Validating Post-Emergent N Application Algorithms for the GreenSeeker[tm] Optical Sensor in Cereals and Canola using Small Plot Studies and UAN Solution (YEAR 2)

G. P. Lafond[1], C. B, Holzapfel[2] and W. E. May[1]
[1]Agriculture and Agri-Food Canada, RR#1 Gov. Road, Box 760, Indian Head, SK, S0G 2K0 Telephone: 306-695-5220 or 306-695-5225 Email: lafond@agr.gc.ca and mayb@agr.gc.ca
[2] Indian Head Agricultural Research Foundation, Box 156, Indian Head, SK., S0G2K0 Telephone: 306-695-4200 Email: holzapfelcb@agr.gc.ca

1.0 INTRODUCTION

Nitrogen (N) fertility management encompasses four major components, source, placement, timing and rate (Malhi et al. 2001). Research has demonstrated that there is very little difference between fertilizer forms, providing they are managed appropriately (Johnston et al. 1997; Grant et al. 2002). Placing the fertilizer in the soil, as opposed to on the surface, greatly minimizes losses from volatilization and immobilization and enhances overall N fertilizer recovery (Malhi and Nyborg 1991; Malhi et al. 2001; Grant et al. 2002). The timing of N application should be such that it is available close to the time of maximum crop uptake which in cereal grains extends from the start of elongation until heading with peak uptake during flag leaf extension (Bauer et al. 1987) and in canola from the start of flowering to the end of pod formation (Malhi et al. 2007).

The current N fertilizer rate recommendations on the Canadian prairies generally consider factors such as soil texture, residual soil nitrate levels, soil moisture at seeding, average growing season precipitation, previous crop grown, crop to be grown, target grain yield, expected commodity prices and N fertilizer prices (McKenzie 1998; Anonymous 2007). However there is much uncertainty with all of these factors due to year to year variations in climatic conditions and to spatial variability in soil nutrient levels and inherent fertility of the soil. Nitrogen release during the growing season and the major pathways of N losses (immobilization, volatilization, denitrification and leaching) are also greatly influenced by climatic conditions, making their amounts very difficult to estimate. Consequently, much uncertainty exists in determining crop N requirements and the rate of application can easily be under or overestimated with important economic and/or environmental consequences in either case.

There is interest in exploring post-emergent N applications in annual crops to refine our ability to arrive at more optimal rates of N fertilizer. Delaying some or all of the N fertilizer until after crop emergence may allow for a better sense of yield potential and expected growing conditions. Recent research with spring wheat and canola using post-emergent N applications as an N management tool compared applying all fertilizer at time of seeding in the soil with in-crop surface banded applications of liquid urea-ammonium nitrate at different times after seeding. Holzapfel et al. (2007) showed no adverse effects in canola but some yield depression was observed in spring wheat, especially in those years where little precipitation was received after N application. In order to reduce the risks associated with post-emergent N applications, recent research showed that applying 50% or more of the recommended N at seeding enhances the opportunity for in-crop applications of nitrogen in spring wheat and canola to better match the soil and climatic conditions. (Lafond et al. 2008)

With the recent introduction of commercial optical sensors as a nitrogen management tool, it is now possible to estimate crop yield potential early in the growing season in cereals (5-6 leaf stage) allowing enough time to adjust the rates of N to realize that potential (Raun et al. 2002).

The objectives of this study were to validate the application algorithms developed to date in spring and winter wheat, durum, oat, malting barley and canola using small plots in order to get an accurate assessment of the proposed algorithms. The validation consisted of applying specific amounts of UAN at the 6-7 leaf stage in cereals and the mid-bolting stage of canola using rates determined by the algorithms. The results were then compared to actual N rate studies for each crop adjacent to the plot studies where the algorithms were tested. This was to verify how well the algorithms were able to predict the best N rate possible using the N response curves from the adjacent plots as a measure of precision or accuracy.

2.0 MATERIALS AND METHODS

2.1 Experiment #1: N rate study in cereals and canola.

Crops: Spring wheat, Winter wheat, Durum, Oat, Malting Barley and Canola.
N Rates: 0, 25, 50, 75, 100 and 125 kg N/ha.
Experimental Design: Randomized complete block design with 4 replicates.
Number of Plots: 144 plots
Variables Collected:

1. Plant populations (plants m^{-2})
2. Grain yield (bus/acre)
3. Grain Protein (%)
4. Repeated measurements with the GreenSeeker from the 4^{th} leaf to flag leaf stage in cereals and from the 5^{th} leaf stage to start of flowering in canola.

2.2 Experiment #2: Test of the application algorithms for the GreenSeeker.

2.2.1 Crops: Spring wheat, Durum, Oat, Malting Barley and Canola.
Treatments:

1. Check plot - no nitrogen added
2. N Rich strip: Rate of N 1.5-2.0x the average rate for the area and adjusted for residual Nitrate N.
3. Farmer Practice: Based on residual N level and adjusted for soil moisture conditions at time of seeding, area, soil type and crop using the recommendations from the FARM PHASE II program in use by Enviro-Test Labs.
4. Reduced N rate: 66% of rate used in Farmer Practise treatment and no further N applied.
5. 50% of Farmer Practice Rate at seeding and the balance 50% of N applied at the 6-7 leaf stage in cereals and mid-bolting stage in canola using UAN as a surface dribble.
6. 66% of Farmer Practice Rate at seeding and the balance 34% of N applied at the 6-7 leaf stage in cereals and mid-bolting stage in canola using UAN as a surface dribble.
7 50% of Farmer Practice Rate at seeding and the balance of the N applied using the application algorithm developed for the GreenSeeker optical sensor.

8. 66% of Farmer Practice Rate at seeding and the balance of the N applied using the application algorithm developed for the GreenSeeker optical sensor.

2.2.2 Crops: Winter wheat
Treatments:
1. Check No N
2. N-Rich 175% of recommended applied as UAN in early spring
3. 100% of recommended in early spring using a surface band of UAN
4. 66% of recommended in early spring using a surface band of UAN
5. 66% of Fertilizer recommended using liquid UAN surface banded early in the spring and brought to 100% at between crop growth stage Feekes 4 and 5 using UAN.
6. 66% of Fertilizer recommended using liquid UAN surface banded early in the spring and topped up using the algorithm and the GreenSeeker sensor between crop growth stage Feekes 4 and 5.
7. 34% of Fertilizer recommended using liquid UAN surface banded early in the spring and brought to 100% at between crop growth stage Feekes 4 and 5 using UAN.
8. 34% of Fertilizer recommended using liquid UAN surface banded early in the spring and topped up using the algorithm and the GreenSeeker sensor between crop growth stage Feekes 4 and 5.

2.2.3. Experimental Design: Randomized complete block design with 4 replicates.
Number of Plots: 192 plots
Variables Collected:
1. Plant populations (plants m^{-2})
2. Grain yield (bus/acre)
3. Grain Protein (%)
4. Measurements with the GreenSeeker as required

2.3 Other Agronomic details:

These studies were carried out at the Indian Head Research Farm in Indian Head, SK. The soil type is a Rego Black Chernozem (Udic Haploboroll). The spring wheat, durum wheat, barley and oat plots were seeded on April 28 while the canola plots were seeded on May 8, 2008. The winter wheat plots were seeded on September 4, 2007.

All plots for study #1 and #2 were seeded with an Edwards High Clearance Hoe press drill with a row spacing of 8”. Each plot was 8’ x 35’. All nitrogen fertilizer was mid-row banded between every second opener. The rates of N used are provided in the Tables. The phosphorus fertilizer was placed with the seed for all cereals and canola. Mono-ammonium phosphate (11-52-00) was applied at a rate of 50 kg/ha for spring wheat, durum, oat and barley and winter wheat and 58 kg/ha for canola. The nitrogen source used in both experiments was urea (46-00-00).

In study #2, where the post-emergent nitrogen treatments were imposed, the post-emergent N form used was liquid UAN (urea-ammonium nitrate; 28-0-0). The UAN was applied as a surface band on 12” spacing.

All pest management was done as required using recommended products and rates appropriate for the area.

2.4 Application algorithms developed for the GreenSeeker Sensor

Table 1 provides a description of the yield potential equations used for each crop. The equations were derived from small plot trials for each crop where different yield potentials were generated with different rates of N and sensor readings taken at times deemed appropriate for use with the GreenSeeker sensor. Grain yields were collected from each plot and equations developed to relate the sensor readings to grain yields.

3.0 RESULTS AND DISCUSSION

The responses of durum, spring wheat, oat and barley to nitrogen fertilizer rates were linear except for spring wheat where the quadratic form was significant. The overall responses tended to be flat given the high values for the y-intercept (Table 2). It should be noted that for spring wheat, the quadratic form was also significant (Table 2). The rate of yield increase per kg of N applied (bus/kg N) was 0.189, 0.086, 0.208 and 0.3338 for durum, spring wheat, oat and barley, respectively when using a linear function. With winter wheat, the response to nitrogen was quadratic in nature and the optimum N rate estimated as 133 kg N/ha, respectively (Table 3). With canola, the linear and quadratic form were significant and the optimum N rate was calculated as 185 kg N /ha which is much above the economic rate given the prices of nitrogen fertilizers for the 2007 growing season.

The amount of nitrogen used for durum, spring wheat, barley and oat for the various treatments in Experiment #2 is provided in Table 4. With spring wheat and durum, there was a response to nitrogen observed but no other treatment effects on grain yield (Table 5). Consequently for those two crops, there was a saving of 26-44 kg N /ha in spring wheat and durum when the optical sensor was used to fine tune nitrogen rates based on estimated yield potentials in relation to the nitrogen rich treatment (Table 4).

With barley, a nitrogen response was observed and the grain yields for the optical sensor were the same as the farmer practise treatment even though less overall nitrogen was used with the optical sensor although the treatment where only 50% of the target N was applied at seeding tended to be lower (Table 4 and 5). It is interesting to note that that the split application of nitrogen gave higher grain yields than when the optical sensor was used.

With oat, a nitrogen response was observed and the N-Rich treatment gave the highest grain yields and the yield was also higher than the farmer practise treatment (Table 5).When the optical sensor was used, the treatment where 66% of the target nitrogen rate was applied at seeding used gave a higher yield than when only 50% of the target N rate was used at seeding. The sensor treatments gave similar yields to the Farmer Practise treatment but used less nitrogen fertilizer (19-26 kg N/ha less).

With winter wheat, a response to nitrogen was observed but no other treatment differences were noted (Table 6). Use of the sensor gave similar grain yields as the farmer practise treatment but with 27-58 kg N /ha less nitrogen. The overall grain yields for winter wheat were low due to the dry spring and wide temperature fluctuations in April and early May.

With canola, a nitrogen response was observed and the N-Rich treatment yielded higher than the average of all other treatments not including the check (Table 7). The Farmer Practise treatments yielded more than the split applied treatment where only 50% of the target N rate was applied at seeding but similar to the treatment where 66% of the target N rate was applied at seeding. Using the optical sensor resulting in lower nitrogen fertilize use but also lower yields relative to the Farmer Practise treatment. In 2008, the sensor underestimated the yield potential resulting in lower nitrogen rates. The weather after application improved significantly resulting in overall above average grain yields. With canola in 2008, even adding 66% of the target N rate at seeding did not lessen the chances for lower grain yields when the optical sensor. The final N rates used in canola were much lower than the target N rate when the optical sensor was used.

4.0 CONCLUSIONS

The study results in 2008 support the merits of in-crop N applications for all crops except for canola when combined with the optical sensor. With canola, the environmental conditions improved greatly after the sensor readings resulting in an underestimate of yield potential when the sensor readings were taken. This N management approach when combined with optical sensors, offers the possibility of refining N rates to match the crop with soil and crop conditions and to also take into consideration spatial variability in soil nitrogen and yield response.

5.0 REFERENCES

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Table 1. List of yield potential equation for each crop used in the study in 2008.

Crop	Yield Potential Equation[1]
Canola	$Y = 739.25\ e^{877.85*insey}$
Spring wheat	$Y = 855.04\ e^{913.90*insey}$
Malting barley	$Y = 1211.7\ e^{925.79*insey}$
Oat	$Y = 1567.5\ e^{764.08*insey}$
Winter wheat	$Y = 2082.2\ e^{475.6*insey}$
Durum	$Y = 565.31\ e^{1390.5*insey}$

[1] insey=NDVI/GDD where NDVI is the reading from GreenSeeker sensor and GDD is the number of growing degree days using a base temperature of $0^{o}C$ from seeding to day of sensing.

Table 2. The response of durum, spring wheat, oat and barley to different rates of nitrogen fertilizer in 2008.

N rate (kg/ha)	Bus/acre			
	Durum	Spring wheat	Oat	Barley
0	40.6	33.3	105	58.6
25	48.8	38.0	110	58.3
50	46.0	40.4	117	73.3
75	49.1	44.3	126	72.0
100	51.3	41.8	124	71.9
125	53.5	44.2	126	74.6
cv (%)	9.9	7.4	7.5	11.1
Contrasts	***p*-values**			
linear	0.019	0.001	0.007	0.0017
quadratic	ns	0.037	ns	ns
cubic	ns	ns	ns	ns
Linear Regression				
Y intercept	38.8	31.7	94.3	44.6
Slope	0.189	0.086	0.208	0.338
R^2	0.91	0.79	0.68	0.85
	Quadratic Equation			
Spring Wheat	$y=-0.0009x^2 + 0.200x+29.7 \quad r^2=0.90$			

Table 3. The response of winter wheat and canola to different rates of nitrogen fertilizer on grain yield (bus/acre) in 2008.

N rate (kg/ha)	Winter Wheat		N rate (kg/ha)	Canola
0	30.3		**0**	20.7
25	36.6		**25**	27.2
50	38.1		**50**	31.9
75	41.0		**75**	39.5
100	42.6		**100**	42.3
125	41.9		**125**	44.9
150	43.4		**cv(%)**	6.7
cv (%)	5.9		***p*-value**	**0.0001**
***p*-value**	**0.0001**		**Linear**	0.0001
Y intercept	34.2		**Quadratic**	0.043
x^2	-0.448		**Cubic**	ns
x	5.5		$\mathbf{y}=0.199\mathbf{x}+21.993$ $r^2=0.97$	
R^2	0.97		$\mathbf{y}=-0.0008\mathbf{x}^2+0.296\mathbf{x}+20.4$ $r^2=0.99$	

Table 4. The evaluation of different N management strategies on the amount of nitrogen fertilizer (kg N/ha) applied in durum, spring wheat, oat and barley in 2008.

Treatments	Durum	Spring wheat	Barley	Oat
1. Check	0	0	0	0
2. N Rich	130	130	160	112
3. Farmer Practice (FP)	90	90	105	56
4. 66% of FP (RR)	59	59	69	37
5. 50% N at Seeding + 50% at 6 leaf stage	90	90	105	56
6. 66% N at Seeding + 34% at 6 leaf stage	90	90	105	56
7. 50% N at Seeding + balance based on GreenSeeker (GS) readings at the 6 leaf stage	46	48	52	30
8. 66% N at Seeding + balance based on GreenSeeker (GS) readings at 6 leaf stage	64	64	73	37

Table 5. The evaluation of different N management strategies on the grain yield (bus/acre) of durum, spring wheat, oat and barley in 2008.

Treatments	Durum	Spring wheat	Barley	Oat
1. Check	31.2	31.0	48.2	97
2. N Rich	46.5	41.0	74.5	119
3. Farmer Practice (FP)	40.1	40.3	70.3	109
4. 66% of FP (RR)	44.4	39.2	68.8	111
5. 50% N at Seeding + 50% at 6 leaf stage	11.9	38.3	75.6	112
6. 66% N at Seeding + 34% at 6 leaf stage	45.5	38.3	73.8	116
7. 50% N at Seeding + balance based on GreenSeeker (GS) readings at the 6 leaf stage	39.3	38.0	62.0	105
8. 66% N at Seeding + balance based on GreenSeeker (GS) readings at 6 leaf stage	39.4	39.7	70.1	115
LSD(05)	10.0	3.9	9.4	8.7
cv(%)	16.6	7.0	9.4	5.4
Contrasts	***p*-values**			
Check vs Rest (1 vs 2-8)	0.006	0.0001	0.0001	0.0001
N Rich vs Remaining N treatments (2 vs 3-8)	ns	ns	ns	0.026
N Rich vs FP (2 vs 3)	ns	ns	ns	0.033
FP vs RR (3 vs 4)	ns	ns	ns	ns
FP vs Split (3 vs 5+6)	ns	ns	ns	ns
FP vs GS (3 vs 7+8)	ns	ns	ns	ns
FP vs Split 50% (3 vs 5)	ns	ns	ns	ns
FP vs Split 66% (3 vs 6)	ns	ns	ns	ns
FP vs GS 50% (3 vs 7)	ns	ns	ns	ns
FP vs GS 66% (3 vs 8)	ns	ns	ns	ns
Split vs GS (5+6 vs 7+8)	ns	ns	0.013	ns
Split 50% vs GS 50% (5 vs 7)	ns	ns	ns	ns
Split 66% vs GS 66% (6 vs 8)	ns	ns	ns	ns
Split 50% vs Split 66% (5 vs 6)	ns	ns	ns	ns
GS 50% vs GS 66% (7 vs 8)	ns	ns	ns	0.037
RR vs Split (4 vs 5+6)	ns	ns	ns	ns
RR vs GS (4 vs 7+8)	ns	ns	ns	ns

Table 6. The evaluation of different N management strategies on the grain yield and total nitrogen fertilizer used in winter wheat in 2008

Treatments	Bus/acre	kg N fertilizer /ha
1. Check	28.7	0
2. N Rich	42.4	207
3. Farmer Practice (FP)	40.9	110
4. 66% of FP (RR)	38.2	78
5. 66% N in Early Spring and 34 % at Feekes 4-5	43.5	110
6. 66% N in Early Spring + balance with GreenSeeker (GS) at Feekes 4-5	41.3	83
7. 34% N in Early Spring and 66 % at Feekes 4-5	41.1	110
8. 34% N in Early Spring + balance with GreenSeeker (GS) at Feekes 4-5	39.4	52
LSD(05)	3.5	-
cv(%)	6.1	-
Contrasts	***p*-value**	
Check vs Rest (1 vs 2-8)	0.0001	-
N Rich vs Remaining N treatments (2 vs 3-8)	ns	-
N Rich vs FP (2 vs 3)	ns	-
FP vs RR (3 vs 4)	ns	-
FP vs Split (3 vs 7)	ns	-
FP vs GS (3 vs 6+8)	ns	-
FP vs Split 34% (3 vs 7)	ns	-
FP vs GS 66% (3 vs 7)	ns	-
FP vs GS 34% (3 vs 8)	ns	-
Split 34% vs GS 34% (7 vs 8)	ns	-
GS 34% vs GS 66% (6 vs 8)	ns	-
RR vs GS (4 vs 6+8)	ns	-

[1] Treatment lost due to misapplication of nitrogen fertilizer. Not included in the analysis.

Table 7. The evaluation of different N management strategies on the grain yield (kg/ha) and total nitrogen fertilizer (kg/ha) used in canola in 2008.

Treatments	Grain Yield	N Rate
1. Check	24.5	0
2. N Rich	44.7	148
3. Farmer Practice (FP)	44.4	114
4. 66% of FP (RR)	39.8	75
5. 50% N at Seeding + 50% at 6 leaf stage	40.8	114
6. 66% N at Seeding + 34% at 6 leaf stage	43.0	114
7. 50% N at Seeding + balance based on GreenSeeker (GS) readings at the 6 leaf stage	38.9	59
8. 66% N at Seeding + balance based on GreenSeeker (GS) readings at 6 leaf stage	37.7	75
cv(%)	5.0	-
Contrasts	***p*-values**	
Check vs Rest (1 vs 2-8)	0.0001	-
N Rich vs Remaining N treatments (2 vs 3-8)	0.002	-
N Rich vs FP (2 vs 3)	ns	-
FP vs RR (3 vs 4)	0.004	-
FP vs Split (3 vs 5+6)	ns	-
FP vs GS (3 vs 7+8)	0.0001	-
FP vs Split 50% (3 vs 5)	0.059	-
FP vs Split 66% (3 vs 6)	ns	-
FP vs GS 50% (3 vs 7)	0.0008	-
FP vs GS 66% (3 vs 8)	0.0001	-
Split vs GS (5+6 vs 7+8)	0.0013	-
Split 50% vs GS 50% (5 vs 7)	ns	-
Split 66% vs GS 66% (6 vs 8)	0.0013	-
Split 50% vs Split 66% (5 vs 6)	ns	-
GS 50% vs GS 66% (7 vs 8)	0.0012	-
RR vs Split (4 vs 5+6)	ns	-
RR vs GS (4 vs 7+8)	ns	-