ESTIMATING CANOLA (*BRASSICA NAPUS* L.) YIELD POTENTIAL AND NITROGEN REQUIREMENTS USING OPTICAL SENSORS

C.B. Holzapfel, G.P. Lafond, S.A. Brandt, R.B. Irvine, D. James, M.J. Morrison,
W.E. May and P.R. Bullock
Indian Head Agricultural Research Foundation, Indian Head, SK
holzapfelcb@agr.gc.ca (306) 695-4200

ABSTRACT

Optical sensors have potential to improve our ability to match N fertilizer rates with crop requirements. Experiments with canola (*Brassica napus* L.) were completed to determine if normalized difference vegetation index (NDVI) could be used to estimate canola yield potential (YP) and N requirements, as well as to assess if sensor-based N management for canola is feasible relative to conventional practices. Canola plots were repeatedly measured with handheld GreenSeeker™ sensors and the NDVI values plotted against grain yield. While the exponential relationship between NDVI and yield was significant (R^2=0.45), it was improved by dividing the NDVI by various normalizing factors such as various heat units and days from planting (R^2=0.474 – 0.562). We also completed several large, on-farm trials where we compared sensor-based N management with placing the entire, fixed rate of N in the soil at seeding. NDVI was able to detect relative differences in N status and N fertilizer use was reduced using the sensor-based N application algorithm in 66% of the trials. We reduced N-use without affecting yield, but the reductions were not usually sufficient to cover the cost of the post-emergent (PE) N application. In the cases where sensor-based N management was more profitable, grain yields were always increased relative to the conventional treatment. While sensor-based management appears to be agronomically feasible in western Canada, it will require further refinement to consistently provide increased economic returns for producers.

INTRODUCTION

The major factors to consider for N fertilizer management are the form, placement, timing, and finally, the rate of N fertilizer application. While the forms of N generally perform similarly when managed appropriately, the optimum rate of N tends to vary and is arguably the most difficult factor to determine. Crop N requirements depend on their YP, the soil's capacity to supply N, and potential N losses, all of which tend to be variable and difficult to estimate at or before the time of seeding.

Active optical sensors, such as the GreenSeeker™ (www.ntechindustries.com), have potential to improve our ability to match N rates with crop requirements by simultaneously estimating the crop's YP and potential responsiveness to PE N (Raun et al. 2002). These sensors measure reflectance of emitted visible and near-infrared (NIR) light, which in turn are used to calculate NDVI. The NDVI is correlated with the crop's YP (Raun et al. 2001). When a crop's NDVI is compared with that of an N-rich reference crop in the same field, optical sensors can be used to estimate the PE N requirements of a crop (Raun et al. 2002).

To the best of our knowledge, senor-based N management has not previously been evaluated for canola. However, it has been previously established that spring-grown canola responds to PE N under the right circumstances (Holzapfel et al. 2007; Lafond et al. 2008). Holzapfel et al. (2007) showed that while deferring the entire quantity of N fertilizer to 30 days post-seeding was viable in normal years, doing so reduced grain yields in drought years. Applying 50 – 66% of a crop's N requirements at seeding reduces the risks associated with PE N, allowing producers to reassess environmental conditions and decide whether to apply PE N (Lafond et al. 2008). Optical sensors that measure the N status of crops can potentially allow producers to make decisions about the quantity of fertilizer to apply in a more informed manner than has been previously possible (Raun et al. 2002).

Our objective was to determine if we could estimate canola YP using optical sensors and to investigate the feasibility of sensor-based N management relative to the practice of placing the entire, fixed quantity of N in the soil at or before seeding.

MATERIALS AND METHODS

The results from two separate studies completed in 2005 and 2006 are discussed. Study #1 evaluated the ability of NDVI to estimate canola yield throughout the growing season and the goal of Study #2 was to evaluate the feasibility of sensor-based N management relative to conventional practices.

Study #1 was completed at Agriculture and Agri-Food Canada (AAFC) locations at Brandon, Indian Head, Ottawa, Scott, and Swift Current. Small plots of canola were planted between May 6 and May 19 and the treatments were a factorial combination of six N fertilizer rates (0, 25, 50, 100, 150, 200 kg N ha^{-1}) and four seeding rates (25, 50, 100, and 200 viable seeds m^{-2}) to ensure plots with a wide-range of early season biomass cover and grain yields. The plots were scanned repeatedly over the growing season using handheld GreenSeeker^{TM} sensors and the NDVI data for each sensing date was plotted against grain yield. The exponential relationship between the two parameters was determined using SigmaPlot 10 (Systat Software Inc.).

All of the NDVI data collected when the crop was between growth stages 2.5 and 4.1 (Harper and Berkenkamp 1975) was combined for further analysis. As part of the combined analysis, NDVI was divided by each of several normalizing values to reduce the impact of differences in crop growth between site-years (Raun et al. 2002). The divisors evaluated were days from planting to sensing (DFP), cumulative growing degree days with base-temperatures of 0˚C (GDD$_0$) and 5˚C (GDD$_5$), corn heat units (CHU), and physiological days (P-days). Refer to Holzapfel (2007) for more detailed descriptions of the various heat units.

Study #2 evaluated the feasibility of sensor-based N management and consisted of 9 on-farm field trials completed in cooperation with various producers. Aside from the PE N application, all field operations were completed by the producer. The treatments were N management strategies where the forms, rates, and application timings of N were varied. The treatments of interest were: 1) Farmer Practice (FP) where the entire quantity of N fertilizer was soil-placed at the time of seeding at the rate chosen by the producer for the non-study area of the field and 2) Variable Rate Application (VRA) where 66% of the rate applied in the FP treatment was applied at the time of seeding and a variable rate of PE N was applied with rates determined using the sensors.

Post-emergent N was liquid urea ammonium-nitrate (UAN) applied in a surface dribble-band using a high-clearance sprayer equipped with a GreenSeeker^{TM} RT200 variable rate application system and a Raven SCS 4400 rate controller (Raven Industries Inc.). The RT200 was also used to map NDVI and high N reference treatments were included in each study and used to estimate the upper YP for each field, which was then used to adjust the variable rate application. Yield data was collected using yield monitors and GPS. Grain yield and NDVI data were analyzed using the Mixed procedure of SAS 9 (Littel et al. 1996). Marginal economic returns were calculated from the total N rates and observed yields assuming \$375 Mt canola^{-1}, \$1.00 kg N^{-1}, and a fixed technology / application cost of \$15.00 ha^{-1} for the VRA treatment. Refer to Holzapfel (2007) for a more detailed account of the methods used in these experiments as well as the results presented in the following section.

RESULTS AND DISCUSSION

Study #1

The relationship between NDVI and canola yield was generally not significant until the crop reached the five-leaf stage (GS 2.5), improved through the vegetative growth stages, peaked at the late-bolting to early flowering stage (3.2-4.1), and again became weak as the canola went into full bloom (Figure 1). The poor correlation at the start of the growing season was possibly due in part to high variability in plant populations resulting from the different seeding rates, with low plant populations having a larger impact on early season NDVI than on grain yield. The period where the NDVI – yield relationship again became weak (40 – 50 DFP), corresponds to the period where the canola was in full bloom, which is in agreement with Basnyat et al. (2004).

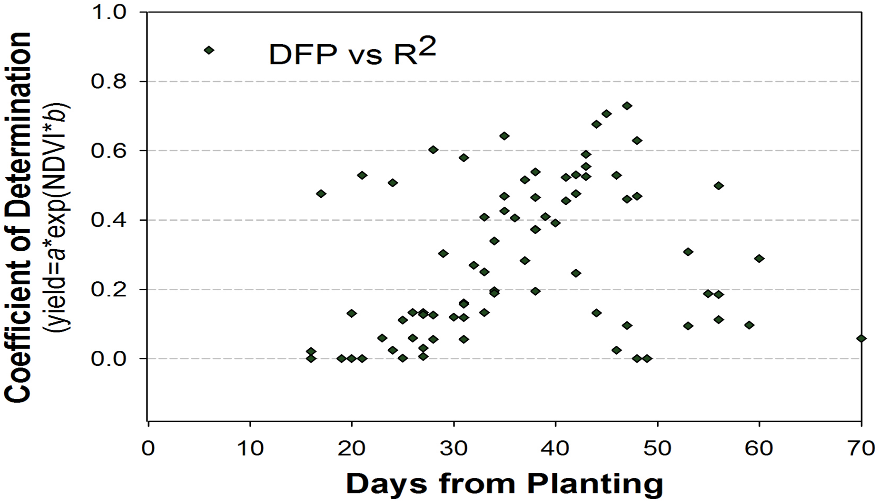

Figure 1. Coefficients of determination (R^2) for NDVI-yield relationships.

For the final analysis, data from Scott in both years and Swift Current in 2006 were removed because extreme post-sensing environmental conditions reduced grain yields. Raun et al. (2001) demonstrated how data from site-years where environmental conditions after sensing reduced grain yields can weaken the NDVI-yield relationship, explaining that such data should not be used to develop empirical relationships for estimating YP. Such negative environmental conditions could include hail, heat/drought during flowering and pod-filling, or late-season insect infestations.

There was a significant correlation (R^2=0.444) between NDVI and yield in the combined analysis prior to dividing NDVI by the normalizing values (Table 1). While dividing NDVI by DFP improved the relationship relative to NDVI by itself, DFP was not as effective for normalizing NDVI as the heat units formulae were. The best NDVI-yield relationship resulted when NDVI was divided by CHU, however both GDD_0 and GDD_5 performed equally well for practical purposes. While P-days was reasonably effective for normalizing NDVI, the complex calculations required for these units make P-days unlikely alternatives to CHU or GDD.

Table 1. Parameter estimates and coefficients of determination for the NDVI (x) - grain yield (y) relationship (n=1799). NDVI data were collected between crop stages 2.5 – 4.2. Values enclosed in brackets are standard errors of the parameter estimates and all R^2 values were highly significant (p<0.001).

	Parameter estimates $y = a*\exp(b*x)$		
x-axis	*a*	*b*	Adj. R^2
NDVI^z	806.6 (23.0)	1.48 (0.04)	0.444
NDVI/DFP^y	883.3 (21.1)	51.5 (1.3)	0.474
NDVI/GDD_0^x	787.4 (18.7)	878.6 (19.7)	0.545
NDVI/GDD_5^w	782.6 (18.4)	585.3 (12.9)	0.552
NDVI/CHU^v	780.1 (18.0)	949.6 (20.5)	0.562
NDVI/P-Days^u	832.8 (19.2)	370.1 (8.6)	0.528

^{z}NDVI – normalized difference vegetation index; ^{y}Days from Planting; ^{x}Growing degree days (base 0ºC); ^{w}Growing degree days (base 5ºC); ^{v}Corn heat units; ^{u}Physiological days

Study #2

At the time of the PE N applications, the mean NDVI of the VRA treatment was significantly lower than that of the FP treatment at 44% of the site-years and tended to be lower at 78% of the site-years (Table 2). Except for VJ05 and VS05, NDVI always tended to increase with the N rate applied at seeding.

Total N fertilizer use was reduced in the VRA treatment at 67% of the site-years (Table 2). In the remaining site-years, we applied 2 – 10 kg N ha^{-1} more N in the VRA treatment than in the FP treatments. Averaged across site-years, the VRA treatment received 10 kg ha^{-1} less fertilizer N than the FP treatment.

For grain yield, BA05 and VS05 were the only site-years where a significant difference was observed and in both cases the VRA treatment yielded higher (Table 2). There were instances where the yields of the VRA treatment were low enough relative to the FP treatment to be of concern to producers (NH05, VJ05, and BA06), but the differences were not significant.

While we usually reduced N fertilizer use in the VRA treatment without reducing yields, the VRA treatment was rarely more profitable than the FP treatment, and in the majority of cases was slightly less profitable (Table 2). Note that in the cases where the VRA treatment was more profitable, the observed yield of the VRA treatment was also higher than that of the FP treatment. Similarly, the cases where the VRA treatment was notably less profitable than the FP treatment, the VRA treatment tended to yield lower. For irrigated spring wheat in Mexico, Ortiz-

Monasterio and Raun (2007) increased economic margins by \$62 ha^{-1} using sensor-based N management. For winter wheat in Oklahoma, Raun et al. (2002) increased economic margins by \$13 ha^{-1} with sensor-based N management relative to applying a fixed rate of N before seeding. A difference between these studies and ours is that we included an additional PE application cost when calculating marginal returns for the VRA treatment. Omitting this cost can be justified for winter crops where producers commonly apply PE N or where seeding equipment is not configured for single pass seeding / fertilizer applications, but not for spring crops in western Canada where all N is normally applied at the time of seeding.

Table 2. Marginal NDVI, grain yields, N rates, and profits for each site-year.

Site-Year	NDVI^{z}	Yield^{z} kg canola ha^{-1}	N Rate^{z} kg N ha^{-1}	Profit^{z} \$ ha^{-1}
BA05	(-0.012)	+223**	-6	75
NH05	(-0.064)**	(-123)	-10	(-51)
VJ05	0.012**	(-229)	-33	(-68)
VS05	0.001	+146**	-28	68
BA06	(-0.028)**	(-166)	-8	(-69)
KS06	(-0.014)	(-12)	+10	(-30)
RE06	(-0.019)**	(-2)	+2	(-18)
RP06	(-0.013)**	(-26)	-22	(-3)
VJ06	(-0.003)	(+82)	+7	9

*significant at 0.01p≤0.05; **significant at p≤0.01; ^{z}Reported values are the observed mean for the FP treatment subtracted from that of the VRA treatment

CONCLUSIONS

While both canola YP and relative N status are estimable using NDVI, it is uncertain whether using these estimates to fine-tune N application rates is beneficial over conventional practices. Except in systems where not considering applying PE N an additional cost is justifiable, this technology is more likely to increase N use-efficiency (NUE) than economic returns. For an economic benefit in cases where N use is reduced without affecting yields, savings in N inputs must be sufficient to cover the fixed costs of applying PE N. On the other hand, the same scenario should theoretically increase efficiency of the applied N. Increases in both NUE and economic returns are much more probable where yields are increased with sensor-based N management.

There are compelling reasons that producers may hesitate to adopt this technology and increase their reliance on PE N, such as the increased costs associated with applying PE N over many acres. Applying PE in a timely manner can potentially interfere with herbicide and fungicide applications, and wet conditions can prevent applying PE N early enough to attain a yield response. Our results show that canola yield potential can be most accurately estimated between mid-bolting and the start of flowering and previous research has shown that PE N must be applied prior to flowering to prevent yield losses (Lafond et al. 2008), leaving a relatively narrow window over which PE N requirements can be estimated and a yield response to N can be reasonably expected.

Rather than reducing the quantity of N applied at seeding, it may be more profitable and less risky to apply enough N at seeding to produce average yields and use the sensors to identify situations where PE N is likely to increase yields to above average levels. Regardless of how much N is applied at seeding, if no differences in NDVI are observed between the crop being assessed and the high-N reference crop, no further action is required. When the NDVI of the high N reference is higher than that of the adjacent crop, producers should quantify the potential increases in grain yield and only proceed to apply PE N if the magnitude of the yield increase is sufficiently large to cover the cost of the PE application under realistic economic assumptions.

ACKNOWLEDGEMENTS

Financial aid was provided by AAFC's Environmental Technology Assessment for Agriculture (ETAA) program and the Saskatchewan Canola Development Commission. In-kind contributors include Pattison Liquid Systems Inc., Markusson New Holland, New Holland North America, Simplot AgriScience, Bayer CropScience, Accutrak Systems Ltd., the Fluid Fertilizer Foundation, Nite-Hawk Trucking, OmniSTAR Inc., Raven Industries, Patterson Grain, Oklahoma State University, and N Tech Industries Inc. Special thanks to Chris Omoth at the Indian Head Research Farm, Don Flaten and Gary Martens at the University of Manitoba, the cooperating producers and all of the AAFC staff who assisted with the plot experiments.

REFERENCES

Harper, F.R., and B. Berkenkamp. 1975. Revised growth-stage key for *Brassica Campestris* and *Brassica Napus*. Can. J. Plant Sci. 55:657-658.

Holzapfel, C.B. 2007. Estimating nitrogen fertilizer requirements of canola (*Brassica napus* L.) using sensor-based estimates of yield potential and crop response to nitrogen. M.Sc. Thesis. University of Manitoba, Department of Soil Science. [Online] Available: https://mspace.lib.umanitoba.ca/browse-author [2008 Jan. 03].

Holzapfel, C.B., Lafond, G.P., Brandt, S.A., May, W.E., Johnston, A.M. 2007a. In-soil banded versus post-seeding liquid nitrogen applications on no-till spring wheat and canola. Can. J. Plant Sci. 87: 223–232.

Lafond, G., S.A. Brandt, B. Irvine, W.E. May, and C.B. Holzapfel. 2008. Reducing the risks of in-crop nitrogen fertilizer applications in spring wheat and canola. Can. J. Plant Sci. (accepted).

Littel, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 1996. SAS System for Mixed Models. SAS Institute, Cary NC. 656 pp.

Ortiz-Monasterio, J.I., and W.R. Raun. 2007. Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico, using sensor based nitrogen management. J. Agric. Sci. 145:1-8.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, E.V. Lukina, W.E. Thomason, and J.S. Schepers. 2001. In-season prediction of potential grain yield in winter wheat using canopy reflectance. Agron. J. 93:131-138.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Improving N use-efficiency in cereal grain production with optical sensing and variable rate application. Agron. J. 94:815-820.