PRECISION FARMING: YIELD, TERRAIN, AND FERTILITY MAPPING
WITH GLOBAL POSITIONING SYSTEMS (GPS).

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Introduction

A project titled, Precision Farming Systems To Maximize Profits and Minimize Environmental Impacts”, was initiated in April, 1993, with funding from the Canada/Alberta Environmentally Sustainable Agriculture Agreement (CAESA). The participating agencies include: The University of Calgary; The University of Alberta; Agriculture and Agri-Food Canada Research Branch, Lethbridge; and Alberta Agriculture Food and Rural Development. Support is also provided by Sherritt Fertilizers Ltd. and Concord Inc. The overall objective of the project is to develop and use two emerging technologies; global positioning systems (GPS), and geographic information systems (GIS), to manage crop nutrients to increase profits and minimize environmental impact.

Land resource scientist and practitioners (eg. soil scientists and farmers) recognize the spatial variability of the resource they study and manage. GPS and GIS are new tools that allow us to quantify and map spatial variation. One of the most obvious and important variations observed is crop yield. Using a combine yield monitor with GPS and GIS provides a convenient method of mapping crop yield. These tools can also be used to automatically adjust management practises to match this spatial variation. The technology of yield mapping is revealing that measured spatial variation in yield is often greater than that estimated by visual observation.

When farm fields were small, management practises could be adjusted from field to field to match some of the major differences in soil/landscape. As fields became larger, greater variations in soil/landscape were encompassed within each field. These large fields are treated as homogeneous units. GPS and GIS provide the means to define and manage much smaller units than the current field size. Variable rate application technology provides a means of automatically adjusting nutrient inputs to match the requirements of these smaller management units.

Before yield mapping technology was developed, efforts to define smaller management units within fields concentrated on using detailed soil survey. This approach was only moderately successful. The use of detailed soil surveys to define management units within fields was impeded by two factors: i) the high cost of the surveys; and ii) lack of a strong relationship between the mapped units and fertilizer requirements. An important component of models that predict fertilizer requirements is yield potential. Estimates of the yield potential of map units defined by soil surveys have lacked precision (Carr et al., 1991). The evaluation of yield mapping as a component in models to predict fertilizer inputs is in its infancy.

GPS and GIS Systems and Methods

Four farmer cooperators near Bow Island, Hussar, Stettler, and Mundare were selected in 1993 (Figure 1). One test field from 80 to 200 acres in size was selected on each farm. The Bow Island field is under centre pivot irrigation on undulating topography. The soil is a Brown Chemozem developed on alluvial-lacustrine material. The hussar field is on strongly rolling topography. The

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soil is a Dark Brown Chemozem developed on calcareous till. The Stettler and Mundare fields are on rolling (hummocky) topography. The soils are Black Chemozems developed on till and resorted till.

An Ag Leader Technology - Yield Monitor 2000TM was installed in each of the farmers combines. The yield monitors were interfaced with the portable DGPS when each of the project fields was harvested. The DGPS consisted of NovAte195 1 GPS cards installed in two laptop computers. One receiver was a base station with known coordinates located at the comer of the field. The other receiver was on the combine interface with the yield monitor. For fertilizer application, the mobile receiver was on the tractor, interfaced with a Concord X2094 Variable Rate Air Seeder.

For real time positioning, required for variable rate fertilizer application, the base station and mobile receiver were linked with two GINA wireless radio modems. With a base station to provide differential correction (DGPS), three dimensional accuracy in the 10 cm range was achieved. Accuracy within one to two metres is adequate for yield mapping but centimetre accuracy is required for digital elevation models (DEM). The GPS system was developed by the University of Calgary, Department of Geomatic Engineering (Gehue et al 1994).

Figure 1. Precision farming project sites.

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Forty-five to 65 acres at each location were soil sampled using a 220'x 220' grid (approx. one sample per acre). At each grid-line intersection, composite samples of 12 to 15 cores were taken to depths of O-15, 15-30, 30-60 and 60-90 cm. The soil test results were used in conjunction with the yield maps and aerial photographs to construct fertilizer application maps. Map units with similar levels of N and P were defined. The optimum application rates for N and P were estimated based on soil test values, yield and landscape features. The Bow Island and Mundare sites were mapped for salinity using an EM38 salinity meter and GPS as described by Cannon et al. (1994).

The landform regimes were described using the system of Pennock et al. 1987 and 92 (Figure 2). The GRASS (Geographic Resource Analysis Support System) geographic information system was used for data analyses and mapping. Using the digital elevation data, GRASS can calculate slopes, curvature, landscape element maps and aspect maps. GRASS routines were also used to further enhance the yield maps and to provide overlay analyses of yield, salinity, aspect and sampling grid maps.

Fertilizer rate experiments were conducted in strips 42' wide across the full length of the fields. Four constant rates of N with one rate of P were used in one block. The other block had three constant rates of P with one rate of N. Each rate was replicated twice. On an adjacent area, variable rate applications (N and P) were compared to constant rate applications in alternating strips.

Figure 2. Example of the seven landform elements for digital elevation model. Each cell on the model is classified into one of the seven elements.

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Results and Discussion

The study began in 1993 with site selection, preliminary yield mapping and grid soil sampling as described. The first evaluations of fertilizer response, across soil/landscapes, were planned for 1994. At the Hussar site in 1993, one half of the farmer fertilizer applicator didn't function for several passes, creating fertilized and unfertilized strips. As a result, fertilizer responses were obtained on a landscape basis, for two years from this site. The results presented in this paper are preliminary. Analyses of the 1994 data are not complete. Several years of data will be required to adequately evaluate the benefit: cost relationship of 'site- specific' nutrient management. The large differences in yield and nutrient levels found within the fields being studied indicate that there is a large potential to improve fertilizer use efficiency with variable rate fertilizer application.

Results of grid sampling at the Bow Island site in fall 1993 show very large differences in NO3 - N levels (Figure 3). Areas of high NO3 - N were associated with high salinity and low yield. A constant rate of N application based on a composite sample of the field would result in over fertilization of the areas with high levels of N likely under fertilize significant areas with low levels of available N. The estimated optimum rates of N based on results of grid sampling and yield map ranged from zero to over 160 kg N/ha.

Soil test P levels at the Hussar site ranged from very low on some eroded shoulder slopes to moderately high on some back and foot slopes (Figure 4). The estimated optimum P rate ranged from 10 to 45 kg $P_2 0_5$/ha.

The soil test potassium (K) level obtain from a composite sample of the field (the mean of 40 grid samples) at the Mundare site would not result in a recommendation for K, yet 20 of the 40 grid samples were below the critical level of 250 lb/ac (Figure 5). Potassium was not included in the fertilizer trials at this site but lodging of the wheat crop indicated that the addition of K on some areas of the field may have been beneficial.

The greatest range in soil test levels within the areas sampled occurred with sulphur at the Stettler site (Figure 6). Sulphate - S in the O-30 cm depth ranged from 4.9 ppm (low) to 6705 ppm (excessively high). This extreme range in sulphate-S indicates that a composite sample from the field would not be a reliable method of predicting the need for sulphur fertilization.

The results of the grid sampling carried out at the four sites indicates a serious lack of precision with composite sampling of fields. A lack of precision is indicated by both the wide range in values and by positive skewness. Positive skewness results from a low frequency of very high values which cause the mean to be higher than the 'typical (most frequent) value. For example, in Figure 6, sixty one percent of the S values are betweeen 0 and 10 ppm yet the mean is 285 ppm. The very wide range and extreme positive skewness of the sulphate-S values obtained from the grid sampling of the Stettler site illustrates why many farmers apply sulphur for canola production, irrespective of the sulphur soil test.

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Figure 3. Soil nitrate - N : Bow Island site, fall 1993.

Figure 4. Soil phosphorus: Hussar site, fall 1993.

Figure 5. Soil exchangeable potassium: Mundare site, 1993.

Figure 6. Frequency distribution of sulphate-S (Stettler 1994).

Soil testing models used for predicting fertilizer application rates often includes a ‘yield goal or some estimate of potential yield. The large variations in yield within fields identified by yield mapping, therefore provides one of the criteria on which to vary fertilizer application rates. By superimposing information with respect to landscape, salinity and nutrient levels on to the yield maps, the cause of much of this yield variation can be identified. Areas where yields are restricted by nutrient supply can be distinguished from areas where other factors such as salinity or moisture supply restricting yield. For example, yield, salinity and fertility mapping of the Bow Island site identified low yielding areas associated with high salinity and high levels of available N.

The fertilized (60 kg N and 30 kg P_2O_5/ha) and unfertilized strip created by a malfunctioning of the farmers fertilizer applicator at the Hussar site in 1993 were harvested with a plot combine. Yield from 24 segments per treatment were measured and positioned using DGPS. The landform of each segment (shoulder slope, back slope and foot slope) of each segment was classified (Pennock et al. 1987). The detailed results of this study were presented at the 2nd International Conference on Site - Specific Management for Agricultural Systems (Nolan et al 1994). The ratio of fertilized to unfertilized yields on the three slope positions show similar trends for 1993 and 94 in (Figure 7). Differences in the fertilized to unfertilized yield ratios on the different slope position were mainly a result of differences in the unfertilized yield (shouldercbackcfoot). A comparison of fertilized and unfertilized yield on six landform elements at the Hussar site are shown in Table 1. As would be expected in a dry climate, the yield on convergent slopes were greater than on divergent slopes. Responses to N fertilization however were similar.

Figure 7. Ratio of fertilized to unfertilized yields on three slope positions at Hussar (1993 and 1994).

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Table 1. Yield of fertilized and unfertilized wheat on various landform elements (Hussar ‘94)

Wheat Yield (bu/ac)							
Fertilizer	Landform					Element	
Treatment	C	D	S S	B S	F S	C S S + C B S	D S S + D B S
FY	58.3	50.9	53.4	55.7	54.6	59.1	50.0
UY	45.8	38.4	37.8	39.2	49.4	42.8	34.2
FY-UY	12.5	12.4	15.6	16.5	5.2	16.3	15.2

FY = Fertilized (65 N and 20 P_2O_5)
UY = Unfertilized (0 N and 20 P_2O_5)
c = Convergent slopes
D = Divergent slopes
ss = Shoulder slopes
BS = Back slopes
FS = Foot slopes

Crop responses to fertilizer N were similar on all of the various combinations of slope and curvature, except for the foot slopes where response was low. Using a constant rate of 65 lb N/ac resulted in a contribution margin of $38.50 on shoulder and back slopes and a loss of $4.70 on the foot slopes (Table 2).

Table 2. **Effect of slope position on yield response of wheat to N fertilizer (Hussar 1994)**

	Yield of Wheat (Bu/ac)	
	Slope Position	
	SS and BS	FS
YI to applied N	16.0	5.2
Value of YI ($4.00/bu)	64.0	20.80
Fertilizer Cost	25.50	25.50
Contribution Margins	38.50	-4.70

YI = Yield Increase
ss = Shoulder slopes
BS = Back slopes
FS = Foot slopes

A detailed comparison of the fertilizer use efficiency of constant vs variable rate fertilization cannot be made at this stage of the study. Both the 'potential benefit (optimized inputs to all areas of the field) and 'actual benefit (what can be achieved) of variable rate application need to be assessed. A compatision of crop response to an 'optimum' rate vs a constant rate is required for each map unit plus a proportional total. Optimum vs the predicted input levels must then be compared to obtain the 'actual' benefit. These types of analyses will be done when more site years of data are available.

Acknowledgement

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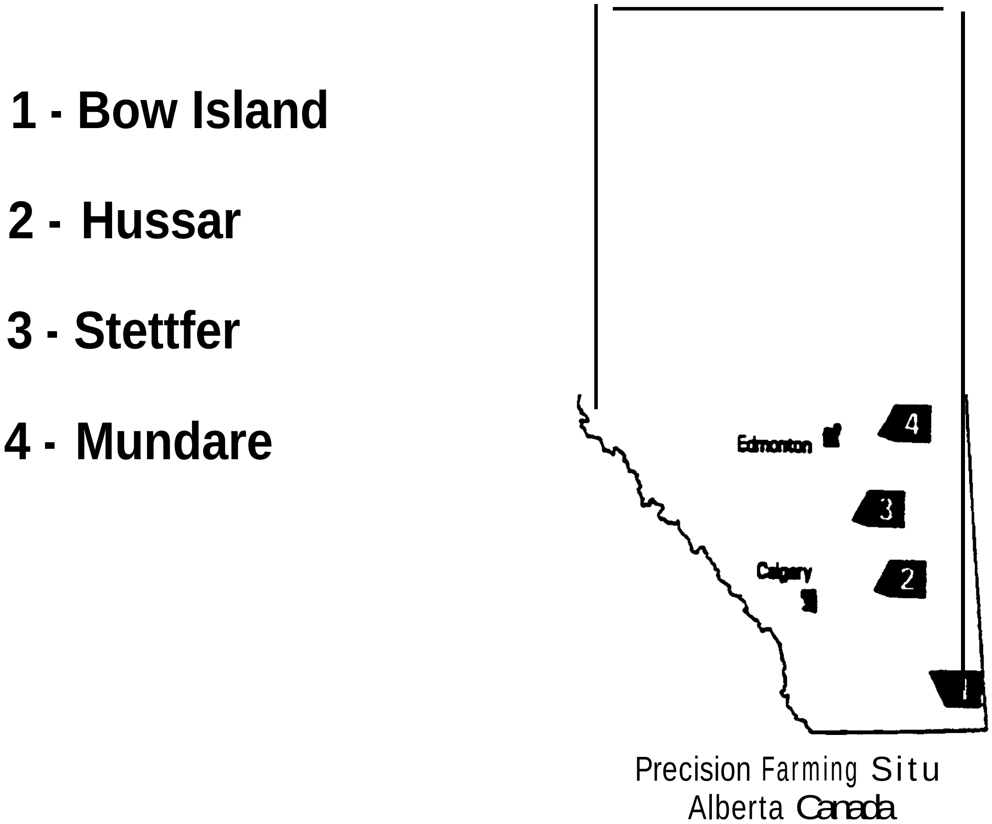

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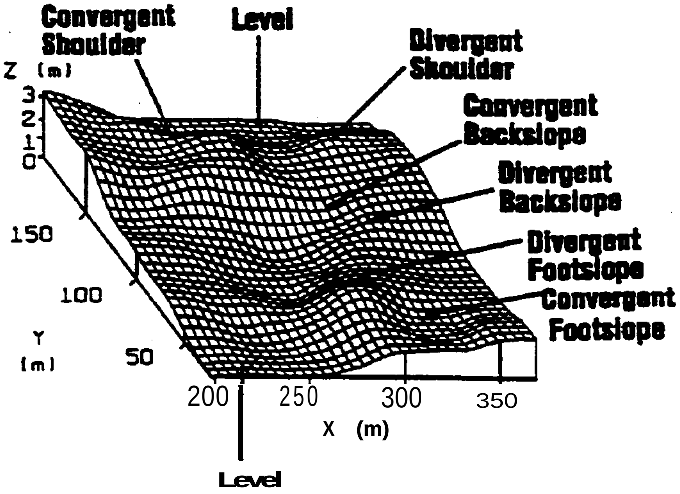

Examples of 5-m by 5-m Landform Elements

Figure 2. Example of the seven landform elements for digital elevation model. Each cell on the model is classified into one of the seven elements.

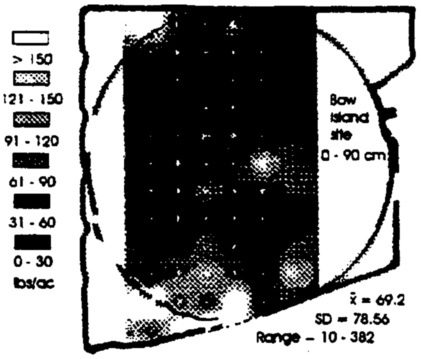

Figure 3. Soil nitrate - N : Bow Island site, fail 1993.

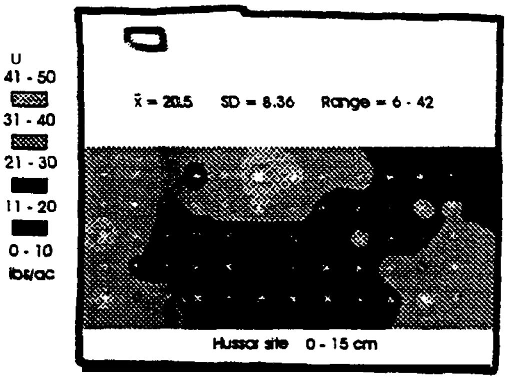

Figure 4. Soil phosphorus: Hussar site, fall 1993.

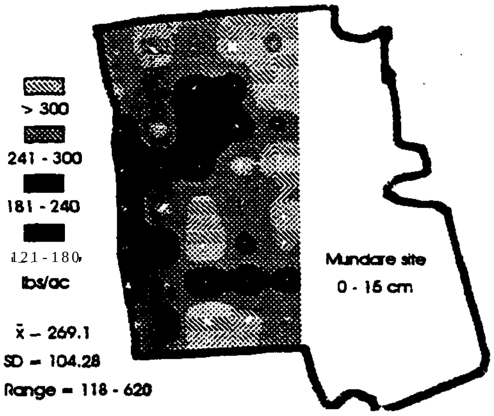

Figure 5. Soil exchangeable potassium: Mundare site, 1993.

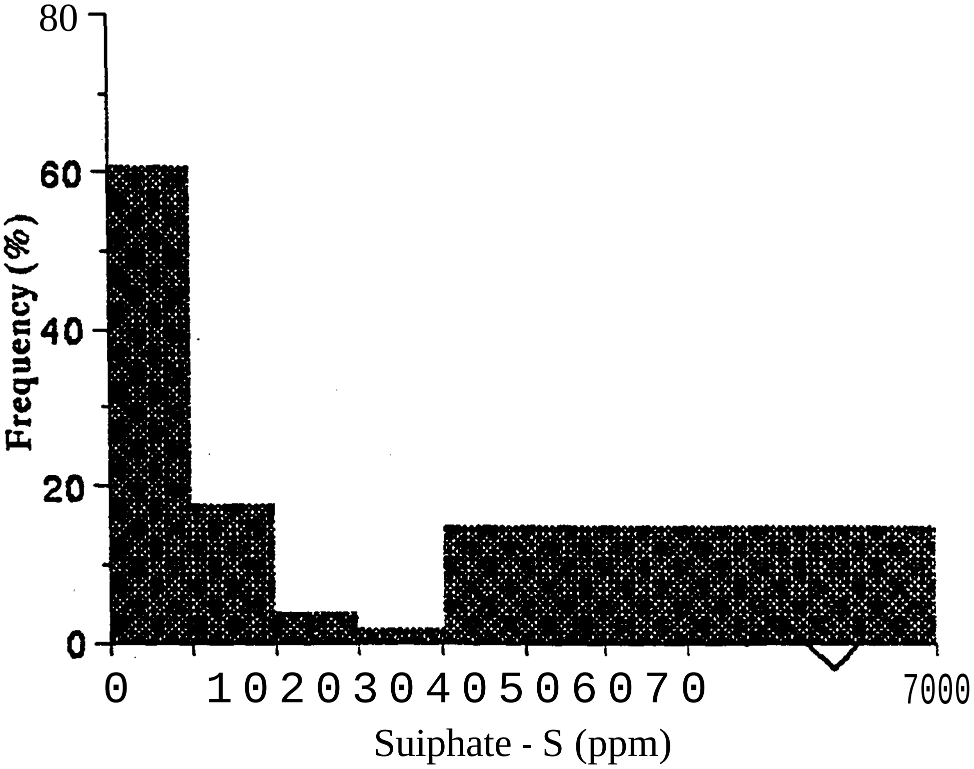

Figure 6. Frequency distribution of sulphate-S (Stettler 1994).

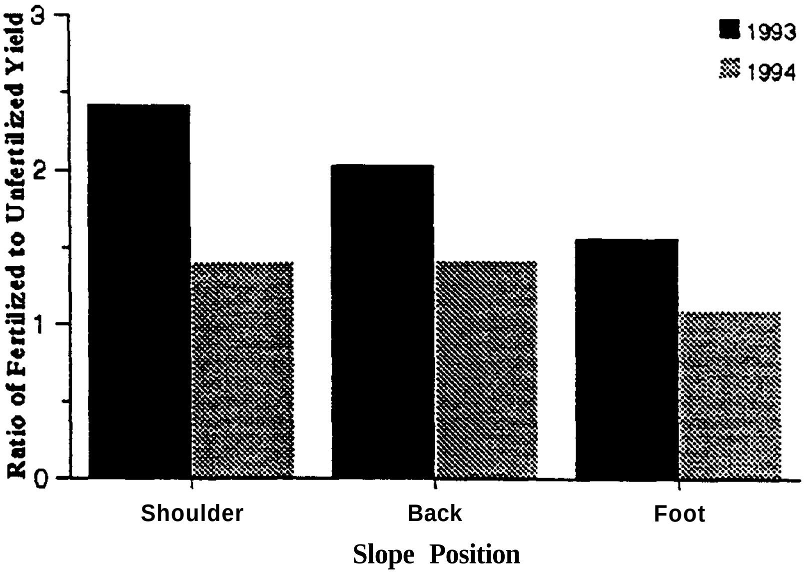

Figure 7. **Ratio of fertilized to unfertilized yields on three slope positions at Hussar (1993 and 1994).**