Using the Greenseeker^{tm} to Manage Nitrogen in Canola and Wheat

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Introduction

Nitrogen is the most limiting nutrient in crop production and more N is applied as fertilizer in western Canada than any other nutrient. Nitrogen fertilizer also accounts for the largest portion of total energy required for production of non-N fixing crops on the Canadian prairies (Zentner et al.2004) and the manufacture of nitrogen fertilizers is an important source of greenhouse gas emissions, specifically nitrous oxide and carbon dioxide. Excessive use of N fertilizers can also have important negative environmental consequences such as surface and ground water contamination with nitrates and emissions of nitrous oxide form the soil (Malhi and Lemke 2007). Furthermore, producers are looking for ways to improve their ability to manage N fertilizers more effectively because of the recent large increases in N fertilizer prices.

Nitrogen 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 2007b).

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 2007a). 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. With the recent introduction of commercial optical sensors as a N management tool, it is now possible to estimate crop yield potential early in the growing season in cereals (5-6 leaf stage), which is early enough to adjust the rates of N accordingly (Raun et al. 2002).

A series of studies with spring wheat and canola were initiated in 2004 to develop the appropriate mathematical relationships relating values obtained from the GreenSeeker^{tm} sensors to actual grain yields. The first aspect of the study looked at ability of the sensor measurements and the mathematical relationships to to predict the potential grain yield of wheat and canola early in the growing season. The second aspect of the study was to determine the merits of this approach for fine-tuning N management during the growing season. In-field applications of liquid UAN solutions were used to see if the full yield potential of the crop could be realized based on measurements of NDVI with the GreenSeeker^{tm} sensor.

Results and Discussion

The challenge is to find ways to improve our ability to predict the optimum rate of N fertilizer for crops, using spring wheat and canola as our examples.

The basic principle behind the GreenSeeker^{tm} sensor to manage N is that if you can predict the potential yield of a crop, you can determine the amount of nutrients required to support that yield and from there determine the amount of fertilizer required, taking into consideration both residual nutrients in the soil at time of seeding and any N mineralized from organic matter up to the time of sensing. The sensor uses the reflectance of light in the near infra-red (NIR) and red (R) bands to calculated normalized difference vegetation index (NDVI) using the following equation [NIR–R / NIR +R]. This index provides a very good estimate of crop biomass and consequently the GreenSeeker^{tm} can be used to estimate yield potential and crop nutrient requirements.

Given that the GreenSeeker^{tm} can be integrated into a liquid applicator, it is possible to apply N according to the NDVI values in real time as the applicator is travelling over the field. This allows one more very important opportunity, which is the ability to take spatial variability into consideration.

An important finding in the early stages of this research with the GreenSeeker^{tm} was the sensor's ability to predict yield potential early in the growing season (5-6 leaf stage in spring wheat; mid-bolting stage in canola). This means that the amount of biomass accumulated early in the growing season has a large determining effect on the final grain yield. The implications, from a practical perspective are also important. The most obvious one is that crops severely stressed early in the growing season, may not be able to recover and achieve full yield potential.

For detailed information about the GreenSeeker^{tm} sensor, please refer to the following website http://nue.okstate.edu or else simply do a search with Google using the words "nitrogen use efficiency" and the first item listed will get you to the above listed website.

Spring wheat

The first step of the project was to develop the relationship between NDVI and grain yield. In order to minimize the effects of differences in growing conditions from one site-year to the next, we divided NDVI by growing degree days (GDD) using a base temperature of 0^{o}C. [GDD is calculated by taking the average of the daily maximum and minimum temperatures and then adding the values for each day from seeding to sensing]. The relationship between grain yield and NDVI/GDD is presented in Figure 1 and can account for 57% of the observed variation in grain yield.

In order to test to robustness of the relationship, we conducted a field trial with spring wheat in 2007 where we looked at different rates of N and took GreenSeeker^{tm} measurements at different growth stages ranging from the 4 leaf to the flag leaf emergence stage. At each sensing time, we determined the number of GDD and using the relationship presented in Figure 1, we calculated the predicted yield for each sensing date. A summary of the results is presented in Table 1.

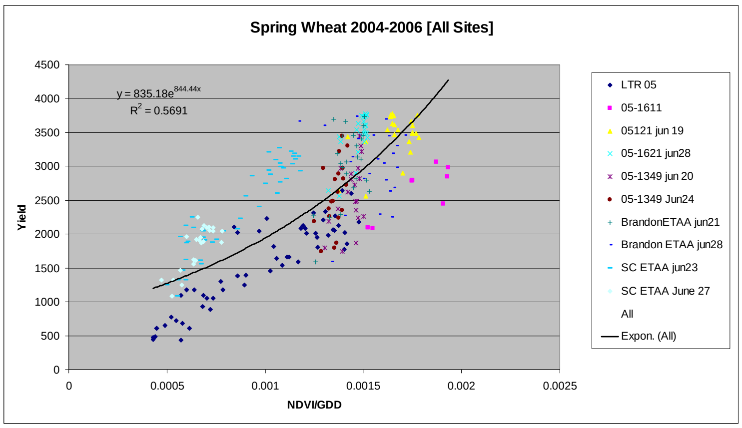

Figure 1. Relationship between grain yield and NDVI in spring wheat based on information collected for the period 2004-2006. Note that NDVI was divided by growing degree days.

Table 1. Comparison of yield (kg/ha) predictions determined at different growth stages and for different rates of nitrogen with actual grain yields in spring wheat in 2007. (Numbers in brackets represent the percent from actual grain yield calculated as predicted yield divided by actual yield and multiplied by 100.)

N rate (kg/ha)	Actual Grain Yields	4-4.5 leaf Stage	5-5.5 Leaf Stage	6-6.5 Leaf Stage	Flag Leaf Emergence
0	2048	1737 (85)	1873 (91)	2629 (128)	2293 (112)
25	2179	1974 (91)	2290 (105)	2958 (136)	2515 (115)
50	2435	1887 (77)	2303 (95)	3144 (129)	2606 (107)
75	2676	1932 (72)	2335 (57)	3188 (119)	2664 (99
100	2830	1972 (70)	2386 (84)	3155 (111)	2657 (94)
125	2608	1843 (71)	2257 (87)	3184 (122)	2649 (102)

The first observation is that for the 4 leaf stage, the predicted yields ranged from 70 – 91% of the actual yields. At the 5 leaf stage, the predicted yield ranged from 84-105% of the actual yields. At the 6 leaf stage, the predicted yields ranged from 111-136% of actual yields and at the flag emergence, 94-115% of actual grain yields. The higher yield prediction at the 6 leaf stage is due to the use of a different sensor which tended to give higher NDVI readings. The sensor will be recalibrated and the results adjusted accordingly. If we look at the yields predicted at the 5 leaf stage and at flag leaf emergence, the overall yield prediction was within 8 and 5% respectively of the actual grain yields. This implies that this sensor represents a useful tool in predicting final grain yield in spring wheat. Even if the results are only within 15 or 20% of actual grain yields, we would at least know if we could expect above average or below average grain yields.

The second step of the study was to use this approach to fine-tune nitrogen rates. A plot study was conducted in 2007 to verify the merits of using this sensor to make adjustments to N rates in order to try and realize the full yield potential of spring wheat, while increasing the efficiency, and by being very efficient with nitrogen fertilizers. The N management treatments investigated are listed in Table 2.

Table 2. Evaluation of the GreenSeeker sensor for adjusting nitrogen rates in spring wheat in 2007 at Indian Head using small plots.

Treatments	**N rate (kg/ha)**	**NDVI on June 20**[z]	**Grain Yield (kg/ha)**	**Grain Yield (bus/acre)**
Check (no N)	0	0.6059a[x]	1488a	22.3a
N Rich Plot	130	0.7886b	2605b	39.1b
Farmer Practice (FP)	90	0.7909b	2425b	36.4b
66% of FP	59	0.7357b	2118b	31.8b
50% FP at seeding and 50% Post E[y]	90	0.7603b	2406b	36.1b
66% FP at seeding and 34% Post E	90	0.7626b	2357b	35.4b
50% FP at seeding and GreenSeeker[tm] Post E.	52	0.7664b	2523b	37.9b
66% FP at seeding and GreenSeeker[tm] Post-E.	61	0.7555b	2586b	38.8b

[z] Spring wheat was at the 6-6.3 leaf stage on June 20th.
[y] Post E refers to a post emergent N application as a surface dribble on 12" centers using liquid UAN (28-00-00).
[x] Means followed by the same letter are not significantly different at the 5% level using Fisher's Protected LSD.

Use of this approach requires that an N rich strip be established at or before the time of seeding where 130-150% of the recommended N rate is applied. In this study the recommended N rate, based on fall soil residual N levels was 90 kg N/ha and we established the N Rich rate as 130 kg N/ha. We also included a treatment where only 66% of the recommended N rate was used. This is to determine if there was a response to post-emergent N applications. We also included treatments where either 50% of 66% of the target N rates was applied at seeding with the balance to 100% applied in-crop as a post-emergent N application. Finally, we applied either 50% or 66% of the target N rate at seeding and then, using the GreenSeeker[tm] sensor, determined if additional N was required by comparing the NDVI values within of the plots in this treatment to those of the N Rich treatment within each respective replicate. From there, depending on the difference in yield potential between the N Rich and the GreenSeeker[tm] treatment, post-emergent N was applied. If the yield potential, based on GreenSeeker[tm] measurements and yield prediction equations, was either equal or greater than the N Rich strip, no additional N was applied. If the difference was less than that observed for N Rich strip, N was applied to according to the yield difference assuming a nitrogen use efficiency of 0.5 and a desired grain N level of 2.25%.

The summary of the results is presented in Table 2. The first observation is that there was a yield response to N. The second observation is that the N Rich plots did not yield more than the other treatments. The third observation is the treatment where only 66% of the recommended rate tended to have lower yields but they were not significantly different from the other N treatments. The fourth observation was that the treatments where the GreenSeeker[tm] was used ended up using an N level that was very similar to the treatment where only 66% of the N was applied at seeding and the final N used was very similar to the optimum N rate observed in the N rate study adjacent to this site with the yields reported in Table 1.

Canola

Similar studies were conducted with canola. The yield prediction equation is presented in Figure 2. The equation can explain ~55% of the variation in final grain yield with GreenSeeker[tm] measurements done around the mid-bolting stage to appearance of first flowers.

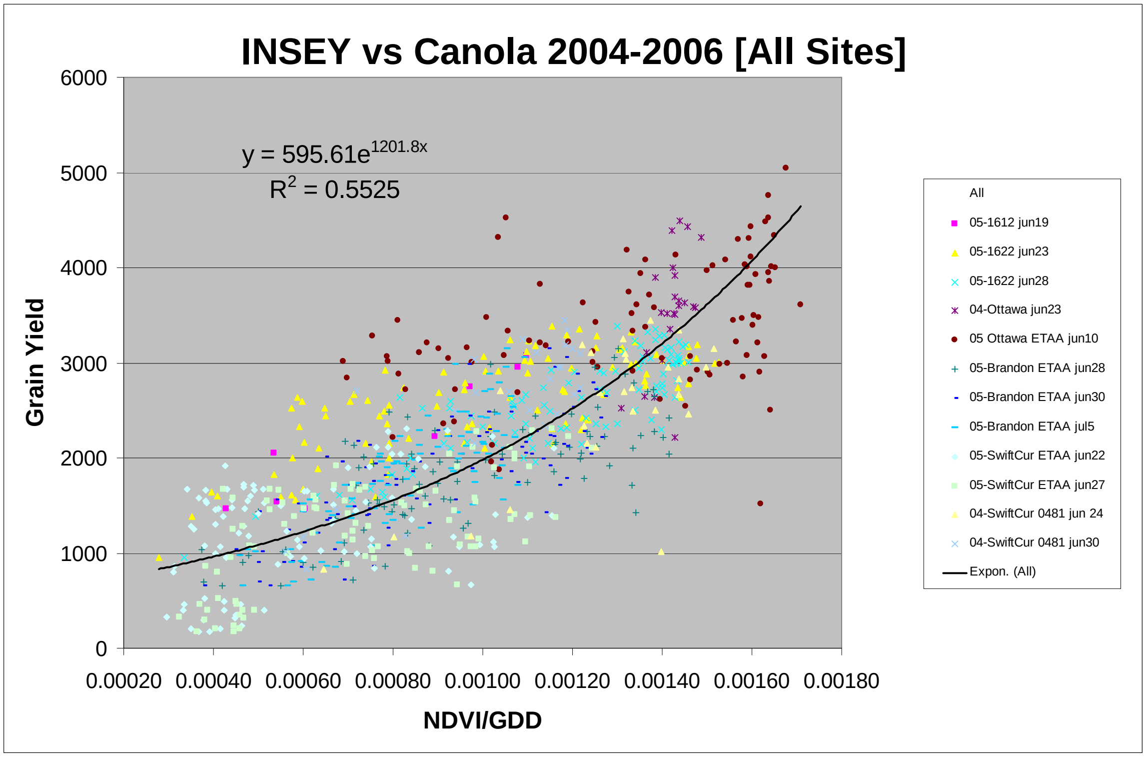

Figure 2. Relationship between grain yield and NDVI in canola based on information collected for the period 2004-2006. Note that NDVI was divided by growing degree days.

Using data collected from an N fertilizer by seeding rate study in 2005, we compared the yield predictions at different growth stages with the actual grain yields using the above equation. A summary of the results is presented in Table 3. The predicted yields at the rosette stage were between 21-33% of the actual yields, 18-26% at the start of bolting, 4-15% at the signs of first flowers and 27-48% at full bloom. The most accurate predictions occurred just when flowers began to appear while the worst predictions occurred at full bloom. Previous studies have shown that during full bloom, the reflectance pattern of the canola canopy is altered making NDVI measurements inaccurate. As with spring wheat, these relationships have the ability to provide relatively accurate predictions of grain yield during the growing season providing for an important planning tool.

Table 3. Comparison of yield (kg/ha) predictions determined at different growth stages and for different rates of nitrogen in canola in 2005 with actual grain yields. (Numbers in brackets represent the percent from actual grain yield calculated as predicted yield divided by actual yield and multiplied by 100.)

N rate (kg/ha)	**Actual Grain Yields**	**Rosette Stage**	**Bolting to Bud Stage**	**~ %5 Flowers**	**Full Bloom**
0	1839	1300 (71)	1377 (75)	1564(85)	1336 (73)
25	2385	1772 (74)	1838 (77)	2131(89)	1376 (58)
50	2529	1990 (79)	2062 (82)	2434(96)	1413 (56)
100	2839	1984 (70)	2145 (76)	2461(87)	1501 (53)
150	2937	1982 (67)	2165 (74)	2500(85)	1537 (52)
200	2951	2022 (69)	2229 (76)	2560(87)	1539(52)

Another aspect of this study was using this approach for fine-tuning nitrogen rates as described in the section for spring wheat. The 2007 plot study at Indian Head consisted of seven treatments listed in Table 4. The first observation is that there was a response to N. The second observation is that the N-Rich treatment yielded more that the treatment with the recommended N rate (FP). The third observation is that even though the FP treatment used as much N as the treatment where 66% of the N was applied at seeding with the remaining 34% applied at the start of flowering, the latter produced higher yields. The fourth observation is that the treatments where the GS was used, utilized less nitrogen and the yields were not different from the N-Rich treatment although they tended to be somewhat lower. The fifth observation was that the yields of the treatment where 66% of the N was applied at seeding with the balance in-crop at time of first flower appearance, yielded the same as the N-Rich treatment.

Table 4. Evaluation of the GreenSeeker^{tm} sensor for adjusting nitrogen rates in canola in 2007 at Indian Head using small plots.

Treatments	N rate (kg/ha)	NDVI on June 27^{z}	Grain Yield (kg/ha)	Grain Yield (bus/acre)
Check (no N)	0	0.4444	1480 a^{x}	27a
N Rich Plot	150	0.7338	2517c	45c
Farmer Practise (FP)	100	0.7375	2051b	37b
66% of FP	66	0.7033	1711ab	31ab
66% FP at seeding and 34% Post E^{y}	100	0.7127	2398c	43c
66% FP at seeding and GreenSeeker Post E using algorithm 1	68	0.7354	2177bc	39bc
66% FP at seeding and GreenSeeker Post-E using algorithm 2	67	0.7316	2159bc	39bc

^{z} Canola was at the late bolting stage on June 27th.
^{y} Post E refers to a post emergent N application as a surface dribble on 12” centers using liquid UAN (28-00-00).
^{x} Means followed by the same letter are not significantly different at the 5% level using Fisher’s Protected LSD.

Conclusion

The results of these studies with spring wheat and canola support the premise that the optical sensor GreenSeeker^{tm} has the ability to assist producers and agronomists in making more informed decisions about the optimum rate of N to apply. Over time, other applications will be uncovered for this sensor.

Note: This same paper was also published in the proceedings of the Reduced Tillage Linkages Direct Seeding Advantage 2007 workshop held in Nisku, AB on November 21 and 22nd. For more details refer to the following website: http://www.reducedtillage.ca/directseedingadvantage.aspx. The paper was entitled “SEEING GREEN: A new tool for predicting nitrogen rates in spring wheat and canola.”

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