitation in a year does not necessarily mean high yield In addition to the spring soil moisture availability, the amount of precipitation received up to the time of 4 to 5 leaves stage(Table 1) may play an important role in determining grain yield levels. Sum of spring soil moisture and precipitation after seeding and up to the 4 to 5 leaves stage reveal the relationship between moisture and grain yield of 0.101 ton per hectare per centimeter of increase in soil moisture.

Table 1. Relationship between Grain Yield and Moisture Level.

| Explanatory Variable | $R^2$ | Regression Coefficients | |
|---|---|---|---|
| | | Constant | Explanatory Variable |
| Cumulative Precipitation up to 10 days after seeding | 0.51 | 1587* | 7.96 |
| Cumulative Precipitation up to 38 days after seeding | 0.76 | 373.24* | 14.91* |
| Cumulative Precipitation up to 115 days after seeding | 0.55 | 3142* | 6.48 |
| Cumulative Precipitation before seeding | 0.62 | 730.91* | 4.33 |
| Spring Soil Moisture | 0.73 | -488* | 15.78* |
| Spring Soil Moisture+ Cumulative Precipitation up to 38 days after seeding | 0.98 | -608.65* | 10.07* |

*Significant at 5%

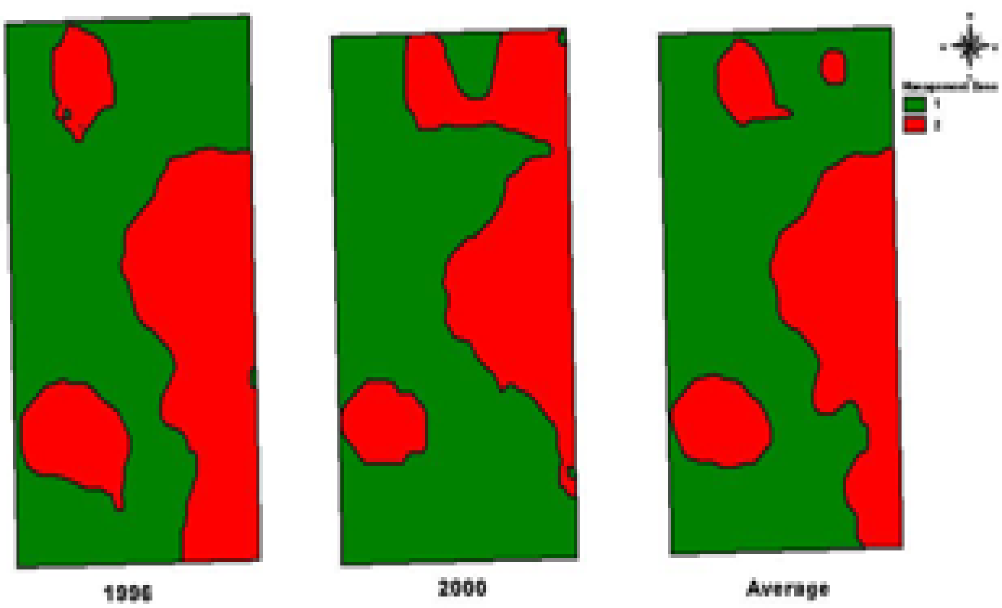



**Figure 2**. Management Zones based on Spatio-Temporal Variation in Crop Vigor.

**Management Zones, Crop Vigor, and Grain Yield**

NDVI extracted using 1996 and 2000 Landsat TM data is presented in Figure 2. The vegetation index were normalized using the relationship shown in the equation 2 for comparison. The data are then grouped into two different classes. Area with low NDVI (average or below average values) were grouped together as "management zone 1" and high NDVI area (area with above average values) were assigned as "management zone 2". Individually, classification of 1996 data revealed the spatial variability in relatively dry weather condition, and classification of 2000 data showed the pattern in relatively wet weather condition. The variations in the spatial pattern among these two years were due to the past treatment effects (lag effect of the past fertilizer application) and climatic variation or other variations which were not accounted for. The final management zones were created using average of information from 1996 and year 2000. When the management zones identified using individual year information were compared with the final management zones(average of 1996 and 2000), it was observed that only 9 percent to 25 percent of the total area are showing inconsistency in classification (Table 2).

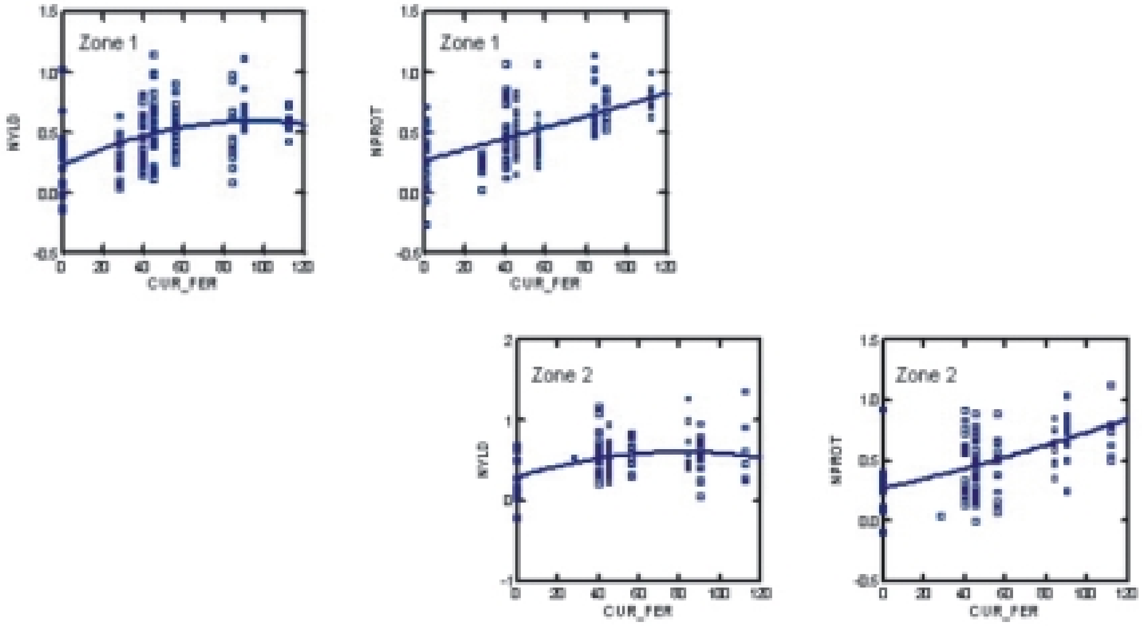
Grain yield normalized (calculated using equation 2 ) for each year of the study and the interaction of the management zone is presented in Table 3. Grain yield were always lower in the zone 1 (below average) whereas zone 2 always yielded more (above average) except for the year 1997. In 1997 average grain yield from each zone were near average. This may be due to the fact that in 1997 N rate varied from 0 to 112 kilogram per hectare and in-season precipitation was near long term average. Therefore, low vigor zone could match the productivity of high vigor zone. In the second year (1998) and third year (1999) of the variable rate trial, the rate were changed to 0, 44.8 and 89.6 kg per hectare. The change in N rate and variation in in-season precipitation has resulted in lower yield from the zone 1 where as zone 2 has shown improvement.

<u>Crop Response to Variable N-fertilizer</u>

The magnitude of the yield and protein response to the fertilizer treatments were obtained by analyzing pooled data from the year 1997, 1998,1999 and 2000. Figure 3 shows the grain yield and grain protein response patterns to variable N-rate. response using pooled information . It can be seen from these figure that fertilizer response of grain yield can be described using quadratic equations, whereas the response of grain protein can be approximated with linear functions (Figure 3). The presence of a positive linear and a negative quadratic coefficient for N rate in the case of grain yield regressions indicate that fertilization with N increases yields at a decreasing rate with each extra unit of N rate until a maximum yield increase is reached (Table 4), further increase in N rate resulted in reduction in yield.

**Table 2.** Changes in the Coverage of Management Zones in Comparison to "Average" Condition

| | Year | | | |
|---|---|---|---|---|
| Change | 1996 | 1997 | 1999 | 2000 |
| Decreased | 7% | 20% | 19% | 8% |
| Same | 91% | 75% | 75% | 83% |




| | | | | |
|---|---|---|---|---|
| Increased | 2% | 5% | 6% | 9% |

**Figure 3.** Relationship between Normalized Grain Yield and Normalized Grain Protein and N Fertilizer.

Table 3. Between Zone Spatial and Temporal Comparison of Grain Yield & Protein.

| | | Year | | | |
|---|---|---|---|---|---|
| | Zone | 1997 | 1998 | 1999 | 2000 |
| Grain Yield | 1 | 0.49[a] (0.23)[Z] | 0.44[a] (0.18) | 0.46[a] (0.22) | 0.41[a] (0.15) |
| | 2 | 0.50[a] (0.25) | 0.62[b] (0.25) | 0.60[b] (0.24) | 0.71[b] (0.31) |
| Grain Protein | 1 | 0.47[a] (0.10)[Z] | 0.50[a] (0.11) | 0.48[a] (0.11) | 0.48[a] (0.11) |
| | 2 | 0.55[b] (0.13) | 0.51[b] (0.07) | 0.48[a] (0.11) | 0.48[a] (0.12) |

[Z] Standard deviations are presented in parenthesis.

a and b Means followed by same letter within each column are not significantly difference according to LSD(0.05).

**Table 4.** Relationship between Grain Yield and Protein with Variable N fertilizer

| Dependent Variable | Zone | Coefficient of Explanatory Variable | | | |
|---|---|---|---|---|---|
| | | Constant | Current Fertilizer | Previous Fertilizer | (Current Fertilizer)$^2$ |
| Normalized Yield | 1 | 0.1731*[a] | 0.00304*[a] | 0.00328*[a] | |
| | 2 | 0.3874*[a] | 0.00229*[a] | 0.00039 [a] | |
| Normalized Yield | 1 | 0.313*[a] | 0.00328*[a] | | |
| | 2 | 0.408 [a] | 0.00225*[a] | | |
| Normalized Yield | 1 | 0.228*[a] | 0.00761*[a] | | -0.00004* |
| | 2 | 0.297*[a] | 0.0075*[a] | | -0.00005* |
| Normalized Protein | 1 | 0.268* | 0.00458* | | |
| | 2 | 0.249* | 0.00476* | | |
| Normalized Protein | 1 | 0.164* | 0.0044* | 0.00244* | |
| | 2 | 0.0939 | 0.0051* | 0.00294* | |
| Spring Soil N | 1 | 43.62* | | 1.14* | |
| | 2 | 47.75* | | 0.77* | |

*Significant at 5 %.

[a] Coefficients of Zone 1 and Zone 2 are statistically not equal (at 5%)

**Conclusions**

The management units developed in this study, were based on the crop response (NDVI is used as a proxy of this) and simple clustering process. T he variable rate fertilization is only applicable to fields with distinct area behaving differently due to variation in soil or topographical properties. The success of site-specific management rests on the ability to identify the area with different crop response to added inputs which are manageable practically and cost of such changes in the management will have to be comparable to conventional practices. The best strategy is to fertilize for a yield goal balancing both quality and quantity, realizing that any additional nitrogen will result in either a yield increase, if additional water is available or a protein response if yield requirements have already been satisfied.

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