THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

Statistical variability of crop yield, soil test N and P within and between producer's fields

Alan Moulin[1], Mohammad Khakbazan[1] Brandon Research and Development Centre, Agriculture and Agri-Food Canada**,** Brandon, Manitoba, Canada

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract. *Soil test N and P significantly affect crop production in the Canadian Prairies, but vary considerably within and between producer's fields. This study describes the variability of crop yield, soil test N and P within and between producer's fields* ***in the context of variable fertilizer rates****. Yield, terrain attribute, soil test N and P data were collected for 10 fields in Alberta, Saskatchewan and Manitoba Canada in 2014 and 2015. The influence of* ***fertilizer management*** *on crop yield, soil test N and P was attributed to the* ***variability between farms****. Development of management zones for fertilizer management of crop yield will benefit from* ***analyses within farms*** *at the field scale.*

Keywords. *Canola yield, soil fertility, variability between farms, management zones, partition analysis*

Introduction

This is a report on the first year of a three year study from 2014 to 2016 on variable management of N fertilizer in canola. Data and analyses presented in this report are preliminary and may change as additional statistical analyses are conducted, and environmental variables are assessed as covariates.

With the significant increase in the use of precision agriculture in the Prairies, members of the Manitoba Zero Tillage Research Association, (MZTRA) concluded that more research was needed to be done to assess and further improve the effectiveness of this technology. Nitrogen was identified as the highest priority for variable management, due to the cost of this input. Agvise Labs reports that % soil sampling in Manitoba based on grid and management zones doubled from 2005 to 2009 to approximately 45%. Statistics Canada reported in 2006 that 57% of farms in the Prairies used tracking or guidance systems, while 10% used the equipment for yield maps. Yield Monitors, Global Positioning Systems, GIS Computer Software, and Remote Sensing, Variable Rate Fertilizer on Seeders, and Ground Based Sensors are available in the market place.

Variable rate application begins with delineation of management zones within fields or variable management to improve economic return. Most fields have soil characteristics in parts of the fields which respond differently and should be managed accordingly (Whelan and McBratney 2001). Best results in the case of crop production may not maximize yield in any given year but may minimize losses of inputs in zones that do not have high yield potential. The goal of a variable rate application strategy is to place the crop inputs in a place where the potential for return is the greatest. Since the inception of Global Positioning Systems (GPS) and the availability of this technology in combination with Geographic Information Systems (GIS), producers can manage zones within fields to optimize inputs and production. Field scale yield data are collected to accomplish this goal.

Several methods have been proposed for delineation of management zones for variable management. These include methods based on landform analysis, soil test, satellite images, soil conductivity, ground based sensors and yield maps(Stafford and Lark, 1997; Fraisse et al., 2001; Boydell and McBratney, 2002; Fridgen et al., 2004; Kitchen et al., 2005). Landform analysis classifies the landscape into upper, middle and lower slope positions based on digital elevation data, and fertilizer is variably applied in these areas. Intensive soil test based on grid sampling has also been used to delineate management zones; though the cost of laboratory analysis is expensive due to the large number of samples. Satellite images have also been used by consultants in Western Canada to delineate areas of low to high production, in order to variably apply fertilizer. Soil conductivity has been used in the United States to delineate areas with low to high productivity, and in Canada to delineate zones where high salinity reduces crop yield. Ground-based sensors such as the Greenseeker can regulate in-crop application of nitrogen fertilizer in liquid form, based on nitrogen deficiency measured by reflectance. These sensors regulate the application of fertilizer by relating sensor measurements to a fully fertilized strip. Analysis of yield maps have also been applied to the delineation of management zones, though this approach is not common in Western Canada.

Statisticians developed new data mining methodology referred to as “Big Data”, in the 1970’s and 1980’s which allow the analysis of large data sets made up of a large number of variables and data. These methods are now used in a wide range of applications from banking to genomics and medicine. The methods are now available in statistical programs commonly used by scientists and researchers. Big Data has recently been applied to the analysis and application of precision agriculture.

But the question is “How is the technology used effectively.”

In other words “Where in the field do the inputs go?”

Producer Questions

- Does precision agriculture work?
- Does precision agriculture provide an economic return to the producer?
- What are the environmental advantages to precision agriculture?
- How does precision agriculture address year to year variability of yield?
- Can precision agriculture address temporal variability of crops from year to year?
- How is the spatial and statistical variability of canola yield, related to soil test N and P at the field scale?
- How is this variability related to current soil test recommendations?

Can the information from the previous questions be combined to develop an improved methodology for variable rate management of N fertilizer?

Research Questions

- Does variable rate N management based on management zones derived from a temporal series of yield maps increase canola yield in areas with consistently high production and low variability?
- What are the economic return and efficiency of fertilizer use from variable rate management of N?

Objectives

This study assesses management zones for variable application of nitrogen fertilizer based on 3 to 5 years of previous yield maps and soil sampling in the fall preceding cropping. Complementary analyses were done with landform analysis and soil sampling. Zones were further assessed in relation to aerial/satellite photos and analysis of elevation data and terrain derivatives at the end of the study.

1. Assess management zones for variable application of nitrogen fertilizer based on 3 to 5 years of previous yield maps combined with pre-seeding soil sampling and soil test recommendations.
2. Complementary analyses will be done with landform analysis and soil properties.
3. Zones will be further assessed in relation to remote sensing data and analysis of elevation data and terrain attributes at the end of the study.

Methods and Materials

Spatial Variability of Yield, MZTRA

Research was initiated in 1997 to assess the variability of crop yield, landforms and soil properties in relation to the potential for variable rate management. Analysis of yield data from a previous study in

1997 to 2001 identified 3 distinct zones in the landscape.

MZTRA study of management zones and fertilizer management

Based on the results of the previous research on spatial variability of yield over time, a study was established in 2008 at the MZTRA Research Farm to determine the most effective means of identifying management zones for variable application of nitrogen fertilizer based on previous yield maps, landform analysis and soil sampling. The study was conducted at the Manitoba Zero Tillage (MZTRA) Research Farm from 2008 to 2015 supported by the MZTRA, Manitoba Agriculture Food and Rural Development (MAFRD) and Agriculture and Agri-Food Canada (AAFC),

Experimental Design:

A randomized and replicated design will be established with four fertilizer treatments in each of three management zones at two trial sites (1 per field) per producer.

Management Zones

Yield maps collected for fields over a 3 to 5 year period prior to the study, were analyzed with statistical and SMS GIS software to identify areas which have high and very high normalized yields (Figure 1), average normalized yields and low and very low normalized yields. Three management zones were delineated with high and very high areas in the high zone, average area in the average zone and low and very low areas in the low zone. Fields for the study will be selected based on these analyses, for sites which show 3 distinct zones. Fertilizer treatments were located within these zones in a randomized replicated design (Figure 2).

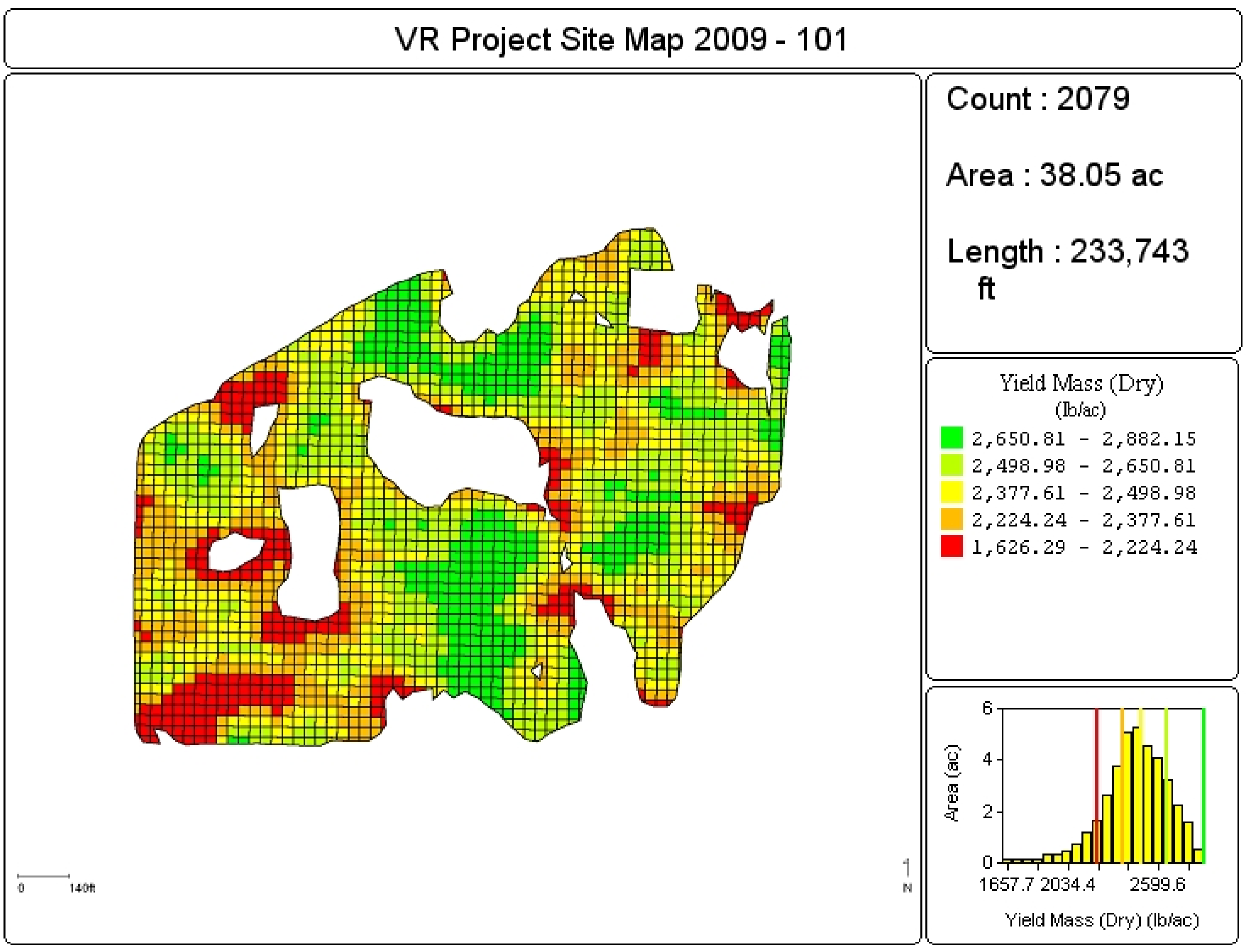


Figure 1. Management zones based on analysis of yield maps.

Fertilizer Treatments

The treatment comparisons include:

- control no nitrogen fertilizer
- full rate of nitrogen fertilizer (100% of recommended) based on the maximum recommendation for the field across all management zones
- Nitrogen fertilizer based on variable rate in 3 management zones based on 5 years yield data. These zones will cover a range of upper, middle and lower/depression landforms
- 50 and 150% nitrogen fertilizer applied based management zones derived from yield data alone.

Eight strips (25 to 50 m in length), 2 for each of 4 N fertilizer treatments were located in each of 2 fields seeded to the same crop in the annual crops rotation. It is anticipated strips were one or two seeder (or seeder section) widths wide and extend through the management zones, and include upper to lower/depression landforms. Fertilizer rates are based on target yields and NO3-N soil test data for each of the zones in the treatments. Maximum rates were for highest possible yield in the recommendations. Fifty % rates were assessed in upper and lower/depression zones.

Four rates of N fertilizer (0, 50, 100 and 150% recommended rate) were applied within two randomly located replicates in 2 trial sites (4 replicates total) per field (Figure 4). Fertilizer rates were based on soil test NO_3-N analysis from the previous fall, and the corresponding target yields for the crop seeded that year. Nitrogen fertilizer was applied in four treatments at 0, 50%, 100% and 150 % of N requirements based on fertilizer guidelines for soil test analyses and yield goals. Plot areas did not include areas affected by previous agronomic research, or headlands. These sites were a minimum of 120 feet wide with 4 treatments on each of the management zones. Boundaries of field scale plots were geo-referenced. Phosphorus and other plant nutrients were added at uniform rates based on soil test analysis.

Yield monitor data, values greater than the 97.5% quantile were removed, were used for analysis of treatment effects. All yield monitor data were calibrated with commercial scales or weigh wagons. Treatment effects were compared with mixed and generalized linear models, Tukey HSD, comparisons or contrasts, and partition analysis in JMP Pro (version 12.1). Partition analysis was based on 9 splits or comparisons between group means, selected on the basis of the optimum root mean square error for the training data set of 222 data points. A subset of 114 data points, not used in the analysis, was used to validate the model developed with the training data.

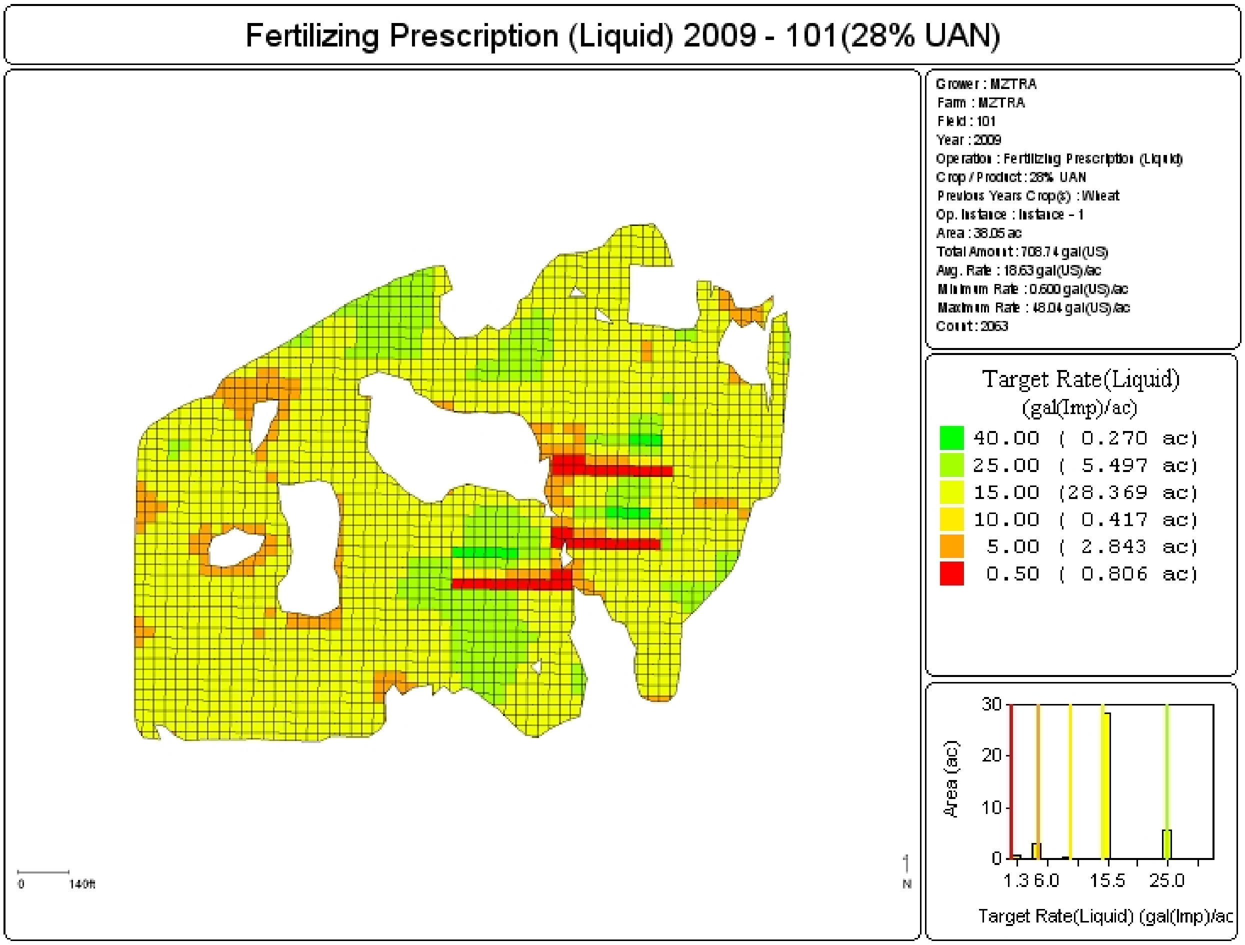


Figure 2. Location of N fertilizer treatments in field.

AAFC/Canola Council Variable Rate N Project

The results of the study at the MZTRA Research Farm were used to design a second study supported by the Canola Council of Canada and AAFC in field scale research for farms in Alberta, Saskatchewan and Manitoba in 2014 and 2015. The methods and materials for the two studies were similar. Variable application of nitrogen fertilizer was assessed in terms of crop yield and nutrient use in both studies. Trial sites were located in fields during the growing season 2014 and 2015 for the Canola Council study, with additional locations planned for 2016 in Alberta, Saskatchewan and Manitoba. Multiple sites in Manitoba, Saskatchewan and Alberta, were established at the field scale in producer fields. Nitrogen fertilizer treatments (0, 50, 100 and 150% recommended by soil test) were randomized within yield based zones (low, average and high yield) similar to the MZTRA study of management zones and fertilizer management. Variability of yield averages by zones were analyzed with traditional plot trial statistics, such as ANOVA and with multivariate analyses and statistical data mining (Big Data) to facilitate the analysis of multi-year and site yield data, landform, meteorological and remote sensing data. Digital elevation data were collected along with yield data and were used to analyze terrain attributes such as surface curvature and landforms.

Selection of producer collaborators:

Study sites were selected in Alberta, Saskatchewan and Manitoba for the AAFC/Canola Council study in 2014, 2015 and 2016 based on the willingness of producers to cooperate, availability of yield data (3 to 5 years yield monitor data), delineation of 3 management zones in a field appropriate for the study, and proximity to the producer organizations and research facilities (home base for equipment such as soil samplers). Producers have 3 preferably 5 years of yield monitor data including elevation data at harvest, a variable rate seeder which can be programmed to apply the N rates required for the study, combine with yield monitor/GPS to collect data, and flexibility to work with coordinators.

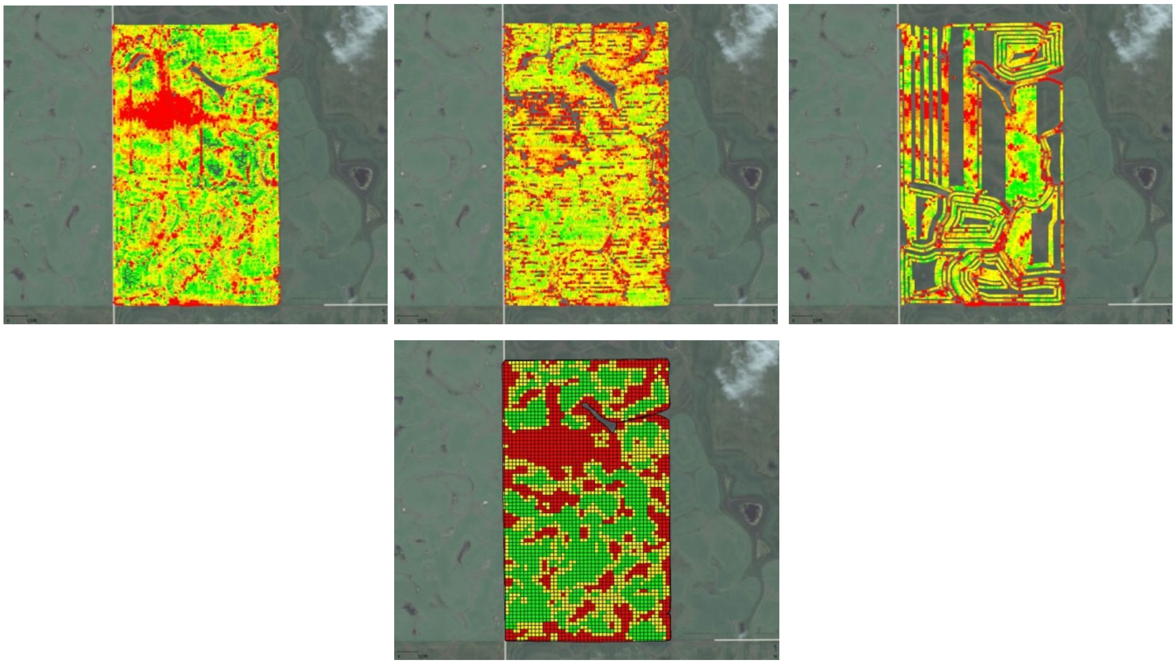


Figure 3. Calculation of low, average and high production zones from 2011, 2012, and 2013 yield monitor data for the SK1 field.

Variables of Interest

- Canola yield
- Management zone, N fertilizer rates, P, K and S
- Landform and terrain attributes calculated from elevation data recorded by yield monitors.
- Soil associations and series
- Spring soil moisture as characterized by Radarsat data
- Soil pH, texture and conductivity
- Crop disease and pests
- Emergence, weed populations
- Precipitation and growing degree days

Sources of Variability: Data Collection

- Variability of yield averages in zones
- Yield map accuracy
- Yield and position outliers
- Alignment of GPS points along harvest paths
- Recalculation of yield position to minimize effects of grain residence time

- Normalize crop for analysis of multiple years
- Multiple combines and calibration

Results

MZTRA study

The response of canola yield to nitrogen fertilizer in the MZTRA study showed a general trend with management zone and fertilizer rate. Yield and N removal tend to be highest in the high yield zone with 150% of recommended fertilizer rates. However these trends were not statistically significant (Figures 4 and 5) and additional site years of data were required to assess the effects of zones and fertilizer management.

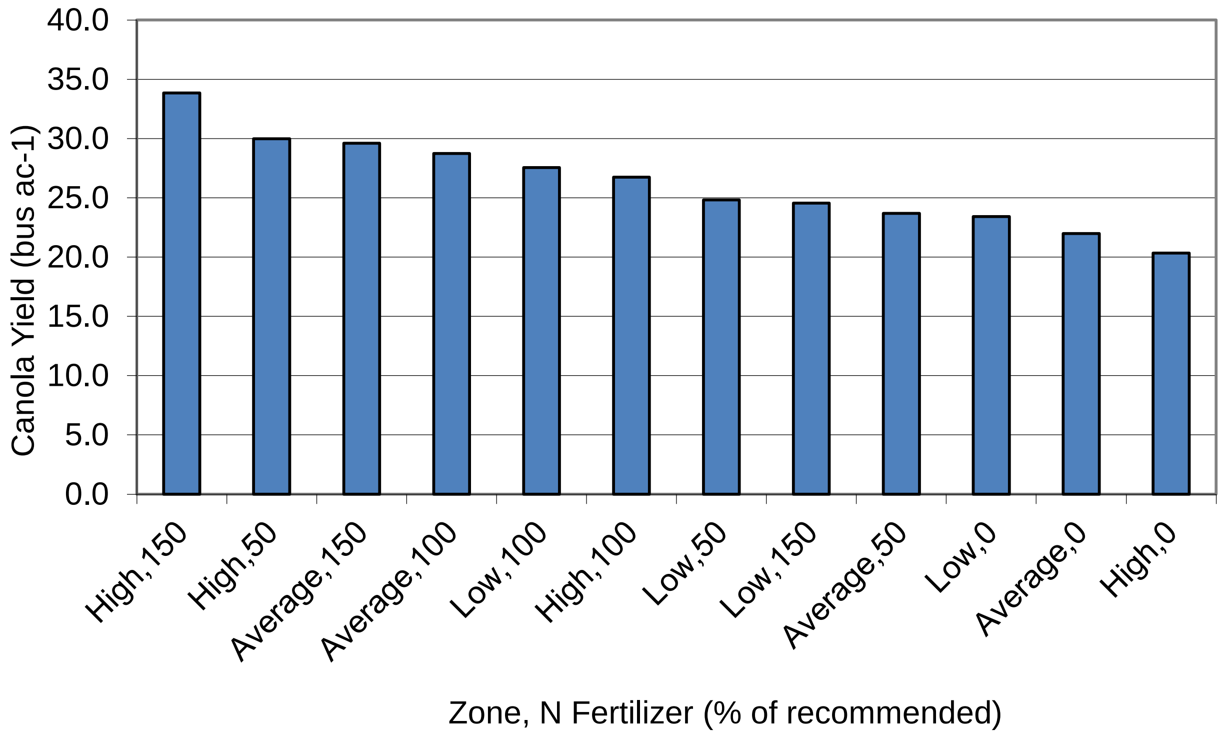


Figure 4. Yield response of canola to fertilizer treatments in management zones , MZTRA 2009.

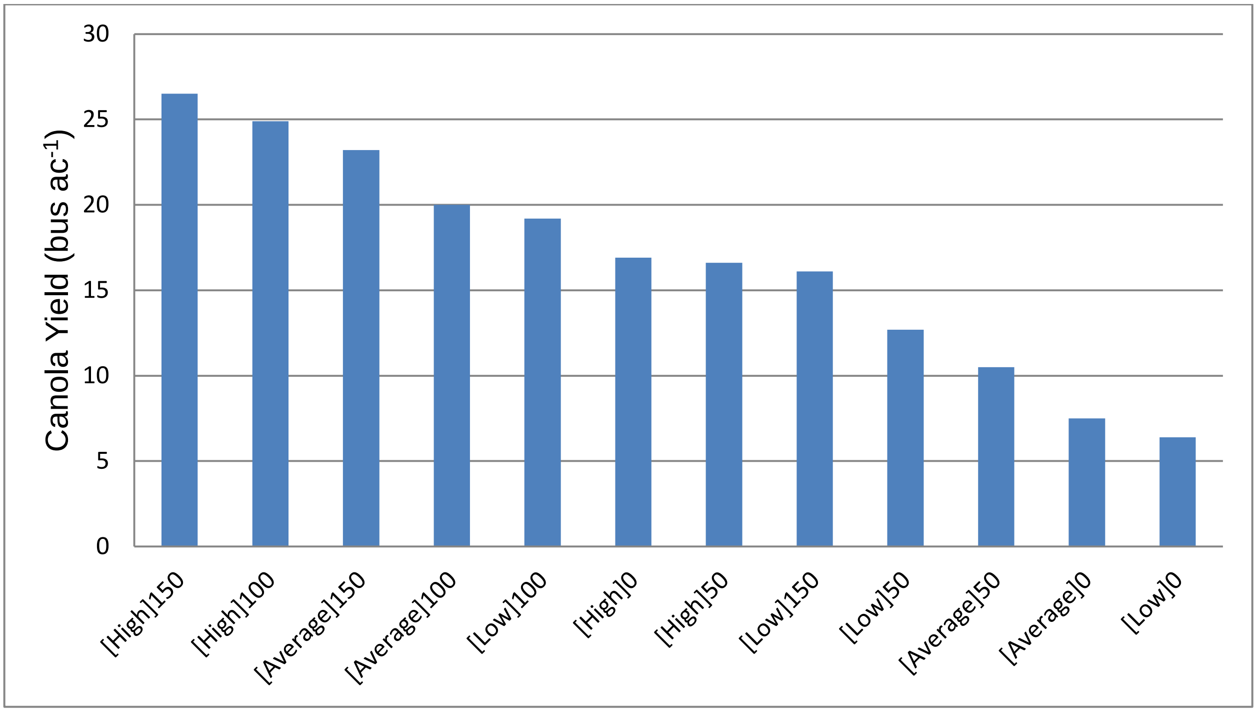


Figure 5. Yield response of canola to fertilizer treatments in management zones, MZTRA 2012.

AAFC/Canola Council Variable Rate N Project

Variability between zones and fertilizer management

Canola yield increased with fertilizer rate in an overall trend combined across 7 fields in 2014 (Figure 6). Yields were lowest in the low producing zone, intermediate in the average, and highest in the high, reflecting the spatial trend in production (Figure 6). Yields in controls without N fertilizer, were 1.45 Mg ha^{-1} for the low, 1.59 Mg ha^{-1} for the average, and 1.75 for the high reflecting the inherent potential for production in the zones. Yields in the 150% treatment, were 1.87 Mg ha^{-1} for the low and 2.22 Mg ha^{-1} for the high. There appeared to be a consistent difference between fertilizer treatments between zones. However this difference was not statistically different due to the variability between and within fields.

Variability between fields

There was considerable variability between fields with respect to the response of canola yield to management zone and fertilizer treatment (Figure 7). Interactions between management zone and fertilizer treatment varied between fields, as canola yield responds in some fields and not in others. However there was a clear statistically significant differences in fields AB1, AB2, and MB1between the 0 rate and the 50, 100 and 150% recommended fertilizer rates in analyses with plot type statistical analysis (ANOVA) and big data analysis (Figure 8 and 9). Statistically significant differences between 50, 100 and 150% rates were less frequent and often influenced by interactions with zone and field (Figure 7).

The MB-1 field in Manitoba stands out in comparison to the other fields in this study (yield monitor data were checked with a commercial scale or weigh wagon). This field had significantly higher yield than others in the study. There was a significant response to N fertilizer in the comparison between the 0 and 5 50, 100 and 150% rates of fertilizer (Figure 9) in this field. Additional soil analysis is required to determine if the field, relative to the others, has accumulated a significant pool of mineralizable N, and the status of other nutrients. The AB1 and AB2 fields were the lowest in the remaining group of fields (Figure 9). Canola yield in the high producing zone was higher than the average and low zone for the AB1 and AB2 sites, with a distinct response to fertilizer rates at 50, 100 and 150% N rates (Figure 9).

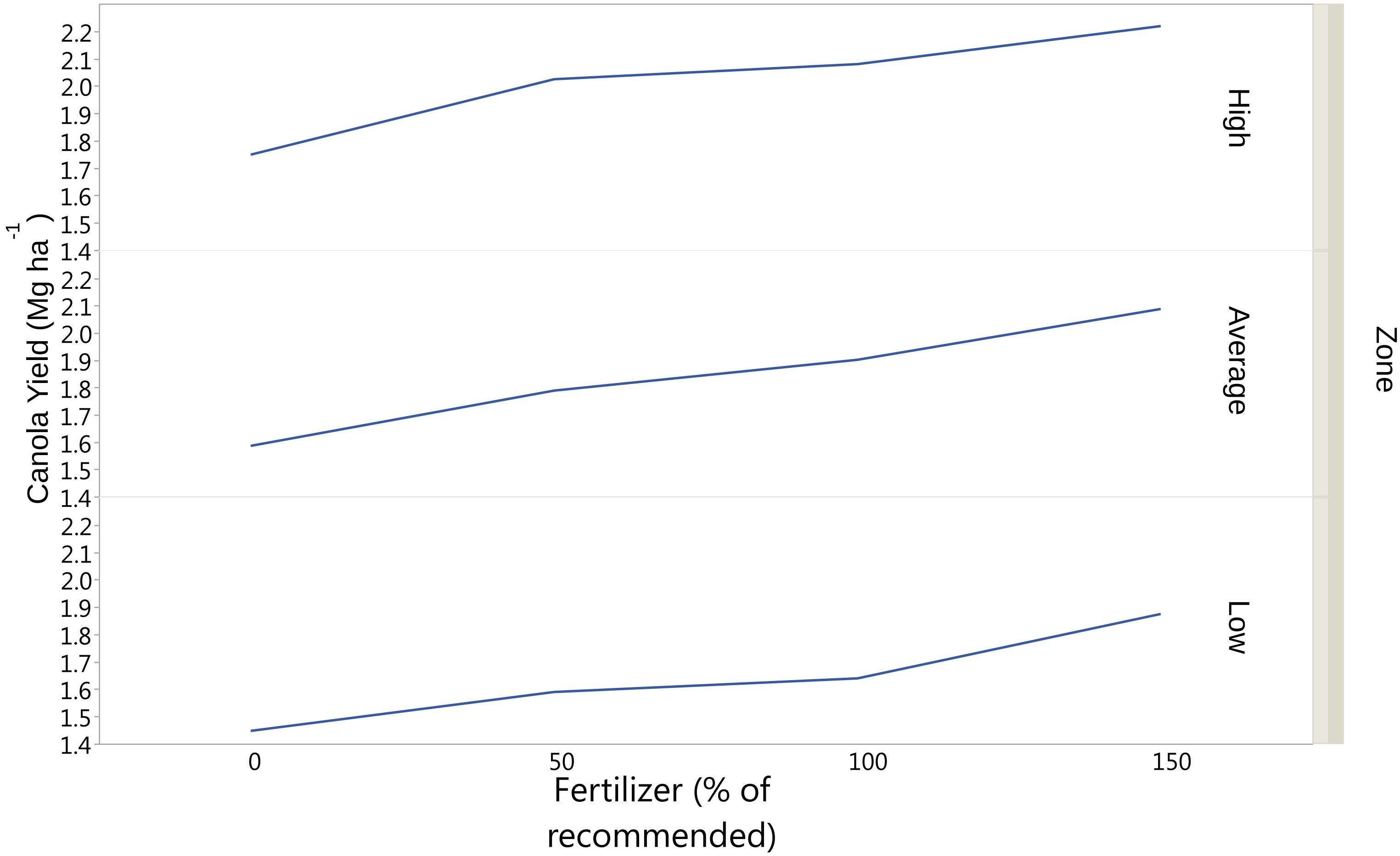


Figure 6. Yield response of canola to fertilizer treatments in management zones averaged across all fields in 2014.

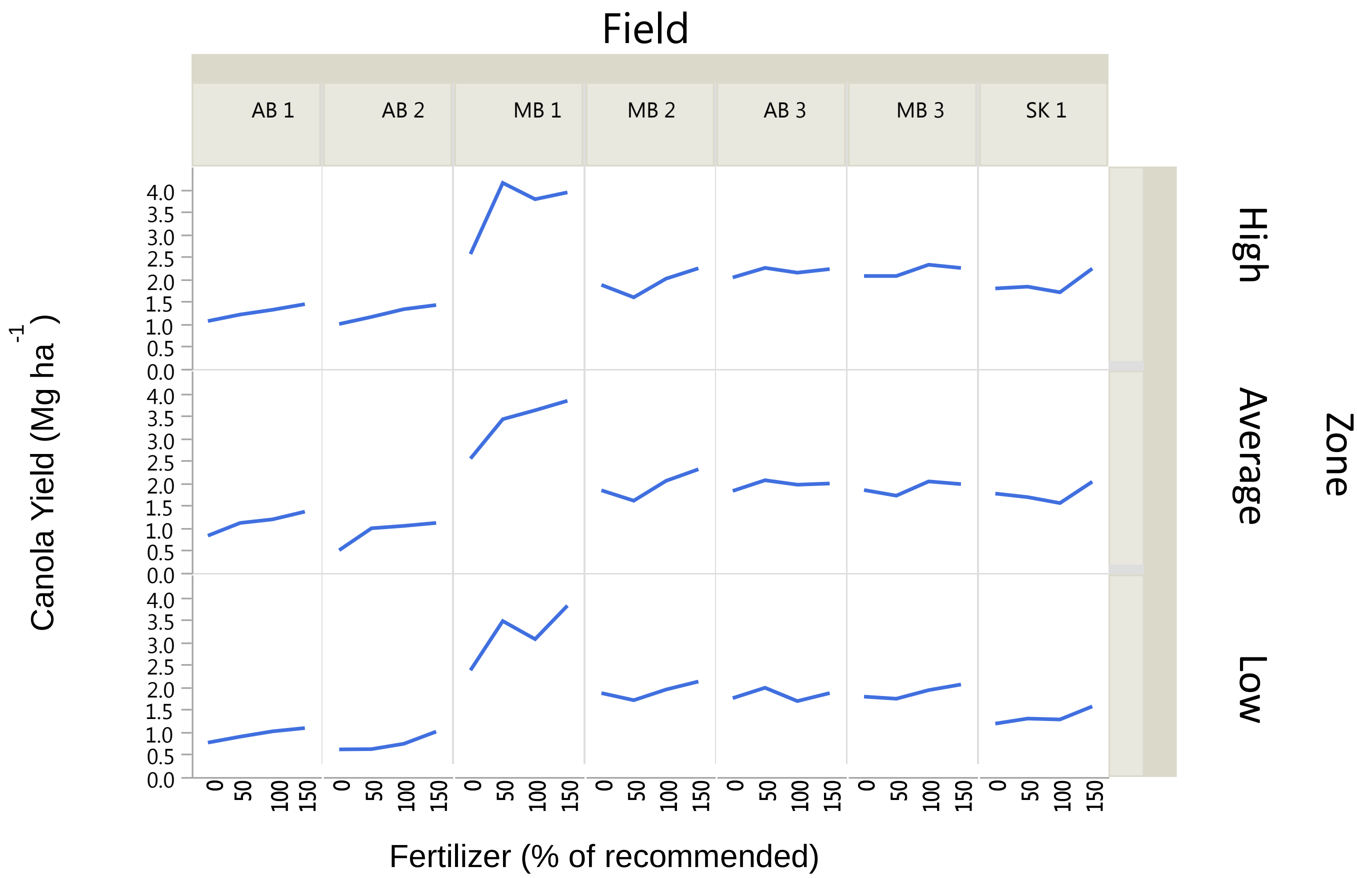


Figure 7. Canola yield by fertilizer treatment, management zone, and field.

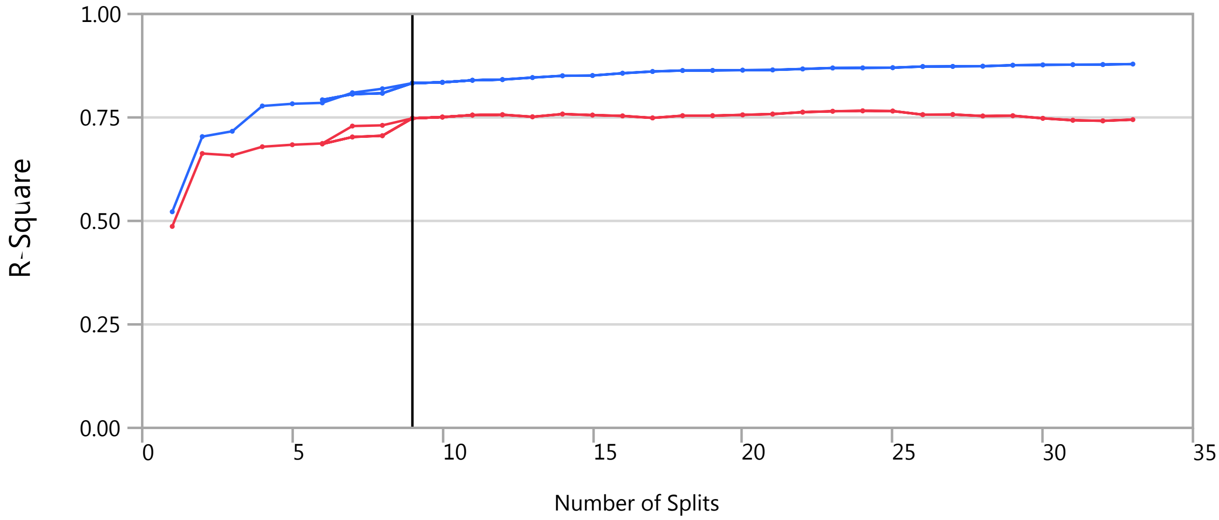
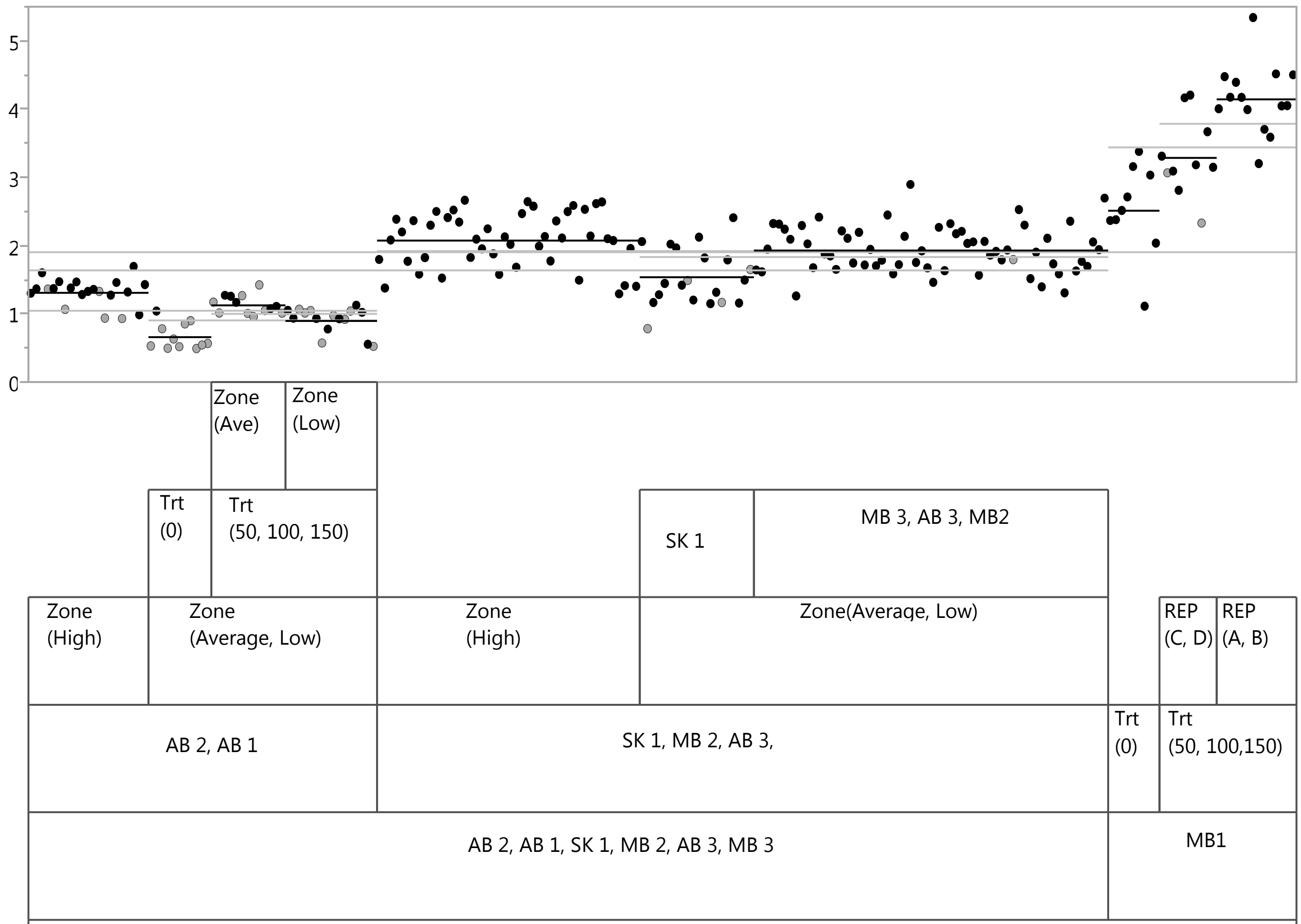


Figure 8. Number of splits for partition analysis of canola yield for fertilizer treatments, management zones and fields.



	RSquare	RMSE	N	Number of Splits	AICc
Training	0.833	0.36	222	9	203.033
Validation	0.75	0.43	114		

Figure 9. Partition analysis of canola yield for fertilizer treatments, management zones and fields.

Variability due to fertilizer treatments in fields

Responses to fertilizer (0 and 50 % treatment comparisons) were most evident and consistent in the AB1, AB2 and MB1 fields. The AB1 and AB2 fields had the lowest canola yield, while MB1 had the highest. Both showed fertilizer responses though these varied with treatment and zone. Canola yield responded to fertilizer in the comparison between the 0 and 50% rate in all three zones for both the AB1 andAB2 fields. Responses were also observed for the comparison between 100 to 150 rates in the average and high zones of the AB2 field, and for the 100 to 150 rates in the low zone for the AB1 field. In contrast the response in the MB1 field was from 0 compared to 50 in the average and high producing zones.

Discussion

Overall the general trend was for higher canola yields in the high zones but there was no significant interaction with fertilizer rate on a field by field basis. Canola yield increased with when fertilizer was applied, relative to treatments with 0% of fertilizer soil test recommendations.

Canola yields in 2014 were lower than those in 2013 which was a record year, but higher than those for 2012 on average over the Prairies. Target yields influenced by 2013, may not have been attainable in 2014. Overall soil test P, K and S levels appeared sufficient for the target yields planned for the zones. Further analysis is required to assess potential limitations to the fertilizer response of the fields.

Data were collected for 9 fields in 2015 with 10 more planned in 2016. The results in this presentation are preliminary and may change as further statistical analyses are conducted.

Conclusion

Variability between farms is the most significant factor in the analysis of canola response to variable management. Yield responses to variability between farms exceed the effects of management zone and variable management of N fertilizer. The influence of terrain on crop yield, soil test N and P may be related to the distribution of soil moisture in the landscape which reflects the processes of management, soil formation and glacial geomorphology. Development of management zones for fertilizer management of crop yield will be further assessed with the inclusion of terrain attributes in multivariate analyses at the field scale.

Acknowledgements

AAFC Science and Technology Branch, Farming Smarter (Lethbridge, Alberta), the Northeast Agricultural Research Foundation (Melfort, Saskatchewan), and Deerwood Soil and Water Management (Miami, Manitoba) will continue collaborative field scale research with producers in 2016. AAFC staff, Andrew Kopeechuk, MAFRD, Rejean Picard, Canola Council staff, Curtis Rempel, Lisa Campbell, Taryn Dickson, Shawn Senko, Kristen Phillips, NARF staff, Stewart Brandt, Jessica Pratchler, Farming Smarter staff, Ken Coles, Lewis Baarda, Funding from AAFC and Canola Council 2014-2015, ASI and MAFRD 2008-2012

References

Boydell, B., and McBratney, A.B.. 2002. Identifying potential within-field management zones from cotton-yield estimates. Precis. Agric. 3:9–23.Fraisse, C.W., Sudduth, K.A., and N.R. Kitchen, 2001. Delineation of site–specific management zones by unsupervised classification of topographic attributes and soil electrical conductivity. Transactions of the ASAE, 44(1):155–166

Fridgen, J.J., Kitchen, N.R., Sudduth, K.A., Drummond, S.T., Wiebold, W.J., and C.W., Fraisse, 2004. Management Zone Analyst (MZA):Software for Subfield Management Zone Delineation. Agron.J. 96:100–108

Kitchen N.R., K.A. Sudduth, D.B. Myers, S.T. Drummond, and S.Y. Hong, 2005. Delineating productivity zones on claypan soil fields using apparent soil electrical conductivity Computers and Electronics in Agriculture, 46: 285–308

Stafford, J.V., Ambler B., Lark R.M., and J. Catt., 1996. Mapping and interpreting the yield variation in cereal crops. Computers and Electronics in Agriculture 14:101-119

Whelan, B. M. and McBratney, A. B. 2001. The "null hypothesis" of precision agriculture management. Precision Agriculture 2: 265-279.