MULTILAYER AND MULTIYEAR DATA ANALYSIS IN PRECISION YIELD PLANNING

A.Melnitchouck

IntelMax Corp.
Calgary, Alberta, Canada

ABSTRACT

This work covers two separate field experiments. In the first one, the results of 1-ha grid soil analysis for soil organic matter (OM), pH, cation exchange capacity (CEC), nitrate N, P, K, S, Ca, Mg and soluble salts were compared with the results of yield mapping, biomass index from optical on-the-go sensors, as well as multispectral imagery analysis for the last 30 years. As a result, it was found that none of the analyzed soil characteristics was predominant for determining yield. Correlation between the soil properties and yield of spring wheat was -0.24 for soil pH, -0.15 for phosphorus, -0.13 for nitrate nitrogen, -0.06 for potassium, 0.12 for soil OM, and 0.01 for soil electrical conductivity. At the same time, correlation between one-year normalize difference vegetation index (NDVI) and grain yield was 0.51, and multi-year NDVI resulted in r=0.65. In the second experiment, we analyzed spatial variability of vegetation in the field using 22 layers of NDVI collected between 1984 and 2013, and compared these 22 years of data with one-year yield dataset to estimate the accuracy of management zones. Soil electrical conductivity (EC) measurement was also compared with the yield data. Correlation coefficients between one-year NDVI and yield data fluctuated between 0.3 and 0.75 depending on the year, and for soil EC the value of this coefficient was -0.34 for EC deep and -0.37 for EC shallow. Management zones delineated from soil EC data gave good separation for different soil types, but poorly separated areas with different yield potential. Field analysis of yield potential is contrast EC zones three weeks prior to harvesting revealed almost identical yield potential, whereas in the zones delineated from vegetation indices and yield data, the difference between high and low productive areas exceeded 200%. Based on our results, we concluded that yield is an integrated result of many different factors, including various soil characteristics, relief, PAR, air moisture etc., and it is very difficult to create an accurate model for yield planning based just on soil characteristics. The main goal of spatial analysis and delineation of management zones should be aimed to determine main yield limiting factors in the field. Yield data or vegetation indices obtained from multispectral satellite imagery give better results for delineation of management zones in the field than soil EC, and the accuracy of multi-year mapping is better than utilization of one-year data. Also, analysis of yield data or spatial variability of green biomass through various vegetation indices gives more predictable results for accurate yield goal planning than analysis of soil variability using grid sampling or soil EC measurement.

Keywords: Precision agriculture, satellite imagery, variable rate technology, management zones, grid soil sampling, soil EC.

INTRODUCTION

There are several ways of analyzing field variability. They are based on completely different concepts and methodologies. Grid soil sampling is the oldest approach based on the idea that crop variability in the field is mostly related to unequal concentrations of the main nutrients, and using variable rate technology, it is possible to achieve uniform yield across the whole field. Grid sampling does not take into account the fact that crop yield is an integrated result of many different factors acting together in one field.

The second method is based on soil electrical conductivity (EC) measurements and mapping. In most cases, EC analysis gives pretty good separation of various soil types, which, however, often do not match yield variability.

Yield data analysis and mapping helps to delineate areas with the same yield potential, but yield zones, in many cases, do not match soil types, or variability of the main soil nutrients.

Remote sensing can provide two main types of information (Faleide and Rosek, 1996). Reflectance of bare soil is highly correlated to soil organic matter content, which, again, does not always explain yield variability. Reflectance of crop canopy in the near-infrared band, typically, is strongly correlated to crop yield, but not necessarily to soil properties. In addition, both yield data and reflectance of canopy significantly vary from year to year.

There are also other methods of management zones delineation, such as based on field topography, or combinations of different layers, but they are not accurate, when it comes to crop planning and determining accurate yield goals.

All the approaches described above have certain advantages and disadvantages. Therefore, the main aim of our experiments was to work out the optimal strategy for delineation of site-specific management zones.

MATERIALS AND METHODS

Our experiments were carried out in two farmer's fields in Manitoba and Alberta, Canada. In the first one, the results of 1-ha grid soil analysis for soil organic matter (OM), pH, cation exchange capacity (CEC), nitrate N, P, K, S, Ca, Mg and soluble salts were compared with the results of yield mapping, biomass index from optical on-the-go sensors, as well as multispectral imagery analysis for the last 30 years.

In the second experiment, we analyzed spatial variability of vegetation in the field using 22 layers of NDVI collected between 1984 and 2013, and compared these 22 years of data with one-year yield dataset to estimate the accuracy of management zones and yield goals. Soil electrical conductivity (EC) measurement was also compared with the yield data. Both multi-year and EC zones were scouted one month prior to the harvesting. Soil and plant samples were collected from the highest and lowest producing areas and then compared.

Spatial analysis and mapping were carried out using Zoner.Ag – a web platform created by IntelMax Corp.

RESULTS AND DISCUSSION

Our results clearly showed that one-year yield or NDVI maps cannot be used for delineation of stable management zones in the field. Weather conditions, different crops and their varieties or hybrids, their reaction on environmental conditions lead to major changes in the spatial variability of grain yield or green biomass (Fig. 1 and 2).

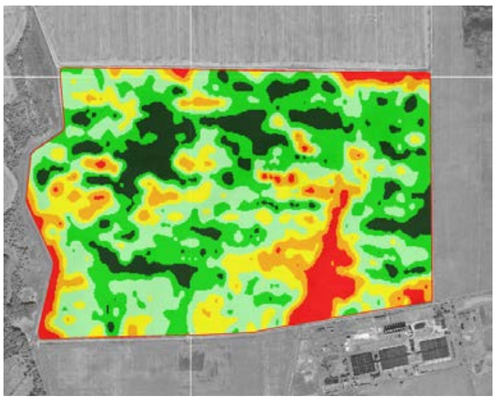

Fig. 1. NDVI map, 2011.

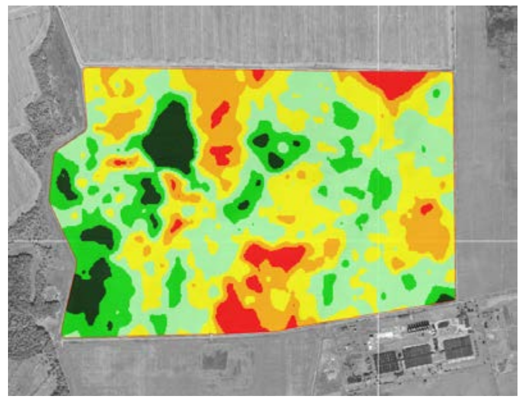

Fig.2. NDVI map, 2013.

At the same time, spatial and temporal variability of yield data and green biomass implies that it is difficult to develop accurate fertilizer rates based on grid sampling, since the nutrient requirements vary depending on both location in the field and the year. In addition, grid soil analysis for the main nutrients cannot be used for variable rate seeding, targeted application of chemicals, and has to be repeated every year.

As a result of our analysis, it was found that none of the analyzed soil characteristics was predominant for determining yield. Correlation between the soil properties and yield of canola in 2010 was -0.24 for soil pH, -0.15 for phosphorus, -0.13 for nitrate nitrogen, -0.06 for potassium, 0.12 for soil OM, and 0.01 for soil electrical conductivity. At the same time, correlation between one-year normalize difference vegetation index (NDVI) and grain yield was 0.51, and multi-year NDVI resulted in r=0.65.

Comparative analysis of elevation and surface curvature maps also indicated that field relief also did not correlate with the yield data (Table 1, Fig. 3-8). The only characteristics correlated with the yield of canola and spring wheat, were one-year and average NDVI. NDVI average had consistently medium to high correlation coefficient with grain yield of both canola and spring wheat (r=0.61 and 0.65), whereas one-year NDVI was strongly correlated with same year grain yield, but weakly correlated with the yield data from a different year. It means that if management zones are delineated using one-year yield data or imagery, they might work one year and fail another year.

In both experiments, low-yielding spots in the field were found in both elevated areas, where soil had lower organic matter and soil moisture, and depressions with excessive moisture or salinity problems.

Table 1. Correlation matrix, experiment 1.

Variables	Yield, 2010, canola	Yield, 2011, spring wheat
Biomass Index (Yara Sensor)	0.12	0.31
Soil EC, Deep	0.01	-0.07
Al	0.07	0.13
Salt	-0.07	-0.06
S	-0.11	-0.11
Cl	-0.11	-0.02
NO_3 N	-0.13	-0.17
OM	0.12	0.16
CEC	0.1	0.14
P	-0.15	-0.13
K/Mg Ratio	0.14	-0.07
K	-0.06	-0.21
Mg	-0.19	-0.06
Ca	-0.11	-0.09
Percolation	-0.29	-0.29
Buffer	-0.37	-0.33
pH	-0.24	-0.23
NDVI Average	0.65	0.61
NDVI 2010	0.51	0.37
NDVI 2011	0.66	0.73
Yield 2010 (canola)	1	0.6
Yield 2011 (spring wheat)	0.6	1
Elevation	-0.01	0
Surface curvature	-0.26	-0.26

Analysis of the data shown in Table 1 indicated that grain yield in the field was determined by a complex combination of different factors. Obviously, grid sampling did not take this fact into account. There are two main implications here:

(i) Grid sampling is based on the concept of achieving even yield across the field; however, it is not possible, when yield is limited by factors other than concentrations of the main nutrients. The end goal of crop production is growing yield, not fertilizing soil.

(ii) Uptake of soil nutrients by plants in different parts of the field varies depending on both year and crop. Therefore, for precise field management, we need two main layers of information including the information about both soil properties and yield.

Fig. 3. Field boundary

Fig.4. NDVI average, 1984-2013

Fig. 3. Yield Map, 2010

Fig. 4. Yield Map, 2011

Fig. 5. Elevation Map

Fig. 6. Soil EC Map

Fig. 7. Soil OM Map

Fig. 8. Soil Nitrate Nitrogen Map

In the second experiment, correlation coefficients between one-year NDVI and yield data fluctuated between 0.3 and 0.75 depending on the year, and for soil EC the value of this coefficient was -0.34 for EC deep and -0.37 for EC shallow (Table 2). Management zones delineated from soil EC data gave us good separation between different soil types, but they poorly separated areas with different yield potential. Field scouting and assessment of yield potential three weeks prior to harvesting revealed almost identical yield potential in two contrast EC zones, whereas in two contrast zones delineated from vegetation indices and yield data, the difference between high and low productive areas exceeded 200% (Tables 3 and 4).

Fig. 9. Field boundary

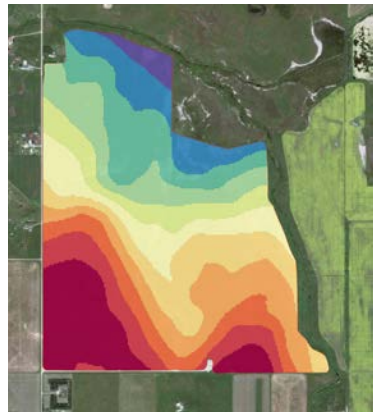

Fig.10. Elevation Map

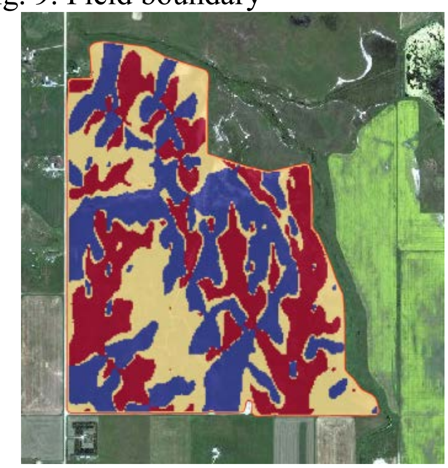

Fig. 11. Surface Curvature Map

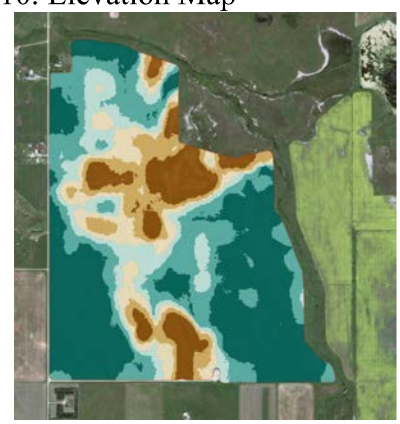

Fig. 12. Soil EC Map

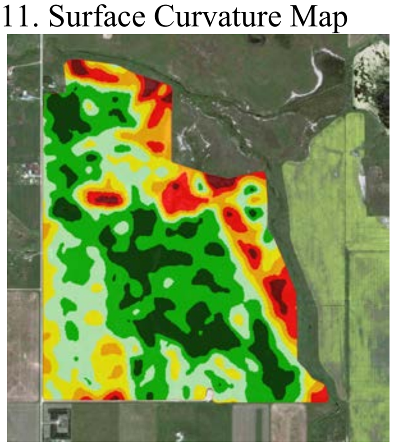

Fig. 13. NDVI 1984-2013

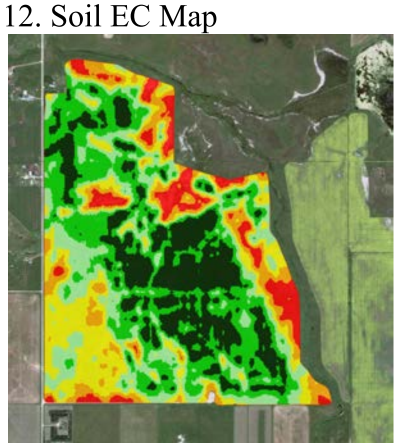

Fig. 14. Yield Map, 2013

Table 2. Correlation between grain yield, vegetation indices and soil EC, experiment 2.

Variables	Yield, 2013	NDVI Average	NDVI, 2013	EC Deep	EC Shallow
Yield	1	0.75	0.67	-0.34	-0.37
NDVI Average	0.75	1	0.55	-0.28	-0.3
NDVI 2013	0.67	0.55	1	-0.63	-0.65
EC Deep	-0.34	-0.28	-0.63	1	0.86
EC Shallow	-0.37	-0.3	-0.65	0.86	1

Based on our results, we concluded that yield is an integrated result of many different factors, including various soil characteristics, relief, PAR, air moisture etc., and it is very difficult to create an accurate model for yield planning based just on soil characteristics. The main goal of spatial analysis and delineation of management zones should be aimed to determine main yield limiting factors in the field. Yield data or vegetation indices obtained from multispectral satellite imagery give better results for delineation of management zones in the field than soil EC, and the accuracy of multi-year mapping is better than utilization of one-year data. Also, analysis of yield data or spatial variability of green biomass through various vegetation indices gives more predictable results for accurate yield goal planning than analysis of soil variability using grid sampling or soil EC measurement.

One month before harvesting, we did field observations to validate management zones created using multiple years of multispectral satellite imagery and soil EC. The results are shown in Tables 3 and 4.

Table 3. Soil EC zones (average of 10 samples), experiment 2.

Characteristic	**Higher soil OM**	**Lower soil OM**
Texture class	Silty clay loam	Sandy loam over clay loam
Available H_2O capacity	2.6	1.6
% of field capacity	<54	<41
Crop available H_2O in 1 ft, in	1.9	1.2
pH	6.2	5.6
Topsoil depth, in	8	5.1
Yield potential, t/ha	67	61

Table 4. Mutli-year NDVI zones (average of 10 samples), experiment 2.

Characteristic	**High yielding**	**Medium-low yielding**
Crop height, in	39.1	28.4
Fruit development stage	Late milk to soft dough	Medium dough
Crop stage (tiller count)	3 tillers, BBCH 80	1.7 tillers, BBCH 91
Root development	Good	Poor
Plant count, per sq. ft	26.4	21.1
Predicted yield, bu/ac	**76**	**32.7**

Our results showed that soil EC measurements provided good separation of different soil types (Table 3). Two contrast zones had very different soil characteristics. On average, the soil with higher OM content had higher water holding capacity and crop available water, different texture and deeper topsoil. However, estimated yield potential in both zones was very similar: 67 vs 61 bu/acre.

When we compared the results from the zones delineated using multi-year satellite imagery, the difference between crop conditions in two contrast zones was obvious (Table 4). Plant in the low yielding areas had lower height; they started senescing earlier than plants in the highest yielding zone. Root development was also better in the high yielding zone, as well as number of plants per unit area was higher there. The main difference was found in the estimated yield potential: 76 bu/ac in the zone with the highest yield potential vs. 32.7 in the lower yielding area.

CONCLUSION

Grain yield is an integrated result of many variables. In those cases, when the main soil nutrients are not the main yield limiting factors, grid sampling cannot be used for calculation of accurate site-specific fertilizer rates. Yield data or vegetation indices from aerial and satellite imagery are much better indicators for delineation of site-specific management zones.

REFERENCES

Faleide, R. and Rosek, M., 1996. Application of Remote Sensing for Selected Soil Sampling Sites. SPIE, Vol. 2818, pp. 59-60.