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2010F007R

Optimizing variable rate nitrogen fertilizer application in fields with spatial variability

Final Report

Section A: Project overview

1. Project number: 2010F007R
2. Project title: Optimizing variable rate nitrogen fertilizer application in fields with spatial variability
3. Research team leader: Doon Pauly
4. Research team leader's organisation: Agriculture and Forestry
5. Project start date: 2010/04/01
6. Project completion date: 2014/05/20
7. Project final report date: 2016/03/31

Section B: Non-technical summary

The purpose of this project was to develop a method of delineating management zones within fields that would be the basis for variable rate fertilization. The goal was to develop a method based on science and measurable factors that was both accurate and consistent, and could readily and inexpensively be applied to a wide range of Alberta conditions. This project focused on a landform basis for management zone delineation because of the effect landform has on water infiltration and movement, soil forming processes, differences in soil properties and crop production.

A single research site was established near Raymond in 2010. Research sites at Coaldale, Claresholm, Magrath, and Vegreville were added in 2011 with all five sites remaining as part of the project through 2013. In the initial year at each site, a transect, roughly 800 m long and 40 m wide was established across the entire field. The transects were positioned to encompass the full range of topographical variability at each site. The same fields were used each year, but the transects were shifted annually to new ground adjacent to the former transect. Along each transect, 12 to 16 "Benchmarks" (BM) were established. Benchmarks were the width of the transect and were about 15 m long. Benchmarks were situated on "Upper Slope", "Mid Slope", and "Lower Slope" landform positions, with 4 to 5 BMs in each landform at each site. These landform designations were based on how rainfall or snowmelt would run off or infiltrate. Upper slope positions were at or very near the convex part of the slope, lower slope positions were near the level, and the mid slope landform was between upper and lower landform positions. The three landforms were the main plot treatments, and the BMs within each landform position were like blocks or replicates. The transects were divided further into narrow strips that ran the full length of the transect. These strips were the experimental unit that received a range of fertilizer treatments. Transect strips were seeded with the same crop and variety as the cooperating farmer was growing on the rest of the field. The project included flax, canola, wheat, and barley.

Most research sites had landform-related soil properties with soil test N, P, K, S, and OM greatest in low slope positions compared to upper slope positions, and pH elevated at upper slope positions compared to low slopes. Fertilizer treatments affected yield at most of our sites. Slope also affected yield at most of our sites. Due to the positive correlation between soil fertility and crop yield potential or non-limiting nutrient levels, no slope by fertilizer treatment interaction was observed at 15 of 16 site years and our fertility treatments performed in a similar way in the 3 slope positions.

We tried to apply landform-based variable rate fertilization to field scale work in 2013, but we did not generate reliable data, demonstrating the difficulty of assessing the effectiveness of VRF technology at commercial field scale.

Although our results demonstrate that Alberta farmers generally do not need to vary fertilizer application within a field to optimize yield or fertilizer use efficiency, the technology is still valuable to avoid fertilizer application to obvious non-productive areas (saline areas, flood-prone depressions) and ensure uniform application over productive areas (no overlaps or misses). Evaluation in other regions, environments or management systems may yet reveal fields where delineation and management of fertilizer application zones within fields is worthwhile.

Section C: Project details

1. Project team

The original project team was: Ross McKenzie, ARD; Mike Bevans, ARD; Eric Bremer Symbio Ag Consulting; Brian Beres, AAFC; and Chris Willenborg, ARD/U of A. Mike Bevans and Chris Willenborg left ARD to pursue other opportunities soon after the project was initiated. Brian Beres loaned a Greenseeker to the project, but the NDVI data collection and processing was completed by ARD technical staff. Ross McKenzie retired from ARD during the final year of the project. Eric Bremer, as an original team member was joined by Doon Pauly and Virginia Nelson, ARD, and Mark Wobick, MNP.

2. Background

Variable rate fertilization (VRF) is technically feasible with direct seeding and fertilizing equipment available to Alberta farmers. It has the potential to improve economic crop returns through increased N fertilizer efficiency, and reduce environmental impacts associated with N fertilizer use (nitrate leaching, field nitrous oxide emissions). Greenhouse gas credits may be available for producers to utilize this technology to optimize N fertilizer use. The optimization of N fertilizer in spatially variable fields requires knowledge of how N fertilizer response varies over the landscape and the consistency of these crop responses from year to year.

Alberta has approximately 26 million acres of annually seeded crop land. Because every field is unique, simple and effective methods are required for producers and crop advisors to develop appropriate field-specific fertilizer prescription maps. Crop yield maps are easily generated from on-board yield monitoring software on most new combines. Yield monitors are not always very accurate which means yield maps may not be very reliable. Further, crop yield alone is not always well correlated with N fertilizer response, which is strongly influenced by other soil physical and chemical factors and environmental factors such as weather.

Field research in various regions of the Great Plains of North America has shown that variable rate N fertilization can increase yield, reduce yield variability and improve economic returns (Yang et al. 2001). Variable N rate research in Saskatchewan and Manitoba has shown improved N fertilizer efficiency and economic returns in some studies (Beckie et al. 1997; Pennock et al. 2001), but not others (Manning et al. 2001; Walley et al. 2001; Kutcher et al. 2005a; 2005b).

Work in Saskatchewan, Colorado and Australia has shown that the key to successful VRF is the identification of site-specific management zones within fields with predictable N fertilizer response (Pennock et al. 2001; Koch. et al 2004, Taylor et al. 2007). Variable N source application may also improve N fertilizer efficiency and economic return. In a two-year study conducted in Missouri, crop yield and fertilizer efficiency were increased by applying polymer-coated urea or anhydrous ammonia rather than urea in low-lying areas, but were not affected by N source in other landscape positions (Noellsch et al. 2009).

The delineation of management areas within a field is the critical step to shift from uniform management to site-specific management. The adoption of "Field Management" zones in western Canada has been very slow due to limited field research to support how this could be done. The goal of this research project is to develop a cost-effective protocol for management zone delineation by growers and industry agronomists.

3. Objectives and deliverables

The objective of this project was to evaluate fertilizer response across landscape to relate crop yield and quality with measured soil physical, chemical and fertility properties, and topography factors, to determine which variables best predict crop response to fertilizer. This knowledge will then be used to develop and test strategies to delineate field management zones in a simple and cost effective manner. The optimum strategy will be used to develop a fertilizer prescription map for testing in selected fields in the final year of the study. This information will allow development of a protocol for delineation of management zones that can be easily used by Alberta farmers to prepare prescription field maps to utilize VRF technology.

4. Research design and methodology

4.1 Small-plot Work

A single research site was established near Raymond in 2010. This was the start-up year to develop the research protocol. Research sites at Coaldale, Claresholm, Magrath, and Vegreville were added in 2011 and continued to 2013. Sites were selected with visual topographic variability that was assumed to represent soil variability. In the initial year at each site, a transect, roughly 800 m long and 40 m wide was established across the entire field. The transects were positioned to encompass the full range of topographical variability at each site. We returned to the same fields each year, but the transects were shifted annually to new ground adjacent to the former transect. Along each transect, 12 to 16 “Benchmarks” (BM) were established. Benchmarks were the width of the transect and were about 15 m long. Benchmarks were situated on “Upper Slope”, “Mid Slope”, and “Lower Slope” landform positions, with approximately 4 to 5 BMs in each landform at each site. These landform designations were based on how rainfall or snowmelt would run off or infiltrate. Upper slope positions were at or very near the convex part of the slope, lower slope positions were near the level, but not depressional, part of the slope, and the mid slope landform was between upper and lower landform positions. The three landforms were the main plot treatments, and the BMs within each landform position were like blocks or replicates.

The transects were divided further into narrow strips that ran the full length of the transect. These strips were the experimental unit that received various fertilizer treatments (Table 1). The area where a transect strip intersected the BM became a subplot. The 2.2 m-wide transect strips were established with a tractor equipped with a Real Time Kinematic (RTK) Global Position System (GPS) with autosteer. This RTK GPS gave sub-inch accuracy. Transect strips were seeded using this GPS-guided tractor pulling a direct seeding plot drill equipped with 10 atom-jet openers on 20 cm row spacings. Fertilizer was applied at time of seeding: nitrogen (N), potassium (K), sulphur (S), and micronutrients were side banded through a set of disc openers set slightly to the side and slightly deeper than the seed opener, whereas phosphorus (P) was placed with the seed. Nitrogen was applied as urea (46-0-0) except for ESN (45-0-0) treatments. Phosphorus was applied as ammonium phosphate (11-52-0), potassium as potassium chloride (0-0-60), and sulphur as potassium sulphate (0-0-52-17). Transect strips were seeded with the same crop and variety as the cooperating farmer was growing on the rest of the field. The project included flax, canola, wheat, and barley (Table 2).

Table 1. Fertilizer treatments in 2010 and 2011-2013

2010	2011-2013					
		N	P_2O_5	K_2O	S	Micro[1]
1. Urea – 0 kg N/ha	1.	0	25	0		
2. Urea – 30 kg N/ha	2.	30	25	0		
3. Urea – 60 kg N/ha	3.	60	25	0		
4. Urea – 90 kg N/ha	4.	90	25	0		
5. Urea – 120 kg N/ha	5.	120	25	0		
6. ESN – 0 kg N/ha	6.	150	25	0		
7. ESN – 30 kg N/ha	7.	30	25	0		
8. ESN – 60 kg N/ha	8.	60	0	0		
9. ESN – 90 kg N/ha	9.	60 ESN	25	0		
10. ESN – 120 kg N/ha	10.	90	25	50		
11. Urea – 90 kg N/ha + 31 kg K_2O & 10 kg	11.	90	25	50	20	
S/ha from potassium sulphate (0-52-17)	12.	90	25	50	20	yes
	13.	30	25	0		

[1] The micronutrient treatment for wheat was a 3:1 blend of Ultra Yield Copper,12% copper (Cu), 13% S and 6% zinc (Zn), with Ultra Yield Zinc, 20% Zn, 2% N, and 14 % S, applied at 40 kg/ha (3.8 kg/ha Zn, and 3.6 kg/ha Cu). The micronutrient treatment for canola was Ultra Yield Boron, (10% Boron (B) and 1.5 % Sulfur (S)) at 30 kg/ha. When micronutrients were applied, S levels were balanced with ammonium sulphate 21-0-0-24.

Table 2 Crops grown at each site 2010-2013

Location	2010	2011	2012	2013
Claresholm		Canola	Wheat	Wheat
Coaldale		Wheat	Wheat	Canola
Magrath		Wheat	Wheat	Barley
Raymond	Flax	Canola	Wheat	Wheat
Vegreville		Wheat	Canola	Wheat

Soil samples were taken prior to seeding at all sites. At each benchmark, five soil cores to a depth of 90 cm were taken. From these five cores, a composite sample for each of the 0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm depth increments was made. Samples were then air-dried, ground, and analyzed at the Alberta Agriculture Irrigation and Farm Water Division lab for: plant available nitrogen (N), phosphorus (P), potassium (K), sulphur (S), micronutrients, organic matter, pH and electrical conductivity (EC).

Benchmarks were trimmed to a uniform 10 m length after the crops were established. Even though fertility treatments were applied to the entire length of the transect strips, only the BM areas that were trimmed to 10 m were harvested with a small plot combine. After seeding, neutron probe access tubes were installed at each BM site to allow for soil moisture monitoring throughout the growing season. The transect was sprayed for weed control as required. After harvest the following data were determined for each treatment: moisture content, grain yield, bushel weight, grain protein, and oil content (for oilseeds). For yield, test weight (bushel weight) and protein analysis, moisture was adjusted to 13.5% for the cereal crops and 8.5% for canola. Data were analyzed with the SAS mixed model procedure. The Protected Tukey test was used for mean separations.

Additional details of methodology in individual years are available in Appendices 1-4.

4.2 Field-scale work

Field-scale work was completed at all sites except Vegreville in all years of the project. Western Tractor, the Lethbridge area John Deere dealer, supplied a tractor, air drill, combine, and staff for the field work at Coaldale, Raymond and Magrath. Alberta Agriculture staff from the Agriculture Technology Centre (now Farm Stewardship Centre – FSC) worked closely with Western Tractor for all field-scale operations at these sites. The cooperator performed the field work at Claresholm. The seeding and harvesting equipment were equipped with RTK GPS and were used to develop topographical maps for each site as well as yield maps for each site in 2010-2012. During these years, the field scale work used non-variable rate fertilization of a blanket-applied fertilizer blend. The fertilizer rate used at each site was determined by the cooperator in 2010-2012.

In 2013, variable rate fertilization practices were applied to the Claresholm, Coaldale, Magrath, and Raymond sites. David Hildebrand and David Spiess, with Alberta Agriculture's Land Use Section, delineated the landform-based management zones for each site based on data collected in field operations from previous years. For each site, the research team selected target fertilizer rates for each Upper Slope, Mid-slope, and Lower Slope management zone based on small-plot strip trial results from the preceding years of this project. These management zone fertilizer rates became a variable rate fertilizer prescription when mapped across the entire field. In addition to these variable rate prescriptions, the research team also established fixed-rate fertilizer strips that were to run the entire length of the field and were one seeder-width wide. Depending on the site, either two or three fertilizer rates were used in these large strips. There were two replicates of these fixed rate strips at each site. Fertilizer rates for the variable rate areas and large strip areas are given in Tables 3-6.

Table 3 Field-scale fertilizer application at Claresholm in 2013

Claresholm Variable Rate	lb N/ac	lb P2O5/ac	lb S/ac
Saline areas	0	0	0
Lower Slope	90	20	0
Mid Slope	120	30	0
Upper Slope	120	40	0
Claresholm Fixed Rate Strips			
Rate 1	120	30	0
Rate 2	30	30	0
Rate 3	120	0	00

Table 4 Field-scale fertilizer application at Coaldale in 2013

Coaldale Variable Rate	lb N/ac	lb P2O5/ac	lb S/ac
Lower Slope	60	20	10
Mid Slope	90	30	15
Upper Slope	120	40	20
Coaldale Fixed Rate Strips			
Low Rate	60	20	10
High Rate	120	40	20

Table 5 Field-scale fertilizer application at Magrath in 2013

Magrath Variable Rate	lb N/ac	lb P2O5/ac	lb S/ac
Lower Slope	90	20	0
Mid Slope	90	30	0
Upper Slope	60	40	0
Magrath Fixed Rate Strips			
Rate 1	90	30	10
Rate 2	30	30	
Rate 3	90	0	20

Table 6 Field-scale fertilizer application at Raymond in 2013

Raymond Variable Rate	lb N/ac	lb P2O5/ac	lb S/ac
Lower Slope	60	15	0
Mid Slope	90	30	0
Upper Slope	90	45	0
Raymond Fixed Rate Strips			
Rate 1	90	30	0
Rate 2	30	30	0
Rate 3	90	00	20

The field-scale research component in 2013 had numerous problems. The air drill used at all sites used disc openers, but it was not equipped with any residue managers. The heavy residue from the previous wheat crop at Magrath caused considerable emergence problems in the barley research crop. The field manager decided to silage the majority of the field, and had to swath the remainder of the field that was harvested as grain because of uneven maturity. The silaging and swathing operations compromised the fixed rate strips and variable rate zones. The Coaldale and Raymond sites both had substantial hail events in 2013. An early July hail storm at Raymond caused about 75% hail damage across the entire field. At harvest, the crop was a mixture of surviving original crop with some regrowth. Harvest operations did not maintain the integrity of the fixed rate strips or the variable rate zones. The Coaldale site also experienced hail storms that generally caused a gradient in damage from the north to the south of the field. The adjacent quarter to the north had 100% hail damage. The north edge of the Coaldale site also had close to 100% damage, but this diminished to virtually zero damage on the southern third of the field. The field manager at this site also decided to swath and compromised fixed rate strips and variable rate zones.

4.3 Economic Analysis

Alberta Agriculture contracted MNP to perform an economic analysis of VRF based on data generated from this project. Mark Wobick and staff at MNP Lethbridge used the yield response curves generated from the small plot component of this project in 2013 to determine margin over treatment expense for the fertility treatments at each slope position at each site. MNP used the data for all sites regardless of the statistical significance of the various yield responses. The MNP analysis was conducted after fertilizer expense, crop yield, and crop prices were all known, so essentially was conducted with "Perfect Knowledge". For each site, the MNP analysis identified the three top yielding fertility treatments and the three top margin fertility treatments, assigning each Gold, Silver, and Bronze rankings, to determine if there was a difference between yield-based or margin-based assessment of the value of VRF. This analysis also attempted to determine what level of benefit, Large or greater than $100 per ha, Medium or $51-$100 per ha, Small or $26-$50/ha, or Limited under $25 per, would have been achieved if the farm manager had fertilized at the Gold margin level rather than a "reasonable" blanket fertilizer application level. Essentially this analysis was attempting to determine the potential return from VRF and if it made sense for a farm to invest in the technology and applicable consulting fees.

5. Results, discussion and conclusions

5.1 Small-plot results

The underlying assumption for much of the work in this project was that landform affected soil properties and landform could readily be used to delineate soil management zones. At three of five sites (Claresholm, Magrath, and Raymond), slope affected soil test N, P, K, S, OM, and pH significantly a total of 15 out of a possible 18 times (Table 7). At a fourth site, Coaldale, slope significantly affected soil test N and K levels, with a strong tendency of affecting soil test P (p=0.0532) (Table 7). At the Vegreville site, slope did not affect soil test N, P, K, S, OM, or pH significantly. Year, which includes both temporal and spatial variability because transects and BMs within the transects moved each year within the field, significantly affected one or more of the measured soil properties 11 out of a possible 30 times (Table 7). The interaction of slope by year significantly affected soil properties 6 out of 30 times (Table 7).

Table 7 Probability of slope, year, and the interaction of slope and year on soil properties in 0-15 cm

Claresholm	Slope	Year	Slope*Year
N	0.1451	0.017	0.3305
P	0.0123	0.1982	0.9172
K	<0.0001	0.8892	0.8672
S	<0.0001	0.0006	<0.0001
OM	0.0001	0.0758	0.0293
pH	0.0012	0.0827	0.1825
Coaldale			
N	0.0335	0.0098	0.3532
P	0.0532	0.6599	0.281
K	0.0123	0.1965	0.0594
S	0.755	0.1792	0.0422
OM	0.478	0.9467	0.1483
pH	0.3749	0.0011	0.4361
Magrath			
N	0.0425	<0.0001	0.2774
P	0.0001	0.0455	0.3971
K	0.0005	0.2955	0.0212
S	0.0008	0.0005	0.1261
OM	0.0006	0.583	0.7466
pH	0.0678	0.1126	0.3504
Raymond			
N	<0.0001	<0.0001	0.0004
P	<0.0001	0.2368	0.0162
K	<0.0001	0.4318	0.4606
S	0.2698	<0.0001	0.2781
OM	0.0001	0.1452	0.3019
pH	<0.0001	0.4377	0.4915
Vegreville			
N	0.0791	0.0007	0.059
P	0.8845	0.6461	0.9094
K	0.5861	0.2403	0.138
S	0.9136	0.6979	0.6781
OM	0.8412	0.0265	0.6945
pH	0.9381	0.6952	0.3694

For sites with a significant slope effect on soil test N, P, S, and OM levels, the low slope position always had the greatest and the upper slope always had the lowest levels of each of these factors. Soil test K levels also followed the same pattern of differences as N, P, S, and OM, except at the Magrath site, where the mid slope position had greater soil K levels than the other two positions which had similar K. Soil pH levels followed an opposite pattern and were always highest at upper slope versus low slope positions. Except for K at Magrath, the mid slope position sometimes had soil test levels similar to the low slope position at a site, and other times had levels similar to the upper slope position at a site, which was not surprising since it was a transitional area between upper and lower slope positions. From a soil properties perspective, slope or landform seems to be a reasonable basis for delineating upper slope and low slope areas into separate soil management zones.

Fertilizer treatments significantly affected yield at 13 of 16 site-years, and slope affected yield at 14 of 16 site-years (Table 8). At 11 of 16 site years, both fertilizer treatments and slope significantly affected yield (Table 8).

For variable rate fertilization management zone delineation to be effective, fertilizer rates or treatments must respond or behave differently in one zone than in another, which for this project means that the treatment by slope interaction must be significant. However, we found a significant treatment by slope interaction effect on yield only in the flax crop at Raymond in 2010, or only 1 of 16 site-years (Table 8).

Table 8 Probability of Fertilizer Treatment effects, Slope effects, or the interaction of Treatment by Slope effects on yield at all sites 2010-2013

	Treatment	Slope	Treatment*Slope
Claresholm 2011	0.5835	0.0089	0.7321
Claresholm 2012	<0.0001	<0.0001	0.9973
Claresholm 2013	<0.0001	<0.0001	0.9998
Coaldale 2011	0.6952	<0.0001	0.9945
Coaldale 2012	0.0883	0.0180	0.1987
Coaldale 2013	0.0028	0.0018	1.0000
Magrath 2011	<0.0001	<0.0001	0.8307
Magrath 2012	<0.0001	<0.0001	0.9091
Magrath 2013	<0.0001	0.0001	0.9996
Raymond 2010	<0.0001	0.0380	0.0240
Raymond 2011	<0.0001	0.0003	0.9145
Raymond 2012	<0.0001	<0.0001	0.1284
Raymond 2013	<0.0001	<0.0001	0.9999
Vegreville 2011	0.0054	0.8371	0.9803
Vegreville 2012	<0.0001	0.1647	0.5148
Vegreville 2013	0.0016	<0.0001	0.9699

At Raymond in 2010, flax yield at the upper slope position did not increase with N application rates greater than 60 kg N ha^{-1} (Figure 1). However, flax yield continued to increase at low and mid slope positions through 120 kg N ha^{-1}, the maximum rate applied in 2010 (Figure 1). The observed landform-based yield limitation in 2010 was anticipated because the upper slope position was expected to have moisture and/or soil properties that limited yield. It was also thought that the low slope positions would sometimes not respond to fertility treatments in the same way as mid and upper slope positions, possibly due to greater water infiltration and potentially greater yield responses to fertilizer than other slope positions or perhaps because of yield-limiting lodging due to a combination of moisture and fertility effects. The absence of a fertility treatment by slope interaction effect on yield at all sites in 2011-2013 was not expected, especially since fertility treatment and slope effects on yield were usually observed, and because the soil properties of the upper slope position were often different than the other slope positions.

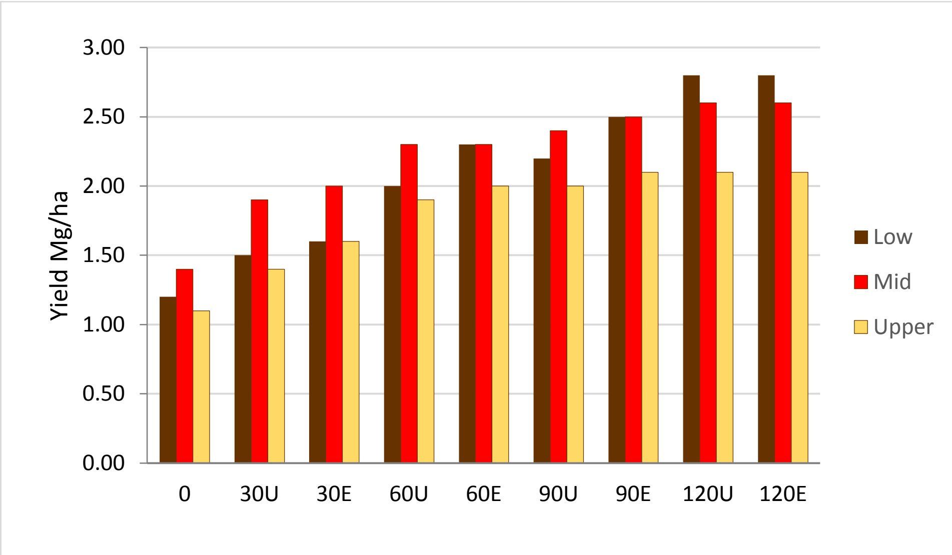

Figure 1. Flax yield response to urea and ESN application rates at Low, Mid, and Upper slope positions at Raymond in 2010

The wheat yield response to N application rates at Claresholm in 2012 illustrates how a site can have a fertility treatment effect on yield, and a slope effect on yield and not have an interaction between the two (Figure 2). In this example, the yield response curves for the low slope and mid slope positions are identical. The upper slope (Hill) yield is significantly lower than the other slope positions when averaged across all N application rates, but the shape/slope of the yield response curves are identical for each slope position. Because the fertilizer treatments behaved the same way in each slope position, there was no fertility treatment by slope interaction. These slope positions were intended to represent different management zones, and indeed had measurable soil property differences. With the benefit of knowing actual yield responses, the correct fertilization strategy would be to manage all of these "zones" the same way, at least based on the fertilizer application rates used at this site in 2012.

The 2012 Claresholm site demonstrates the challenge facing effective management zone delineation. We based our zone delineation on landform positions that had measurable soil property differences and yet our approach probably would have led to under-fertilization of upper slope positions. In the same way, if this site had been fertilized with a blanket application of N to generate a yield map, the relatively low-yielding upper slope areas would have been identified as a different management zone than the relatively high yielding low and mid slope areas with corresponding under-fertilization of upper slope areas in the following years when VRF was practiced. Similarly, a vegetative index, determined through satellite or even unmanned aerial vehicle imaging, would have identified the upper slope areas as a low yield potential management zone, even if the remote imaging had been followed with soil analyses that at best would have produced results equal to our soil analyses. Finally, EM38 or Veris mapping might have detected some differences in soil properties in this field, but these probably would not have been as precise as what we generated through lab analyses, and as we demonstrated, differences in soil properties do not necessarily lead to differences in fertilizer response. A Lethbridge-based organization that sells precision farming services was invited to participate in this project and initially provided some information on their methodology, but subsequently declined to participate any further. Consequently we do not have a direct objective comparison between landform-based management zone delineation with other methods that are available commercially.

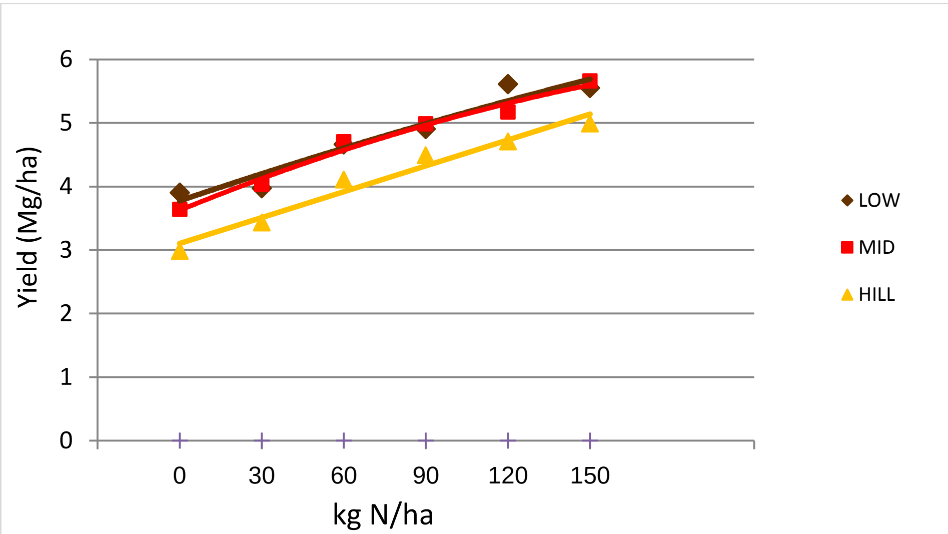

Figure 2. Wheat yield response to N at Low, Mid, and Upper slope positions at Claresholm in 2012

The majority of the time our landform-based approach to management zone delineation was associated with soil property differences. Also, in the majority of site-years we measured fertility treatment effects on yield and slope effects on yield. This should have created conditions where the interaction of these two effects was likely. However, we observed a fertility treatment by slope interaction effect on yield at only one of 16 site-years. The lack of an interaction can be attributed to the positive correlation between yield potential and soil fertility among slope positions: upper slope positions have lower yield potential and lower soil fertility while lower slope positions have higher yield potential and higher soil fertility. Thus the response to fertilizer was similar among slope positions and there was no benefit of varying fertilizer rate among slope positions in these fields. The results from these fields also clearly show that previous crop yields cannot be used by themselves to predict response to fertilizer. Accurate prediction of fertilizer response within fields requires that spatial variation in both crop nutrient requirements and soil nutrient supply are accounted for. If they are positively correlated, as evident here, then there will be minimal economic or fertilizer efficiency benefits from varying fertilizer rate within fields.

Additional results from individual years are available in Appendices 1-4.

5.2 Field-scale Results

Meaningful field-scale yield data from 2013 are not available. Yield maps from years prior to 2013 are available in annual reports (Appendices 1-4).

5.3 Economic Analysis

The MNP economic analysis found that there were differences between yield responses and margin responses for the studied fields and that the highest yield classification (Gold yield) did not consistently align with the Gold margin area of a given field. Another observation from this work was that there was a margin benefit from creating management zones in a field and varying fertilizer rates in those zones. With the perfect knowledge of known fertilizer prices and crop values as well as known optimum margins in the management zones used at each site, the net benefit of hitting the optimum margin compared to a reasonable blanket fertilization rate varied from a high of \$76 ha^{-1} to a low of \$15 ha^{-1} with a mean of \$43.80 ha^{-1} for the five sites in this project. It must be noted that these net benefit numbers were based on treatment means that might have been statistically different or might have been similar and represent a general benefit rather than a real benefit based on true differences. This net benefit did not consider any additional costs for VRF equipment or management and consulting costs. The economic analysis did not make any conclusions about the benefit VRF created and if it was sufficient to justify a switch to VRF.

5.4 Conclusions

We started this project with pretty high expectations of what we could achieve. We wanted to come up with a method of delineating management zones that would be the basis for variable rate fertilization. We wanted a method based on science and measurable factors, a method that was both accurate and consistent, and a method that could readily and inexpensively be applied to a wide range of Alberta conditions. We focused our efforts on a landform basis for management zone delineation because of the effect landform has on water infiltration and movement, soil forming processes, differences in soil properties and crop production. Most of our small-plot research sites had landform-related soil properties with soil test N, P, K, S, and OM greatest in low slope positions compared to upper slope positions, and pH elevated at upper slope positions compared to low slopes. Fertilizer treatments affected yield at most of our sites. Slope also affected yield at most of our sites. We thought our treatments and site selection should have shown that landform was useful as the basis for management zone delineation. However, due to the positive correlation between soil fertility and crop yield potential or non-limiting nutrient levels, no slope by fertilizer treatment interaction was observed at 15 of 16 site years and our fertility treatments performed in a similar way in the 3 slope positions.

We tried to apply landform-based variable rate fertilization to field scale work in 2013, but we did not generate reliable data, demonstrating the difficulty of assessing the effectiveness of VRF technology at commercial field scale.

An economic analysis performed with known fertilizer prices, yield, and crop values indicated that our approach to VRF could lead to \$15-\$76 ha^{-1} of additional margin compared to a reasonable blanket fertilization rate, but it must be noted that this potential benefit is made with hindsight and without factoring in the costs of VRF equipment, or additional management or consulting expenses.

Although our results demonstrate that Alberta farmers generally do not need to vary fertilizer application within a field to increase profitability or fertilizer use efficiency, the technology is still valuable to avoid fertilizer application to obvious non-productive areas (saline areas, flood-prone depressions) and ensure uniform application over productive areas (no overlaps or misses). Evaluation in other regions, environments or management systems may yet reveal fields where delineation and management of fertilizer application zones within fields is worthwhile. Variation in other crop management inputs, such as crop type or seeding rate, may be of value. In all cases, testing is critical to ensure that the practices adopted are effective and profitable for crop producers.

6. Literature cited

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7. Benefits to the industry

a) Our project results have a short-term impact on the crop production industry in Alberta. We were not able to delineate management zones effectively based on landform and known soil differences, and our results should cause Alberta producers to question critically the need for variable rate fertilization equipment and consulting services. In the future, technology and the application of technology may improve to the point that management zone delineation is effective and variable rate fertilization is worthwhile, but in the immediate future this does not seem realistic. The biggest impact of our results will be money saved by Alberta producers on VRF equipment and consulting fees until the technology and application of the technology are proven to be cost effective.

b) With an overall project budget of $463,565.31, and VRF consulting fees assumed to be $4 ac^{-1}, if our project results delay or prevent the needless purchase of consulting fees on minimum of 120,000 ac for one year, this project will be a net benefit to Alberta crop producers.

8. Contribution to training of highly qualified personnel (max ½ page)
None

9. Knowledge transfer/technology transfer/commercialisation (max 1 page)
The agronomic results of the project were communicated to the public at Agronomy Update 2013 (300+ in attendance), Irrigated Crop Production Update 2014 (300+ in attendance), and the Alberta Soil Science Workshop 2013 (80 in attendance). The economic analysis was presented at Agronomy Update 2015 (300+ in attendance). In addition, the Raymond site was included in the Alberta Soil Science Workshop soils tour in 2013 (60 in attendance).

Section D: Project resources

1. Statement of revenues and expenditures:

a) Financial documentation is provided in Appendix 5.

b) Overall, this project was just under $80,000 over budget, primarily because personnel costs were $111,000+ over budget. Part of the personnel overspending was covered by Agrium's $15,000 over budget cash contribution and part was covered by Alberta Agriculture's in-kind contributions that were also $63,000+ over budget. The remainder was covered by underspending in other categories It must be noted that the original project budget and the actual spending reported in this section were for the small plot/transect field work component of this project and do not include any of the field-scale work or economic analysis. Both Western Tractor and Alberta Agriculture's Ag Tech Centre made substantial in-kind contributions for the field scale work, and the Ag Tech Centre made cash payment for the economic analysis.

2. Resources:
Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Agriculture Funding Consortium	$205,000	44.2%
Other government sources: Cash		%
Other government sources: In-kind	$228,565.31	49.3%
Industry: Cash	$30,000	6.5%
Industry: In-kind		%
Total Project Cost	**$463,565.31**	**100%**

External resources (additional rows may be added if necessary)		
Industry sources		
Name (only approved abbreviations please)	Amount cash	Amount in-kind
Agrium	$30,000	

Section E: Research Team Signatures and Employers' Approval

The team leader and an authorised representative from his/her organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

By signing as representatives of the research team leader's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Team Leader's Organisation

Team Leader	
Name: Doon Pauly	**Title/Organisation: Agronomy Research Scientist/Agriculture and Forestry**
Signature:	**Date:** March 31, 2016
Team Leader's Employer's Approval	
Name: Dr. Darcy Driedger	**Title/Organisation: Director Food and Bio-Industrial Crops Section/AF**
Signature: Darcy Driedger	**Date:** March 31, 2016

Research Team Members

1. Team Member	
Name: Virginia Nelson	**Title/Organisation:** Director Engineering and Climate Services Section/Agriculture and Forestry
Signature:	**Date:** March 31/16
Team Member's Employer's Approval	
Name:	**Title/Organisation:**
Signature:	**Date:**

2. Team Member	
Name: Dr. Eric Bremer	**Title/Organisation: Principal and Research Scientist/Symbio Ag Consulting**
Signature:	**Date:** Mar 31, 2016
Team Member's Employer's Approval	
Name: Dr. Eric Bremer	**Title/Organisation: Principal and Research Scientist/Symbio Ag Consulting**
Signature:	**Date:** Mar. 31, 2016

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