Evaluation of the potential for precision agriculture and soil conservation at farm and watershed scale: A case study

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Abstract. Precision agriculture and soil conservation have the potential to increase crop yield and economic return while reducing environmental impacts. Landform, spatial variability of soil processes, and temporal trends may affect crop N response and should be considered for precision agriculture. The objective of this research was to evaluate the viability of precision agriculture in improving N use efficiency and profitability at the farm and watershed level in western Canada. Two studies are described at different scales, 1) within and between producer fields, 2) and the watershed scale. In the field scale study, research was conducted with producer's equipment in Alberta, Saskatchewan and Manitoba during 2014, 2015, 2016, and 2017. Seven fields were seeded to canola in 2014. Randomized fertilizer treatments (0, 50, 100 and 150% of soil test recommendations for N) with 4 replicates were located in low, average and high producing zones based on analysis of 3 to 5 years of yield maps. Preliminary results for 2014 show that variable management of N fertilizer had positive effects in some fields, but the results were not consistent. In the watershed scale study, producer survey data from the South Tobacco Creek (STC) watershed in Manitoba were assessed. A productivity index based on 11-year (2006-2016) moving average yield data for canola and wheat and climate and soil variables was used to delineate five management zones at the watershed scale. ArcGIS and Limdep (NLOGIT 4.0) Econometric Software was used to analyze the data. Preliminary results for the watershed scale study indicate that both spatial (zone) and temporal (time) variability had effects on crop productivity, but temporal variability had the greater effect. Soil conservation also had positive effects on increased wheat and canola yields and net revenues. The results of this study identified the potential for spatial management of N fertilizer in the context of temporal variability due to extremes in precipitation and temperature.

Keywords. *Precision agriculture, Soil conservation, Field, Watershed, Canola, Wheat, Net revenue*

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INTRODUCTION

Canola and wheat are both highly valuable crops for Canada's economy. Wheat is Canada's largest crop and the second biggest export earner out of all of Canada's agricultural products (Agriculture and Agri-Food Canada 2017), while the Canadian canola industry was estimated at an annual average value of $15.4 billion between 2007-08 and 2009-10 (Rempel et al. 2014). Determining and evaluating methods to more efficiently manage wheat and canola is thus very relevant for Canadian producers. Effective management of nitrogen (N) fertilizer through variable rate N management (VRN) is of particular interest. Nitrogen is the most common limiting nutrient other than water for canola production (Canola Council of Canada 2017), and emissions from the production, transportation, storage, delivery, and application of N fertilizer account for approximately 74% of total greenhouse gas (GHG) emissions associated with oilseed crop production (Gan et al. 2012). Precision agriculture strategies such as VRN have the potential to increase crop yield, improve profitability, and reduce environmental impacts.

A review of studies on the impact of VRN on grain yield, fertilizer use, and overall profitability revealed mixed results which are based on the magnitude of yield response to VRN, field scale variability, and costs of production. Beckie et al. (1997) found net returns from VRN to be about $10 ha^{-1} greater compared to uniform rate N fertilization of wheat, canola, and flax grown in black soil climate near Prince Albert, Saskatchewan. Torpy (2011) found that VRN had a beneficial impact on marginal return on investment as canola yield differences were higher in paddocks with high spatial variability. A study on the effect of optical sensing and variable rate application on cereal grains in Oklahoma and Virginia found that the increase in revenue from VRN was sufficient to more than cover the technology costs of VRN (Raun et al. 2002). Boyer et al. (2011), however, found no statistical differences in wheat yield and net returns between VRN and uniform rate application based on optical reflectance measurements, and conventional treatments in Oklahoma. Significant differences in yield between N management systems were also not found for spring wheat in Montana (Long et al. 2000). Similarly, a three-year study in Saskatchewan found little economic rationale for VRN strategies due to the unpredictable nature of wheat yield response to varied N rates (Walley et al. 2001). Conversely, Long et al. (2015) found net returns from VRN of hard red spring wheat in northern Montana to be up to $27.97 ha^{-1} less than from uniform N management.

A variety of different factors can affect the viability of VRN. The spatial variability of soil properties and terrain attributes in a field influences VRN, and can be determined through topographically determined landform complexes (Pennock et al. 2001), soil electrical conductivity (Zebarth et al. 2009; Johnson et al. 2003; Mulla 2013), soil moisture (Malhi et al. 2004; Mzuku et al. 2005; Holzapfel 2009), and other variables. Some researchers have advocated the use of remote sensing over soil sampling methods, due in large part to the costs of grid soil sampling (Fleming and Westfall 2000; Bramley 2009; Zebarth et al. 2009; Ge et al. 2011).

Although there have been several studies on the viability of precision agriculture strategies for a variety of crops, most of these studies have taken place in the United States. Relatively few studies have focused on the impact of variable rate N management on the profitability and environmental effectiveness of Canadian wheat and canola production in particular. The objective of this study was to evaluate the viability of VRN in improving nutrient use efficiency and profitability at the farm and watershed level in western Canada.

MATERIALS AND METHODS

Two studies are described at different scales, 1) within and between producer fields, 2) and the watershed scale.

Field Scale

Research was conducted, with producer's equipment in Alberta, Saskatchewan, and Manitoba during 2014, 2015, 2016 and 2017. Seven fields seeded to canola. Randomized fertilizer treatments (0, 50, 100 and 150% of soil test recommendations for N) with 4 replicates were located in low, average and high producing zones based on analysis of 3 to 5 years of yield maps with SMS advanced (Ag Leader, 2017). Nitrogen fertilizer treatments were based on provincial recommendations for the producers yield goal for each zone, and soil test prior to seeding. Phosphorus, potassium and sulphur fertilizer were applied to provide sufficient plant nutrients for the treatments. Results for 2014 are presented, as the data for other years have not yet been completed.

Net revenue (NR) was defined as the revenue remaining after paying for all variable costs (i.e., seed, nutrients, weed and disease control, transportation, fuel and oil, repairs, crop insurance premium, miscellaneous expenses, land taxes and land investment, interest cost on variable inputs), land costs and ownership costs on machinery and buildings (depreciation, interest on investment, insurance and housing), and labor, as described by Zentner et al. (2002). In 2016, net farm-gate prices were \$480 Mg^{-1} for canola and \$ 230 Mg^{-1} for wheat (Manitoba Agricultural Services Corporation, 2016). 2017 input prices were used to estimate costs for the crop production and NR. The NR was averaged and expressed in CND \$ ha^{-1} for each location. Statistical analysis of NR was conducted using Proc Mixed of SAS (SAS Institute Inc., 2014a, b) for each location, with management zone and N rate as the fixed effects and the replicate as randon effect. Contrast statements for mean comparisons were used to test the NRs of canola between management zones at the same recommended applied N percentage for each location.

Watershed Scale

The South Tobacco Creek (STC) watershed is located in the upper reaches of the Red River Basin about 150 km south west of Winnipeg in south central Manitoba, Canada (Figure 1). The watershed is located in the Aspen Parkland Ecoregion, straddling two other Prairie Ecoregions; the Boreal Transition and Lake Manitoba Plain (Glozier et al. 2006). Headwaters drain from the uplands of the Manitoba Escarpment, a landscape feature associated with the ancient shoreline of glacial Lake Agassiz. The gradient of STC descends some 183 meters over a distance of 50 km to join Tobacco Creek approximately 14 km downstream of Miami, MB. The watershed covers an area of 7,638 hectares of which 71% (5,409 ha) is used for crop and forage production (Khakbazan et al. 2013). The most predominant crop rotation was cereal-oilseeds mainly spring wheat-canola. The total land use for these two crops alone in the watershed was about 50% of the entire area of the watershed (Figure 1). On average, the STC watershed included more than 350 cultivated fields ranging from 200 ha to only a few hectares, with the average being 18 ha. Average N application for wheat was 100 kg ha^{-1} and for canola was 114 kg ha^{-1} (Figures 2). The average yearly temperature is around 9.5 °C; lower temperatures found on the escarpment and higher below the escarpment. The region experiences on average a 127 frost-free day growing season from late April to early October. Approximately 70% of the watershed's precipitation falls between April and October, averaging about 380 mm depending on the location relative to the escarpment (Environment Canada, 2018). Soil great groups are about 50% Gray Luvisol and 50% Dark Gray Chernozem with the dominant soil textures being loam or clay loam.

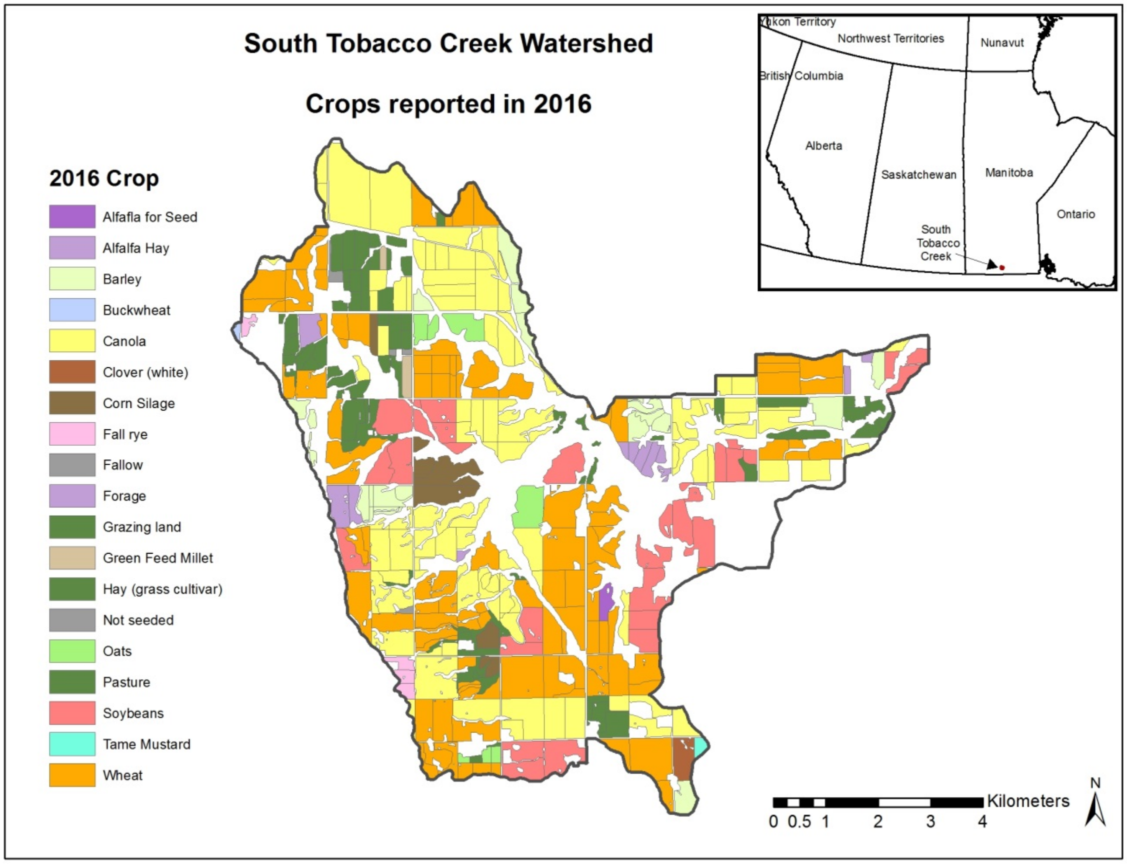

Figure 1. South Tobacco Creek watershed crop management.

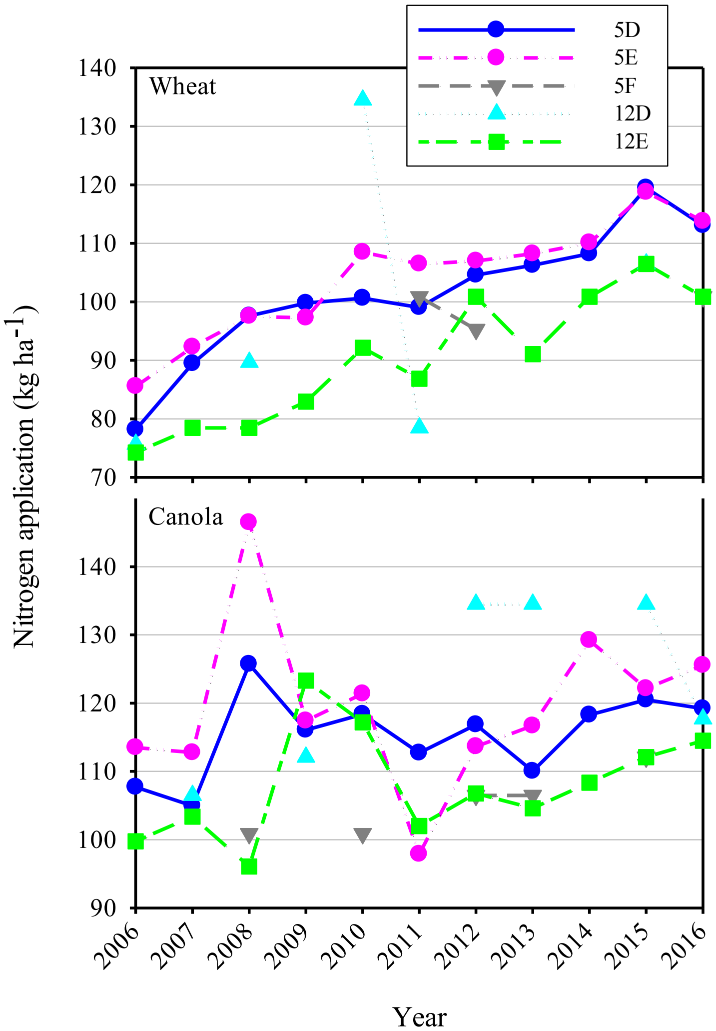

Figure 2. Average nitrogen application per zone for wheat and canola in South Tobacco Creek watershed.

Over the course of the study from 2006 to 2016, field scale data for agricultural activities including crops grown, yield, fertilizer, manure, pesticide use, and tillage practices were collected from farmers operating land in the watershed. A productivity index based on 11-year (2006-2016) moving average yield data for canola and wheat and climate and soil variables was used to delineate five management zones (5D, 5E, 5F, 12D, 12E) within the STC watershed. ArcGIS (ESRI 2017) and Limdep (NLOGIT v 4.0) Econometric Software were used to analyze the data. A crop yield function was specified as linear, with quadratic measures of particular production inputs, such as fertilizer, denoting non-constant marginal physical products (Hansen 1991). Variability in crop production was captured through change in nutrient, zone, and other variables in the yield function. Panel data models comprising cross-sectional (more than 350 fields in each year) and time-series (2006-2016) data was specified and estimated as defined by Woolridge (2002). The panel-data model was specified as follows:

$$y_{ft} = a + bN + cN^2 + \beta_i X_{ft} + \lambda * Zone + \theta * Time \qquad (1)$$

where y_{ft} consists of crop yield for field *f* over time *t*, N is nitrogen application, x_{ft} is a vector of other explanatory variables such as soil conservation and other nutrient applications, and zone represent spatial variability and time to represent temporal trends. Modeled yield, crop prices and crop costs, potential NR changes were then calculated for wheat and canola (Khakbazan et al. 2013).

RESULTS

Field Scale

Results of the field scale study for 2014 are presented, as the data analysis for other years has not yet been completed. Preliminary results for 2014 show that variable management of N fertilizer had positive effects in some fields, but the effects were not statistically significant (Figure 3). Results for two sites (Manitoba 1 and Manitoba 2) indicate that NR was numerically higher for high zones compared to average or low zones but the differences were not significant. At Melfort, NR of the high zone was higher than NR of the low zone, but was similar to the average zone. Data for 2015 and 2016 will also be analyzed to assess the economics of precision N management.

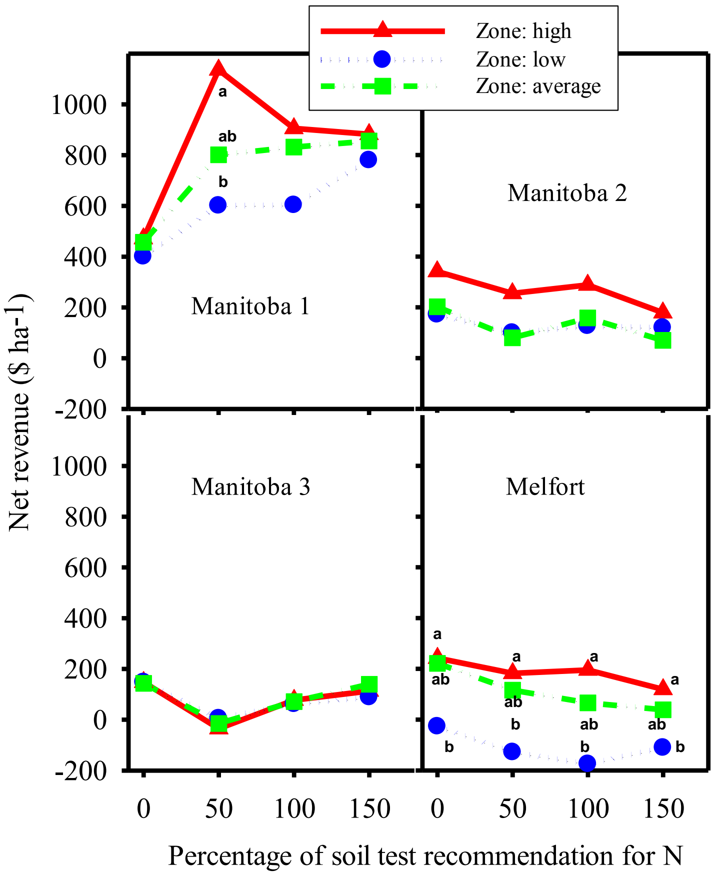

Figure 3. Effect of management zones and applied N rate on canola net revenue at four fields in Manitoba, Saskatchewan, and Alberta. Values with same letters at the same recommended applied N percentage are not significantly different (P > 0.05).

Watershed Scale

Preliminary results for the watershed scale study indicate that both spatial (zone) and temporal (time) variability had effects on crop productivity, but temporal variability had the greater effect (Table 1). High productive zone (5D) performed significantly better than average (5E) or low zone (5F) and positively contributed to the increased yield. More productive land showed higher yield, and nearly \$40 ha^{-1} more NR than less productive land within the STC with the same N rate applied. However, the probability of crop loss in Manitoba due to extreme temporal variability was 37% and 50% for the past 11 years for wheat and canola, respectively, and average crop loss when it occurred was about 15%. Excessive moisture or drought in the past 11 years have caused, on average, approximately 6% and 8% ha^{-1} yr^{-1} yield losses for wheat and canola, respectively. The average net loss was about \$44 ha^{-1} yr^{-1} for wheat, \$76 ha^{-1} yr^{-1} for canola, and \$60 ha^{-1} yr^{-1} for a wheat-canola cropping system. Soil conservation affected NR for both wheat and canola, as reduced tillage increased residue cover and crop yield. The results of this study also identified the potential for spatial management of N fertilizer between zones in the context of temporal variability.

Table 1. Wheat and canola with zone and time effects.

				Estimated fixed effects			Estimated fixed effects	
Variables	**Coefficient (t-ratio)**		**Zone**	**Coefficient (t-ratio)**		**Time**	**Coefficient (t-ratio)**	
	Wheat	Canola		Wheat	Canola		Wheat	Canola
	22.73	3.26		36.05	17.44		-415.64	-361.64
N	(3.85)	(3.52)	5D	(2.08)	(1.65)	2006	(-5.94)	(-7.73)
	-0.04	0		-56.75	4.82		-519.25	-480.69
N^2	(-1.77)	(1.29)	5E	(-2.28)	(0.38)	2007	(-5.73)	(-14.7)
	2.98	-0.61		-607.4	295.59		154.04	326.47
P	(1.54)	(-0.53)	5F	(-2.97)	(2.66)	2008	(2.57)	(8.66)
	0.72	0.36		215.08	90.63		393.39	498.84
K	(0.45)	(0.46)	12D	(0.97)	(1.04)	2009	(5.67)	(17.22)
	0.5	0.17		52.54	-144.95		110.07	484.74
S	(0.2)	(0.15)	12E	(0.87)	(-4.64)	2010	(2.23)	(14.81)
	328.18	371.75					-995.29	-426.77
Res Cov	(2.09)	(3.66)				2011	(-16.17)	(-13.7)
	1486.52	1749.61					126.94	-374.11
Constant	(4.21)	(21.14)				2012	(2.45)	(-12.18)
							76.02	-58.92
						2013	(1.06)	(-2.12)
							512.02	320.87
						2014	(10.34)	(9.41)
							280.57	181.33
						2015	(4.34)	(6.08)
							-148.68	-168.98
						2016	(-2.86)	(-5.34)

CONCLUSIONS

Two studies, at the field and watershed scale in western Canada, were used to evaluate the viability of precision agriculture and soil conservation in improving profitability and N use efficiency. Preliminary results for field scale study in 2014 showed that variable management of N fertilizer had positive effects in some fields, but the effects were not significant. In the watershed scale study, temporal (time) variability had the greatest effect on crop productivity relative to spatial trends. Soil conservation increased wheat and canola yields and net revenues. The results of this study identified the potential for spatial management of N fertilizer, if producers adopt practices in the context of temporal variability.

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