Spatial variability of canola yield related to terrain attributes within producer's fields

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Abstract. Canola production in the Canadian Prairies varies considerably within and between producer's fields. This study describes the variability of crop yield in producer's fields in the context of terrain attributes, and in relation to fertilizer rates in management zones determined from historical yield. Canola yield data were collected for 27 fields in Alberta, Saskatchewan and Manitoba Canada in 2014, 2015, 2016 and 2017. Several terrain attributes accounted for a considerable proportion of canola yield in gradient boosted tree analyses, in combined analyses of all fields. Terrain attributes, such as elevation, accounted for more variability in canola yield, relative to management zones and fertilizer treatments. Analyses of management zones for fertilizer management of crop yield within zones had the best statistical fit when conducted with fields as a factor in statistical analyses. In analyses with fields included as a factor in the linear mixed model, significant differences were observed for canola production between historically low and high yielding zones, and in contrasts between the control with no N fertilizer and treatments with 50, 100 and 150 % of fertilizer applied based on soil test recommendations.

Keywords. *Terrain attributes, canola, landform analysis, field scale, variable management, fertilizer*

Introduction

Crop yield in the Canadian Prairies, may vary considerably within and between fields due to the spatial distribution of soil fertility, moisture and other properties. These variables are often related to landform which directly influences soil properties. High and low yielding areas can be identified, based on analysis of covariates related to landform, and assessed to determine the appropriate management. Management zones, delineated based on combined analysis of crop yield, landform and soil properties, may improve crop yield and economic return by matching fertilizer and other inputs to yield goals for these areas.

Variability of crop yield has been assessed with landform analysis which classifies the landscape based on digital elevation data into terrain attributes used to develop management zones (Reuter et al 2005). However there are few reports for the Canadian Prairies, of the variability of crop yield as a function of landform.

Other methods have also been described to delineate variability of crop yield within and between fields, to develop zones for variable management. These include methods based on producer knowledge, soil maps, soil test, satellite images, soil conductivity, proximal sensors, yield maps and landform analysis (Nawar et al 2017). Although producers have the most direct knowledge of the spatial variability of crop yield, this information is often available in anecdotal form, and unavailable for production which includes large areas. Soil maps are available for most agricultural areas in the Canadian Prairies, but vary in scale from 1:20:000 to 1:250:000 (Agriculture and Agri-Food Canada 2018) and do not provide sufficient information related to spatial variability within fields. However, descriptions of soil series and associations do provide valuable insight with respect to the causes of variability in crop yield due to soil properties. Grid sampling with soil testing has also been used to delineate management zones; though the cost is expensive due to the large number of samples (Flowers et al 2005). Satellite images have also been related to wheat yield (Labus et al 2002), and have been used by consultants in Western Canada to develop management zones. Variability of crop yield has also been determined with proximal sensors, for example soil conductivity combined with analysis of terrain attributes has been used in Canada to delineate areas with low to high productivity (Tremblay et al 2011). Ground-based sensors such as the Greenseeker have been used to 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 (Tremblay et al 2009). The most direct method of determining variability of crop production within fields is based on the analysis of multiple years of yield maps (Robertson et al 2008). Accurate analysis of yield variability within fields is a key requirement to determine optimum fertilizer rates at seeding for variable management (Robertson et al 2008). However few of these methods have been assessed as covariates with landform, and applied to the development of management zones and fertilizer rates.

The first objective of this study was to determine the variability of crop yield within and between fields, and assess the relationship to terrain attributes determined from landform analyses. The second objective was to assess the potential of terrain attributes as a covariate to account for variability in yield response to fertilizer treatments. The third objective was to assess the influence of yield zone and fertilizer treatment on canola yield.

Methods

Selection of study sites and 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 and management data (3 to 5 years yield monitor data) prior to 2014, 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 were also recruited for the project based on the availability of 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. Trial sites were located in fields during the growing season 2014 to 2017 in Alberta, Saskatchewan and Manitoba Canada (Fig. 1).

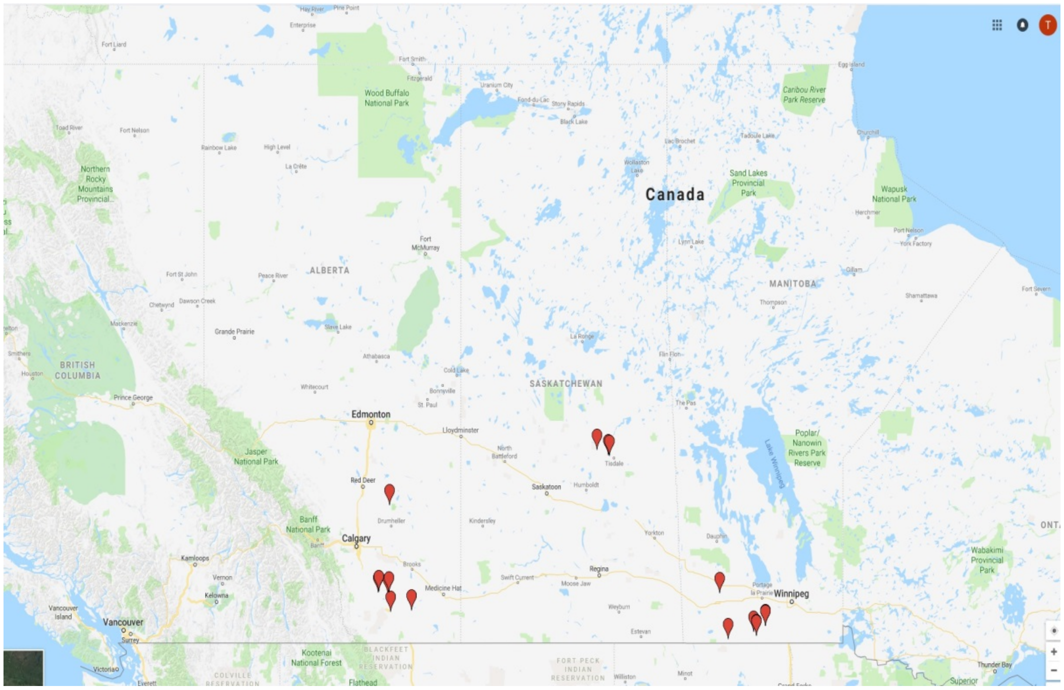

Fig 1. Location of study sites in the Canadian Prairies.

Yield zones (Fig. 2) were calculated from 3 to 5 years of normalized historical yield data, with cluster analysis in SMS Advanced (AgLeader 2017). Nitrogen fertilizer treatments (0, 50, 100 and 150% of recommended rates) were based on soil test and producer yield goals for each zone and were randomized within 4 replicate yield based zones (low, average and high yield) (Fig 3). Fertilizer was spring applied based on the producer's seeding and production system, with treatments nested within zones. Canola hybrid varieties were selected by the producers, and varied between fields. The incidence of weeds and plant disease was low in all fields, and was managed by the producers. All yield data were collected with GPS equipped yield monitors, and were calibrated with commercial scales or weigh wagons. Yield monitor variables, including location accuracy and outliers, and alignment of GPS points along harvest paths were reviewed for quality control of data. The data discussed in this paper are those collected in 2015 and 2016.

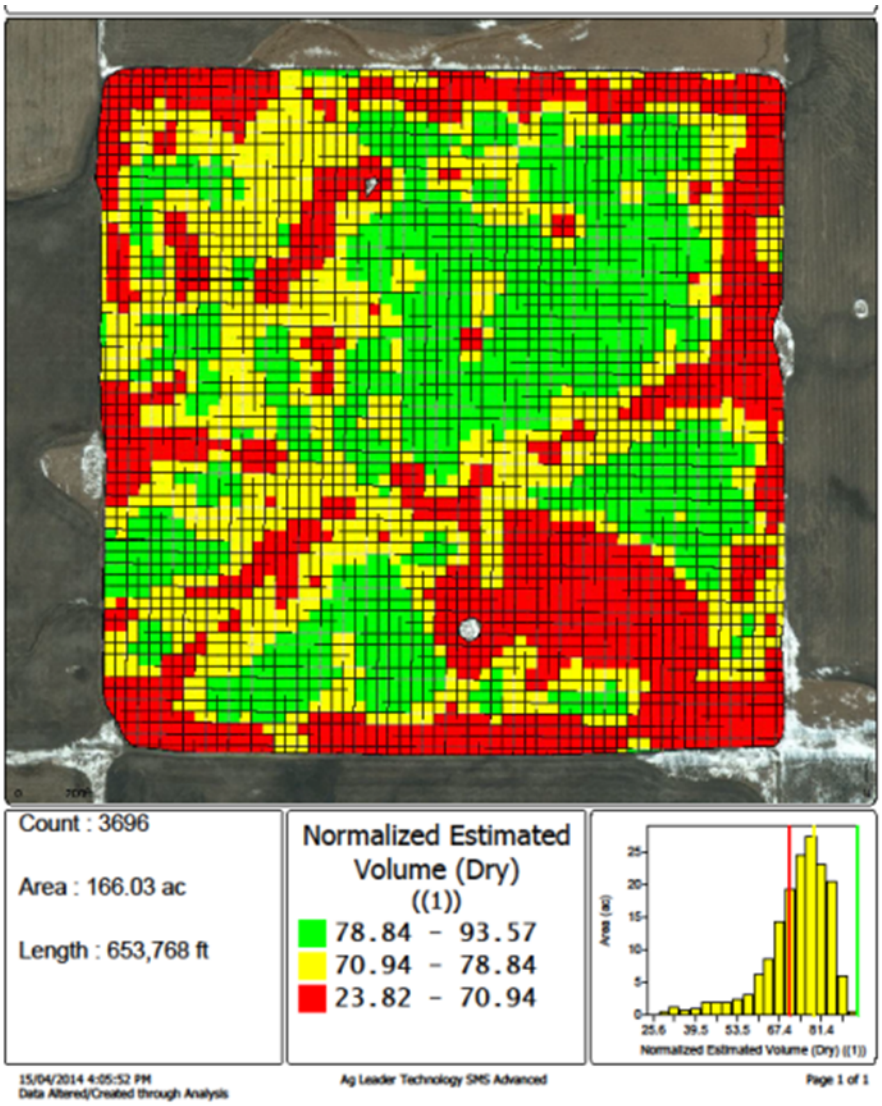

Fig 2. Yield zone for study field.

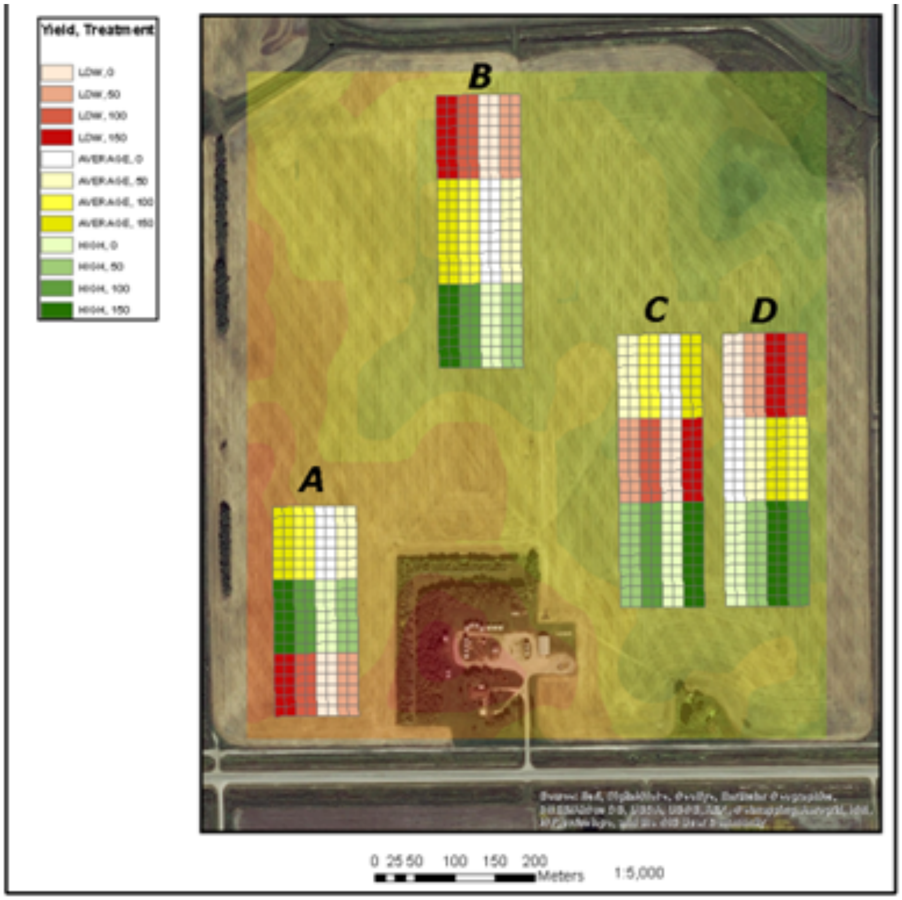

Fig 3. Location of yield zones and fertilizer treatments in a study field.

Yield monitor data, with values greater than the 97.5% quantile, and less than the 0.1 % quantile, were removed and the remainder were interpolated with simple kriging (ArcGIS 10.4.1) and used for multivariate analysis. Linear models were fit with the mixed procedure in JMP (SAS Institute 2017a) The Corrected Akaike's Information Criterion was used to assess fit statistics. Gradient boosted tree analysis (Kuhn and Johnson 2013) in JMP (SAS Institute 2017b) was used (validation fraction of 0.3, bagging fraction of 0.5, learning rate of 0.1) to analyze the relationship of yield to terrain attributes. Digital elevation data were obtained from yield monitors equipped with GPS, or from a Veris EC 3100 or MSP3 with RTX or better GPS in Alberta, or Veris 3150 msp Garmin 18x in Manitoba, based on the most accurate source of data available.

Terrain attributes were calculated from digital elevation data in SAGA (Conrad et al 2015) and LandMapR (MacMillan 2003).

Results and Discussion

Crop Yield

Crop yield varied considerably within fields (Table 1) with CV's varying from 12.7 to 55.7. This variability prompted the analysis of terrain attributes which would account for the variability in a linear model of yield response to zone and fertilizer in 2015 and 2016. Robertson *et al.* (2008) also determined that considerable variation occurred for crop yield within fields. They concluded that the potential economic return from variable management was greater for fields with large differences in yield between zones.

Table 1. Variability of canola yield between and within fields for 2015 and 2016.

Field	Province	N	Yield	Std Dev	CV
			Mg ha^{-1}		%
2015					
AB1	AB	912	1.4	0.4	29.4
AB2	AB	336	2.3	0.5	20.1
AB3	AB	256	2.7	0.3	12.7
MB1	MB	784	2.7	0.4	15.5
MB2	MB	768	2.8	0.5	17.8
SK2	SK	880	2.8	0.4	12.8
2016					
AB1	AB	1064	1.66	0.5	29.2
AB2	AB	968	2.59	1.4	55.7
AB3	AB	344	2.81	0.6	19.7
MB1	MB	448	2.17	0.8	37.4
MB2	MB	480	1.39	0.5	35.3
MB3	MB	840	1.76	0.5	26.7
MB4	MB	256	2.42	0.7	28.7

Terrain Attributes and Landform Analysis

Two terrain attributes were identified as major contributors to variability of yield in 2015. Yield was clearly related to elevation in analysis of all 2015 sites, with a proportion of 0.8163 (Table 2). Channel network base, a variable which represents hierarchical stream order, accounted for 0.0838. However a large number of terrain attributes accounted for variability of canola yield in 2016 (Table 2), with flow accumulation, valley depth and elevation as the top 3 variables. Terrain attributes greatly exceeded the variability accounted for by management zone and fertilizer treatment.

Table 2. Terrain attribute analysis for all fields within 2015 and 2016 with gradient boosted tree analysis, for variable contributions to variability of canola yield.

Terrain Attribute	Portion of variance
2015	
Elevation (m)	0.8817
Channel Network Base Level	0.0330
2016	
Flow Accumulation	0.1991
Valley Depth (m)	0.114
Elevation (m)	0.1055
z2pit (m)	0.0597
Diffuse Insolation-April	0.0557
Topographic Wetness Index	0.0494
Diffuse Insolation-June	0.0484
Channel Network Base Level	0.0453
%2pit (m)	0.0404

Crop Yield and Elevation

Analysis of management zone, fertilizer rates and fields, independent of terrain attributes showed few significant effects for 2015, but were significant in 2016 (Table 3).

Table 3. Analysis of variance with a mixed model for the effects of management zones and fertilizer treatment on canola yield, 2015 and 2016.

Variable	Significance
2015	
Zone	0.6811
Treatment within Zone	0.8763
2016	
Zone	0.0019
Treatment within Zone	0.0025

Yield varied significantly between fields (P<0.001) and between zones (P=0.0218) with a significant interaction between zones and treatments for 2015; and fields (P<0.001), between zones (0.0001) and a significant interaction (P<0.0001) in 2016 (Table 4). Fields were significant when added to the models,.

Table 4. Analysis of variance with a mixed model for the effects of management zones, fertilizer treatment and fields on canola yield, 2015 and 2016

Variable	Significance
2015	
Zone	0.0218
Treatment within Zone	0.0295
Field	0.0001
2016	
Zone	0.0001
Treatment within Zone	0.0001
Field	0.0001

Elevation, one of the terrain attributes which accounted for a significant proportion of variability in yield, did not improve the statistics of fit when added a covariate to the analysis of zones and fertilizer treatments (Table 5).

Table 5. Analysis of variance with a mixed model for the effects of management zones, fertilizer treatment and elevation on canola yield, 2015 and 2016

Variable	Significance
2015	
Zone	0.0225
Treatment within Zone	0.0302
Field	0.0001
Elevation	0.1955
2016	
Zone	0.0001
Treatment within Zone	0.0001
Field	0.0001
Elevation	0.3429

Results with respect to zone and fertilizer treatment varied considerably. Canola yield was significantly different between historically low and high yielding zones, and in contrasts between the control with no N fertilizer and treatments with 50, 100 and 150 % of fertilizer applied based on soil test recommendations. However there were few significant differences between fertilizer rates of 50, 100 and 150% (Table 6). The absence of differences between higher rates across most zones indicates a need to revisit soil test recommendations.

Table 6. Selected comparisons for significant selected contrasts with a mixed model and Tukey HSD for the effects of management zones, fertilizer treatment and elevation on canola yield, 2016

Variable	Significance
2016	
Average 0 vs Average 100%	0.0039
Average 0 vs Average 150%	0.0197
Average 0 vs High 50%	0.0098
Average 0 vs High 100%	0.0001
Average 0 vs High 100%	0.0007
Average 0 vs Low 0%	0.0001
Average 150 vs Low 0%	0.0001
High 0 vs High 100	0.0001
High 50 vs Low 0%	0.0001
High 100 vs Low 0%	0.0001
High 50% vs Low 50	0.0121
High 150 vs Low 0	0.0001
Low 0 vs Low 50%	0.0349
Low 0 vs Low 150%	0.0027

Conclusion

The addition of elevation did not improve the statistics of fit when added to the analysis as a covariate. However it is clear that analysis by fields improved interpretation of the effects of management zones and fertilizer treatments particularly for 2015. Analyses for the data for 2014 and 2017 will be evaluated at a later date to confirm the importance of analyses by field and terrain attributes. Furthermore yield zones and fertilizer management influenced canola yield in analyses which accounted for variability between farms. The absence of differences between higher fertilizer rates across most zones indicates a need to revisit soil test recommendations. Economic analyses will be completed separately.

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