In-Field Management Zone Delineation from Remote Sensing Imagery.

Yann Pelcat[1], Brian McConkey[2], Prakash Basnyat[2], Guy P. Lafond[3], Alan Moulin[4]
[1] Indian Head Agricultural Research Foundation, Indian Head, SK
[2] Semiarid Prairie Agricultural Research Centre, Swift Current, SK
[3] Indian Head Research Farm, Indian Head, SK
[4] Brandon Research Centre, Brandon, MB

Executive Summary
Precision farming concepts have the potential to greatly increase the efficiency of cropping inputs like fertilizers. In turn, the ability to more accurately match the fertility requirements of a crop to different landscapes and areas within a field not only has economic benefits but beneficial environmental effects as well. The first step in a variable rate fertility program is the identification of management zones in a field. The objective of this project was to develop low cost ways of assigning management zones to a field. The approach of using grid soil sampling is too time consuming, expensive and highly variable. A number of other techniques were investigated and it was found that satellite imagery combined with a classification procedure, in this case Fuzzy K-means, offered the best potential in terms of cost. The method consisted of acquiring satellite imagery from Landsat 7 and extracting the normalized difference vegetation index (NDVI) using the red and infra-red bands. The clustering algorithm then classified the imagery into groups having similar NDVI values. The identified groups then became the management zones for a given field. The robustness and accuracy of the zones were then verified using yield data collected from combines equipped with yield monitors. A number of fields were investigated at different areas in Saskatchewan ie. Shaunavon, Young, Semans and Indian Head. The results showed that it was possible to delineate unique management zones using this approach as verified from yield maps. The next step is to determine how to manage these zones in order to extract the higher production efficiency from those zones.

Introduction
Variable-rate fertilization (VRF) management systems can improve the efficiency of fertilizer use and contribute to greater environmental sustainability. The technical issues of applying differing rates of fertilizers on different areas of a field during field operations is no longer the stumbling block to the broader application of precision agriculture. The limitation to VRF is finding cost effective ways of identifying management zones that will behave similarly to fertilizer input and to determine the best management approach for each zone.

The reflectance of wavelengths between 0.63 micrometers (red) and 0.90 micrometer (near-infrared) is related to chlorophyll abundance and energy absorption (Buschman and Nagel 1993; Jacquemound andBaret 1990). Chlorophyll abundance and energy absorption correspond to photosynthetic capacity hence plant growth and vigor (Tucker 1979). Measurements of canopy reflectance has been used to provide information on crop biomass (Bedford et al. 1993), leaf area index (Bouman et al. 1992), nutrient deficiency (Penuelas et al. 1994), water stress (Penuelas et al. 1994), diseases (Nilsson 1995), and grain yield (Zhang et al. 1998). Reflectance can be measured from ground platforms, including handheld, but more usually the reflectance is measured remotely from sensors on aircraft or satellites. Such remote sensing represents a relatively simple and low-cost way to gain information about a crop over an entire field. Remote sensing provides different information from mapped grain yields and so can be used in conjunction with mapped grain yield for identifying spatial patterns. Although measurement of canopy reflectance from ground platforms over large areas would normally be considered too expensive for practical application, there is research underway to use machine-mounted canopy reflectance sensors for on-the-go adjustment of application rates during top-dressing fertilizer or during foliar fertilizer or fungicide application (Raun et al. 1998; Tarpley et al.. 2000).

The optimal time for acquiring remote sensing images usually is from early July to early August -early (including into late June) depending on the type of crop. Remote sensing imagery is appropriate for crops that will mature earlier because of either their phenology or seeding date and later remote sensing is best for crops that will mature later in August or September (Basnyat et al. 2003). Canola is problematic for identifying spatial patterns in the land from remote sensing because of its highly reflective flowers and habit of dropping leaves after flowering therefore earlier imagery acquisition time is the best. Cereals are the most reliable crops to remotely sense and identify spatial patterns. Although data from Landsat satellite is inexpensive, the spatial resolution is very coarse (20-30 m). Basnyat et al. (2004) determined that satellite remote sensing (Landsat 7) was better than digitized color infrared photographs for delineating zones of similar crop and soil attributes. Many current VRF machines cannot change rates over their width (12+ m) or within travel distances of less than 10 m so a practical minimum dimension for management zones is about 20 to 30 m which Landsat-7 imagery is appropriate. An important additional advantage of satellite imagery is its low cost per unit compared to aerial photographs eg: Landsat 7 ETM+ costs about CAN$700 for 185 X 172 km versus aerial photography at about CAN$300 for a few km^2 . Reflectance information is commercially available at finer resolution (1 to 4 m) from satellites such as IKONOS and Quickbird, but it must be pre-ordered and is many times more expensive than that from coarser resolution satellites such as Landsat 7. Landsat information has been archived for several decades so it is possible to select multiple years or specific years of interest for analysis.

The objective of this study was to evaluate the combined use of satellite remote sensing and grain yield information for identifying and verifying management zones for four different fields in central Saskatchewan.

Materials and Methods

Four fields in Saskatchewan were selected for this experiment. The data used in the analysis were yield maps and Landsat-7 ETM+ imagery.

Management zone delineation:

Vegetation Index:

The process of management zone delineation starts by selecting cloud free Landsat-7 imagery over the research sites. Acquisition of satellite imagery ranged from mid-July to early August for the period 1998 to 2002. A Normalized Difference Vegetation Index (NDVI) was created for each year and each field using the red (RED) and near-infra red band (NIR) using the following relationship:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

The two NDVI images were averaged to obtain one NDVI image for both years. The averaged NDVI map was clustered using FuzzMe software to create management zones for each field.

Determination of the optimum number of zones

The main objective of unsupervised classification or clustering was to identify naturally occurring clusters in image dataset, in this case NDVI maps. The clustering algorithm used was the fuzzy k-means with extragrades (deGruijter & McBratney 1988) which is a modification of fuzzy c_means (Bezdek, 1981). This modified algorithm assumes that continuous classes would provide better representations of outliers than discontinuous classes. The fuzzy k_means algorithm gives intermediate membership to intragrades (outliers located between clusters in property space) and not to extragrades (outliers outside the main body of data points). DeGruijter & McBratney (1988) modified the objective function to account for extragrades. This improvement made the memberships directly dependent on the distance to the class centroids. The classification was done using the software program "FuzME" and was developed at the Australian Centre for Precision Agriculture (Minasny and McBratney 2000). This software determined membership in each cluster through an iterative process beginning with a random set of cluster means. Each observation was assigned to the closest of those means. New means were recalculated for each cluster based on the distance (Euclidean, Diagonal, or Mahalanobis) from the observation to cluster mean. To ensure cluster stability, the process was repeated until either the specified convergence criterion was met or the maximum number of iterations, stopping criterion, fuzziness exponent, and distance metric were executed. The software generated a data file containing each observation, the cluster to which it belonged, and a vector of membership values to indicate how closely each individual resembled each cluster. To obtain good convergence, a stopping criterion of 0.00001 was used in this study, which meant that the change in membership with an iteration of means calculation was less than 0.00001. Because the variables used for classification exhibited significantly different ranges, the distance metric was set as to Mahalanobis. In this mode, the data set was transferred to one in which all attributes had zero mean and unit variance. Correlations between variables were accounted for as well (McBratney and Moore, 1985). The optimum number of zones were decided based on the fuzziness performance index (FPI) and modified partition entropy (MPE). FPI estimated the degree of fuzziness generated by a specified number of classes. MPE estimated the degree of disorganization created by a specified number of classes. The optimum number of classes was established on the basis of minimizing these two measures (Roubens 1982).

Yield data :

The fields were harvested using a commercial combine equipped with a GPS antenna and yield monitor. Each producer was responsible for calibrating their yield monitor and collecting the yield data. Yield maps were recorded onto a PC card and transferred onto a home PC for further analyses. The raw yield data was kriged using GS+ software to create a smooth continuous yield map. Using ArcView GIS, mean grain yield was extracted on a 1 acre basis within each management zone and an analysis of variance was used to test the difference in yield between zones at the 0.05 level of confidence.

Results

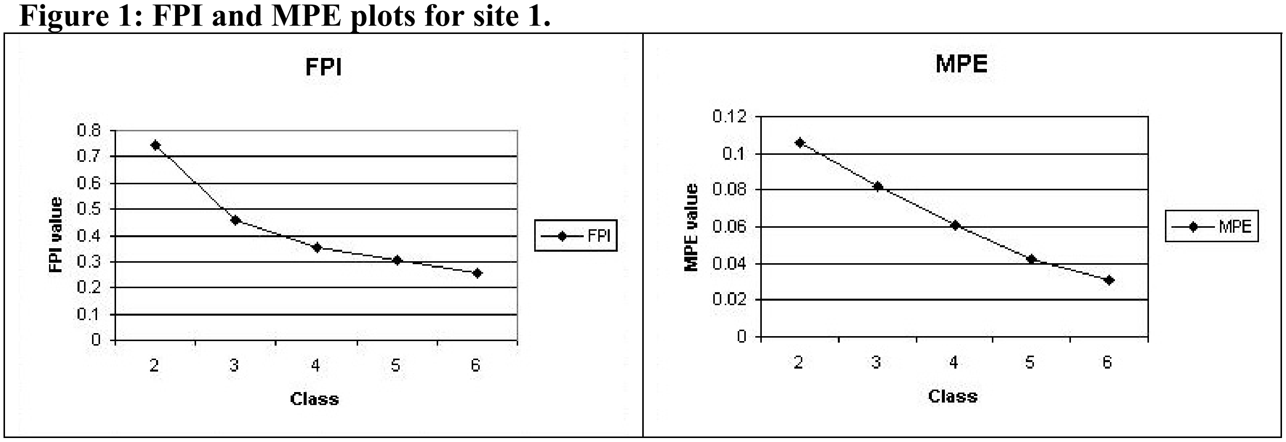
Site 1

A 320 ac field located in the RM # 279 of Mount Hope north-east of Semans , SK was selected as one of the fields. The area was in the moist dark brown soil zone area. The Weyburn Loam soil was classified as class 3 for 80 % of the field area due to limitation in moisture holding capacity and the remaining 20% as class 5 because of wetness (ARDA, 1966). The rolling landscape offered few knolls and depressions, but permanent sloughs were present. The field was continuously cropped with uniform rates of N, P and K since 1998. A crop rotation of cereal-pulse-cereal-oilseed crop was implemented in 2001.

Management zone delineation:

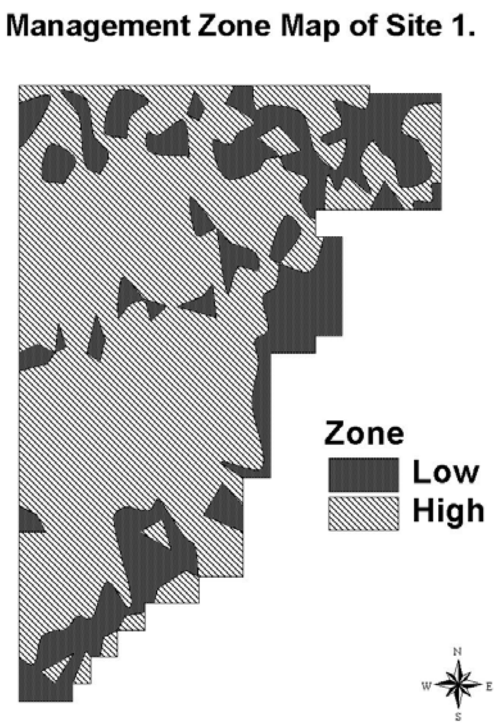
An NDVI image was created from two Landsat-7 image (July 23rd, 2002 and august 5th , 2001) and averaged into one for zone delineation purposes. The Fuzme software was used to divide the study area into two to six zones using NDVI as the input variables. After classification, the optimum number of management zones was determined using the Fuzzyness Partion Index (FPI) and Modified Partition Entropy (MPE). The FPI and MPE modeled the variation in the attributes used to perform the classification which then serves as the first step in the determination of the optimum number of zones. The FPI is a measure of the degree to which different classes share membership and is constrained to values between 0 and 1. As FPI approaches 1, membership sharing increases. As the FPI approaches 0, classes become more distinct with less membership sharing. The MPE is an estimate of the amount of disorganization created by a specified number of classes. Like the FPI, it was also constrained to a value between 0 and 1. As MPE approaches 1, disorganization predominated while values approaching 0 indicated excellent organization. Plotting the values of FPI and MPE against the number of classes and choosing a classification that minimized both measures was the criteria used in the identification of the optimum number of zones shown in Figure 1:

Figure 1: FPI and MPE plots for site 1.



The decision criteria for selecting optimum number of zones should be based on the minimum of both FPI and MPE. However if too many zones are selected, based on the lowest FPI and MPE value, the lack of distinct zones would have been apparent. Therefore the optimal number of zones selected is based on the greatest improvement in degree of membership and organization between classes. The FPI had the greatest change in membership from 2 to 3 classes and MPE decreases linearly from 2 to 6 classes. Therefore, a value of 2 was chosen as the optimum number of classes for this particular field (Figure 2). The validation of the two zones selected was done using grain yield maps from 2001 and 2002 .

Figure 2: Management zone map delineated from Landsat-7 Imagery.



Yield Data Verification:

Using ArcView GIS software, yearly mean grain yield per zone was calculated using an overlay function. Mean grain yield for 2001 and 2002 is summarized in Table 1 and 2, respectively. An LSD test revealed that yields were significantly different between zones each year which confirmed the accuracy of the management zone boundary delineated from Landsat-7 imagery.

Table 1: 2001 Mean crop yield (bu/ac) per management zone for site 1:

	Year 2001 (Peas)
Zone 1	21.4 a
Zone 2	25.2 b

(Means followed by the same letter are different at the 5% level using an LSD)

Table 2: 2002 Mean crop yield (bu/ac) per management zone for site 1:

	Year 2002 (Wheat)
Zone 1	22.2a
Zone 2	27.0 b

(Means followed by the same letter are different at the 5% level using an LSD)

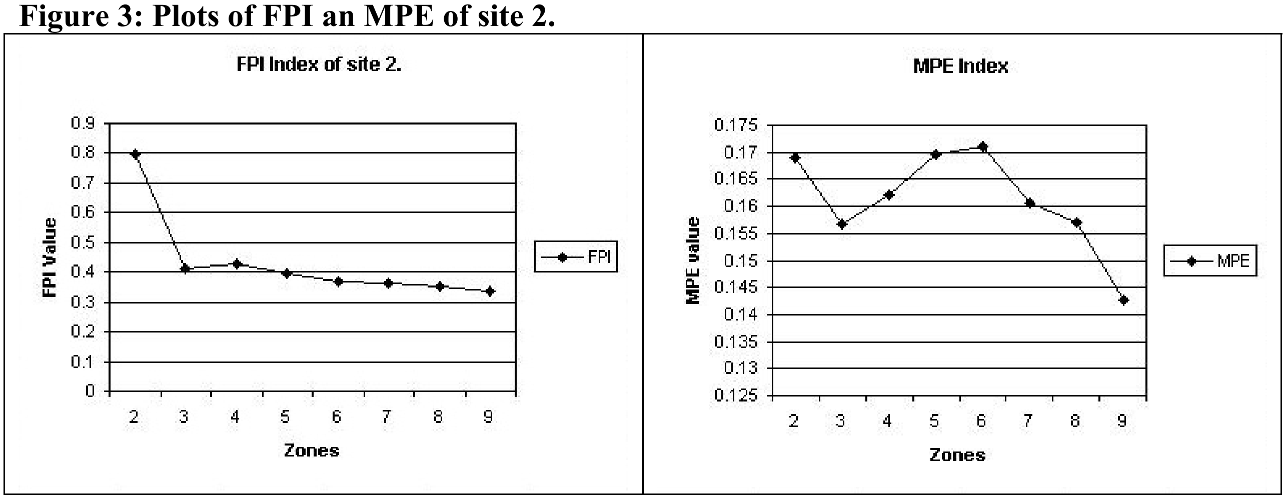
Site 2:

A 160 ac field south of the town of Young SK. in the RM #132 of Morris was selected. The area of interest was in the moist dark brown soil zone. The soil in the north part of the quarter was classified as a Weyburn Loam, with 70% of the area placed in class 3 due to limitation in moisture holding capacity and the remaining 30% of the area in class 5 due to wetness and excess stoniness. The Weyburn Clay Loam soil present in the south part of the field was classified as class 3 soil in 80% of the field area due to limitation in moisture holding capacity and the remaining 20% of the area in class 5 due to wetness (ARDA, 1966). The field had been continuously cropped with conventional rates of N, P, K S since 1999. The rolling landscape offered knoll and depression areas that flooded easily during heavy rainfall events.

Management zone delineation.

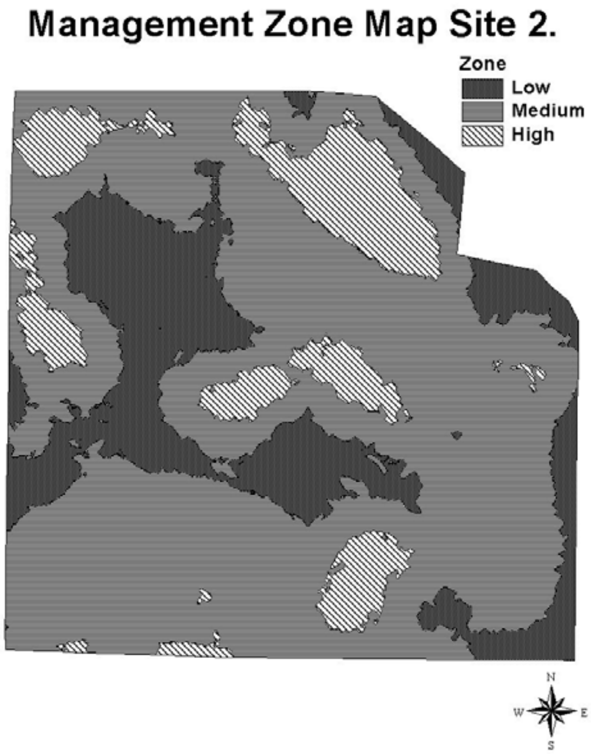
Two NDVI images were created from two Landsat-7 images (July 23rd, 2002 and august 5th , 2001) and averaged into one for zone delineation purposes. The Fuzzme software delineated the NDVI into several management zones and calculated the FPI and MPE for each possible scenario. Plotting the values of FPI and MPE against the number of classes (Figure 3) and choosing a classification that minimized both measures was the criteria used in the identification of optimum number of zones.

Figure 3: Plots of FPI an MPE of site 2.



The decision criteria for selecting the optimum number of zones was based on the greatest improvement in degree of membership and organization between classes. The FPI had the greatest change in membership from 2 to 3 classes and MPE changed drastically from 2 to 3 then increased to 6 classes and decreased again from 6 to 9 classes. Therefore the greatest improvement in both FPI and MPE occurred at the 3 class level which was used to create the management zone map illustrated in Figure 4. To validate the two zones selected, mean grain yield from yield maps of 2001 and 2002 were used.

Figure 4: Management zone map for site 2.



Yield Verification

To verify the accuracy of the 3 management zones, mean grain yield per management zone was calculated using yield maps of 2001 and 2002 and Arcview GIS software. Yearly mean grain yield per management zone is summarized in the Table 3 and 4.

Table 3: 2001 Mean crop yield (bu/ac) per management zone for site 2.

Zones	Year 2001 (Barley)
Zone 1 (low)	32.3a
Zone 2 (medium)	34.0b
Zone 3 (high)	40.1c

(Means followed by the same letter are different at the 5% level using an LSD)

Table 4: 2002 Mean crop yield (bu/ac) per management zone for site 2.

	Year 2002 Field Pea
Zone 1 (low)	10.4a
Zone 2 (medium)	10.1a
Zone 3 (high)	9.24a

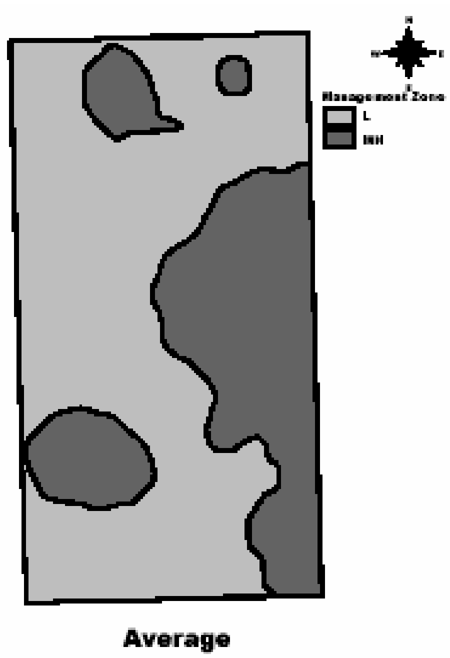
(Means followed by the same letter are different at the 5% level using an LSD)

Results show that yields were significantly different between zones in 2001 which confirmed the accuracy of the management zone map created from satellite images. However , due to a lack of rainfall events during the 2002 growing season, field pea yields were not different between the chosen zones.

Site 3:
This site was a 59 acre field located 11 km NE of Shaunavon, SK in the dark brown soil zone. The topography was hummocky with a maximum local relief of 29 m and slopes ranging from 0 to 0.05 m m^{-1}. Soils consisted of Amulet Association and Wymark Association (Orthic Dark Brown Chernozemic) developed in clay loam glacial till and silty loess over till, respectively (Saskatchewan Soil Survey 1988). For the most part, soils of the Amulet Association occurred on the shoulders and tops of knolls, while soils of the Wymark Association occur in the mid and lower slope positions. The field was in continuous wheat production system from 1996 to 2000.

Management zone delineation:
Two NDVI maps were created using the red and near-infrared bands from an August 15, 1996 Landsat-5 image and from an August 16, 2000 Landsat-7 image. The two NDVI maps were averaged into one and using IDRISI software, an unsupervised classification was performed on the image. The unsupervised classification allowed the input of a desired amount of zones to be delineated from the NDVI image hence creating several possible zone scenarios. The scenarios delineated the field in 2 to 9 zones. Using ArcView GIS, mean grain yield for each zone was calculated and compared using least significant difference test (LSD) at a probability of 5% in each scenario. The optimal number of management zones for the field was determined when the zones were significantly different from each other in terms of yield. In this case, two (2) zones best fitted the field as illustrated in Figure 5.

Figure 5: management zone Map for site 3:



The mean yield per management zone is summarized in Table 5. Yields were significantly different between the two zones in all years.

Table 5: Mean normalized yield per management zone for 1997-2000 for site 3.

Zone	Year			
	1997	**1998**	**1999**	**2000**
L	0.46a (0.02)[Z]	0.42a (0.03)	0.47a(0.04)	0.42a(0.03)
MH	0.65b(0.07)	0.66b(0.07)	0.56a(0.07)	0.62b(0.07)

[Z] Standard errors of mean in parenthesis
Means followed by the same letter are different at the 5% level using an LSD

Site 4:

Located in the black soil zone, the 308 acre site was 2 miles east of the Town of Indian Head, SK. The half section of land was divided in eight 40 acre fields and a crop rotation of wheat-peas-wheat-canola was superimposed in 1998. The Landscape present was near level to gently undulating, becoming inclined near a waterway that runs diagonally across the area from SW to NE. The soils are predominately Indian Head clay developed on uniform lacustrine materials with some Edgeley and Oxbow soils in southern part of the site where the underlying glacial till in near the surface.

Management zone delineation.

Two NDVI images were created using the red and near-infrared band of two Landsat-7 images (July 13th, 1998; July 26th, 1999). The NDVI images were averaged into one for zone delineation purposes. The averaged NDVI image was clustered into 2 to 13 management zones using Fuzzme software. Based on the the FPI and MPE plots (Figure 6), the greatest improvement in the degree of membership and organization between classes occurred at three (3) zones, which was used to create the final management zone map(Figure 7).

Figure 6: Plots of FPI and MPE for Site 4.

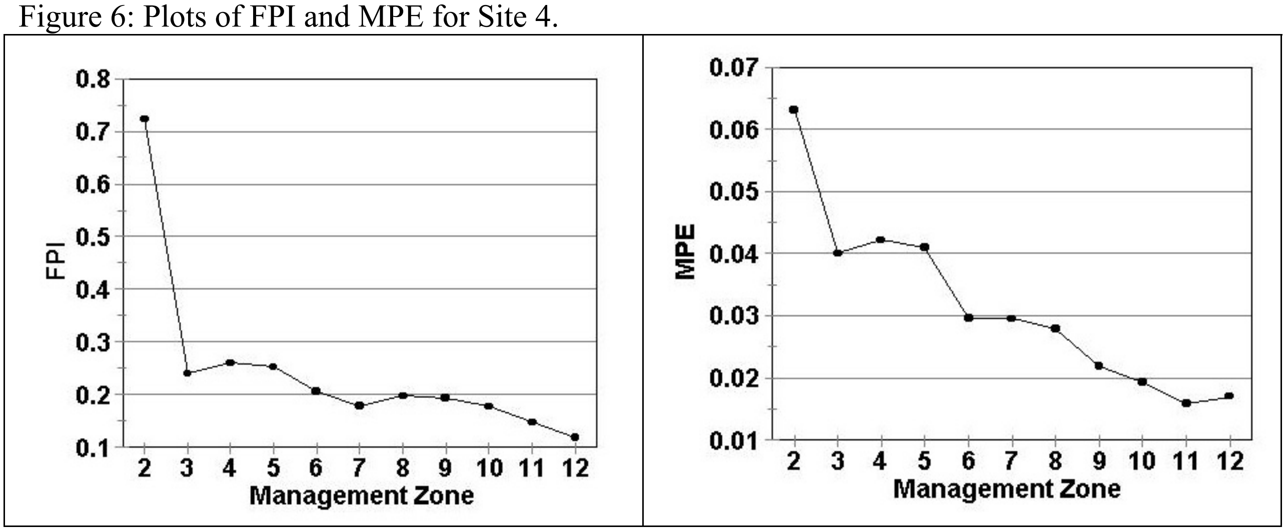
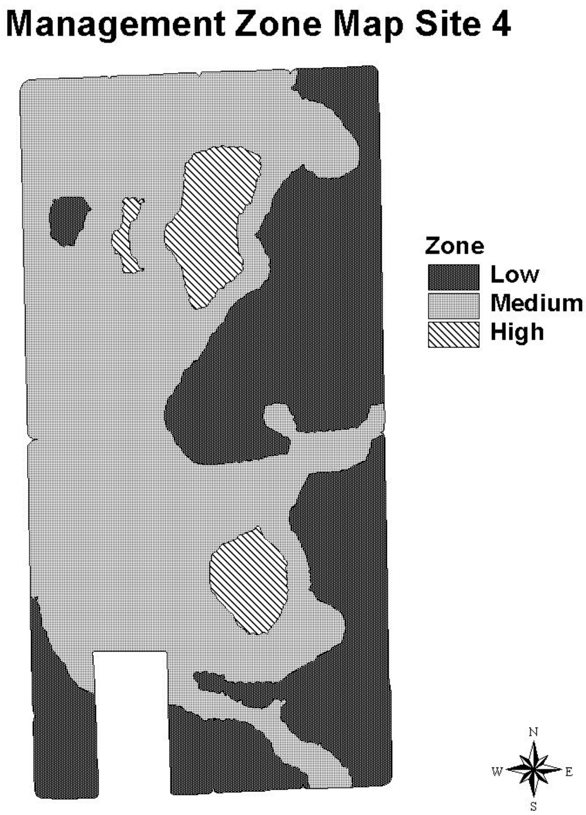


Figure 7: Management Zone map of site 4.



Yield Verification

Yield data of 1998 ,1999 and 2001 was normalized in order to compare yield trends over time. Using ArcView GIS software, yearly mean grain yield per zones was calculated using an overlay function. Mean grain yield per zone for 1998-1999 and 2001 is summarized in Table 6 and 7, respectively. An LSD test revealed that yields were significantly different between zones each year which confirmed the accuracy of the management zone boundary delineated from Landsat-7 imagery.

Table 6: 2001 Mean crop yields (bu/ac) per management zone for site 4.

Zones	Year 1998-1999
Low	0.29a
Medium	0.47b
High	0.67c

(Means followed by the same letter are different at the 5% level using an LSD)

Table 7: 2002 Mean crop yield (bu/ac) per management zone for site 1:

Zones	Year 2001
Low	0.41a
Medium	0.48b
High	0.63c

(Means followed by the same letter are different at the 5% level using an LSD)

Conclusions:

A new method for delineating management zones in a field was tested for four different fields in different areas of Saskatchewan. The first step was to create a normalized difference vegetation index (NDVI) from Landsat-7 archived satellite images acquired either in late July or early August over the area of interest using the red and near infrared bands. The NDVI created for each year were averaged to create one vegetation map per field. Using fuzzy k_means with the extragrades clustering algorithm, a map was developed with different clusters or zones. The optimal number of zones was selected based on the fuzziness partition index (FPI), modified partition entropy (MPE) and geo-referenced yield maps. The zones delineated were significantly different from each other in terms of yield which confirmed the accuracy and robustness of the method tested. This study has demonstrated that it is possible to delineate management zones that are robust and low-cost using Landsat-7 imagery. In turn, these zone maps could be used as a base for soil sampling, scouting or even for a variable rate application program.

Acknowledgements

IHARF would like to acknowledge the sponsorship of New Holland North America and Markusson Country of Regina, Simplot Canada, Bayer Crop Sciences and all of the IHARF Precision Farm sponsors listed on our web site: WWW.IHARF.CA
Furthermore, IHARF would like to acknowledge Dr. Prakash Basnyat, Dr. Brian McConkey, Dr Alan Moulin and Dr. Guy Lafond for their expertise and Chris Omoth for his technical support.

References

A.R.D.A., Soil capability and land inventory maps, 1966, Saskatchewan Institute of Pedology - University of Saskatchewan.

Basnyat, P. McConkey, B., Lafond, G.P., Moulin, A., and Pelcat Y. 2003. Optimal time for remote sensing to relate to crop grain yield on the Canadian Prairies. Can. J. Plant Sci. (submitted).

Basnyat, P. McConkey, B., Meinert, B. Gatkze, C., and Noble, G. 2004. Agriculture field characterization using remote sensing. The Transactions of Geoscience and Remote Sensing (in preparation).

Bedford, R.K., E.R. Harvey, and P. Di Prinzio 1993. Remote sensing of crop biomass with a hand-held multispectral radiometer. P 392. In Proc. 7the Aust. Agron. Conf. Adelaide, Australia.

Bezdek, J.C., 1981. Pattern Recognition with Fuzzy Objective Function Algorithms. Plenum Press, New York.

Bouman, B.A. M., H.W.J. van Kasteren and D. Uenk 1992. Standard relations to estimate ground cover and LAI of agricultural crops from reflectance measurements. Eur. J. Agron. 1:249-262.

Buschman, C. and E. Nagel, 1993. In vivo spectroscopy and internal optics of leaves as basis for remote sensing of vegetation. Int. J. Remote Sensing. 14: 711-722.

deGruijter, J.J., McBratney, A.B., 1988. A modified fuzzy k means for predictive classification. In: Bock,H.H.(ed) Classification and Related Methods of Data Analysis. pp. 97_104. Elsevier Science, Amsterdam.

Jacquemound, S. and F. Baret, 1990. PROSPECT: a model of leaf optical properties spectra. Remote Sensing Environment. 34: 75-91.

McBratney, A.B., Moore, A.W., 1985. Application of fuzzy sets to climatic classification. Agricultural and Forest Meteorology 35, 165_185.

Minasny, B., McBratney, A.B., 2000. FuzME version 2.1, Australian Centre for Precision Agriculture, The University of Sydney, NSW 2006. http://www.usyd.edu.au/su/agric/acpa).

Nilsson, H.E. 1995. Remote sensing and image analysis in plant pathology. Annu. Rev. Phytopathol 15:489-572.

Peneuelas, J., J.A. Gamon, A.L. Fredeen, J. Merino, and C.B. Field 1994. Reflectance indices associated with physiological changes in nitrogen and water-limited sunflower leaves. Remote Sens. Environ. 48:135-146.

Raun, W.R., Johnson, G.V., Sembiring, H., Lukina, E.V., LaRuffa, J.M., Thomason, W.E., Phillips, S.B., Solie, J.B., Stone, M.L., and Whitney,-R.W. 1998. Indirect measures of plant nutrients. Commun Soil Sci Plant Anal. 29: 1571-1581..

Roubens, M., 1982. Fuzzy clustering algorithms and their cluster validity. European Journal of Operational Research 10, 294_301.

Saskatchewan Soil Survey 1988**.** Preliminary soil map and report: rural municipality of bone creek number 108. Saskatchewan Institute of Pedology and University of Saskatchewan,

Tarpley, L, Reddy, K.R, and Sassenrath-Cole, G.F. 2000. Reflectance indices with precision and accuracy in predicting cotton leaf nitrogen concentration. Crop Sci. 40: 1814-1819.

Tucker, C.J. 1979. Red and photographic infrared linear combination for monitoring vegetation. Remote Sensing Environ. 7:279-297.

Zhang, M., P. Hendley, D. Drost, M. O'Meill, and S. Ustin 1998. Corn and soybean yield indicators using remotely sensed vegetation index. P:1475-1481. In P.C. Roberts et al. (Ed) Proc. Int. Precision Ag. Conf. 4th Minneapolis. MN. 19-22 June 1998.ASA, CSSA, and SSSA, Madison, WI.