High-yield no-till canola production on the Canadian prairies

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Harker, K. N., O'Donovan, J. T., Turkington, T. K., Blackshaw, R. E., Lupwayi, N. Z., Smith, E. G., Klein-Gebbinck, H., Dosdall, L. M., Hall, L. M., Willenborg, C. J., Kutcher, H. R., Malhi, S. S., Vera, C. L., Gan, Y., Lafond, G. P., May, W. E., Grant, C. A. and McLaren, D. L. 2012. **High-yield no-till canola production on the Canadian prairies**. Can. J. Plant Sci. **92**: 221–233. Relatively high prices and increasing demand for canola (*Brassica napus* L.) have prompted growers to produce more canola on more cropland. Here we determine if canola seed yield and oil concentration can be increased over current levels with high levels of crop inputs. From 2008 to 2010, direct-seeded experiments involving two seeding rates (75 vs. 150 seeds m^{-2}), two nitrogen rates (100 vs. 150% of soil test recommendation), and the presence or absence of polymer-coated nitrogen or fungicides, were conducted at eight western Canada locations in canola-wheat-canola or continuous canola rotations. Herbicides, insecticides and fertilizers other than nitrogen were applied as required for optimal canola production. Increasing recommended nitrogen rates by 50% increased canola yields by up to 0.25 Mg ha^{-1}. High (150 seeds m^{-2}) versus lower (75 seeds m^{-2}) seeding rates increased canola yields by 0.07 to 0.16 Mg ha^{-1}. Fungicide treatment or polymer-coated nitrogen blended with uncoated urea increased canola yields by 0.10 Mg ha^{-1} in 2010, but not in 2008. The highest canola input combination treatment following wheat (3.50 Mg ha^{-1}) yielded substantially more than the same high input treatment following canola (3.22 Mg ha^{-1}). Average site yields were influenced by site conditions such as soil organic matter, days to maturity, and temperature, but these site and environmental predictors did not alter treatment rankings. Using higher than the soil test recommended rate of nitrogen or planting 150 versus 75 seeds m^{-2} increased canola yields consistently across western Canada. Canola oil concentration varied among canola cultivars, but was consistently low when N rates were high (150% of recommended). Higher than normal seeding rates led to high canola seed oil concentration in some cases, but the effect was inconsistent.

Key words: Combined agronomic practices, crop rotation, direct-seeding, oil concentration, oil-seed rape polymer-coated nitrogen

Harker, K. N., O'Donovan, J. T., Turkington, T. K., Blackshaw, R. E., Lupwayi, N. Z., Smith, E. G., Klein-Gebbinck, H., Dosdall, L. M., Hall, L. M., Willenborg, C. J., Kutcher, H. R., Malhi, S. S., Vera, C. L., Gan, Y., Lafond, G. P., May, W. E., Grant, C. A. et McLaren, D. L. 2012. **La production de canola à haut rendement sans travail du sol dans les Prairies canadiennes**. Can. J. Plant Sci. **92**: 221–233. Le prix relativement élevé du canola (*Brassica napus* L.) et la demande grandissante pour cette denrée incitent les agriculteurs à cultiver davantage de canola sur des superficies de plus en plus grandes. Les auteurs voulaient établir s'il est possible d'accroître le rendement grainier et la teneur en huile du canola comparativement aux valeurs existantes en augmentant les intrants employés. De 2008 à 2010, ils ont effectué des expériences incluant deux densités de semis directs (75 c. 150 graines par m^2), deux taux d'application d'engrais azotés (100 c. 150 % du taux recommandé selon l'analyse du sol) et l'usage ou pas d'azote enrobé de polymère ou de fongicides à huit endroits de l'Ouest canadien où l'on cultivait le canola uniquement ou un assolement canola-blé-canola. Des herbicides, des insecticides et d'autres engrais que l'azote ont été appliqués au besoin, en vue d'obtenir une production optimale de canola. Relever le taux d'application des engrais azotés recommandé de 50 % augmente le rendement du canola de jusqu'à 0,25 Mg par hectare. Une densité de semis élevée (150 graines par m^2 plutôt que 75 graines par m^2) accroît le rendement du canola de 0,07 à 0,16 Mg par hectare. Les fongicides ou un mélange d'azote enrobé de polymère et d'urée non enrobée ont accru le rendement du canola de 0,10 Mg par hectare en 2010, mais pas en 2008. La combinaison d'intrants la plus importante après la culture de blé (3,50 Mg par hectare) a donné un rendement sensiblement plus élevé que la même combinaison lorsqu'elle était appliquée après la culture de canola (3,22 Mg par hectare). Le rendement moyen par site subit l'influence des conditions qui affectent les lieux, notamment la concentration de matière organique dans le sol, le nombre de jours avant maturité et la température, cependant les variables explicatives associées au site et à l'environnement ne modifient pas le classement des traitements. L'application d'une quantité d'engrais azoté supérieure à celle recommandée par l'analyse du sol ou la plantation de 150 semences par m^2 au lieu de 75 augmente constamment le rendement du canola dans l'Ouest canadien. La teneur en huile varie avec le cultivar de canola, mais demeure faible quand le taux d'application d'engrais N est élevé (150 % du taux recommandé). Une densité de semis supérieure à la normale entraîne une forte teneur en huile dans certains cas, mais les résultats ne sont pas uniformes.

Mots clés: Combinaison de pratiques agronomiques, assolement, semis directs, teneur en huile, colza, azote enrobé de polymère

Since the mid-1980s, Canadian canola producers have consistently grown more canola on more land than ever before. From 1986 to 1988, an average of 3.9 million Mg was produced annually on an average of 3.0 million hectares [Canola Council of Canada (CCC) 2011a]. From 2008 to 2010, an average of 12.3 million Mg was produced annually on an average of 6.5 million hectares. Production on a land unit basis increased 46% (1.3 to 1.9 Mg ha^{-1}) over the same time span (CCC 2011a). Nevertheless, there remains an increasing demand for edible oil and biodiesel feedstock from canola.

Inititally, canola cultivars were open pollinated and lacked tolerance to non-selective herbicides. Weed control was relatively simple for monocot species, but was more challenging for some dicot species, especially *Brassicaceae* weeds related to canola (Blackshaw 1989). The advent and adoption of herbicide-resistant cultivars made weed management more effective (Harker et al. 2000), economical, and environmentally benign (Beckie et al. 2006; O'Donovan et al. 2006). Currently, herbicide-resistant, hybrid cultivars dominate the canola production area. Hybrid cultivars are more competitive with weeds (Zand and Beckie 2002; Harker et al. 2003, 2011), greater yielding (Starmer et al. 1998; Harker et al. 2003; Brandt et al. 2007; Malhi et al. 2007; Cutforth et al. 2009), and generally lead to greater net returns than open pollinated cultivars (Upadhyay et al. 2005; Brandt et al. 2007; Hanson et al. 2008).

It is anticipated that food and biodiesel markets will require 15 million Mg of Canadian-grown canola by 2015 (CCC 2011b). In order to meet this production target, canola will need to be grown at greater frequencies on non-traditional canola land, and canola yields on the same land area will need to increase. While the latter option has less agronomic risks than growing canola in shorter crop rotations or on non-traditional canola land, it is not known if the required levels of inputs for the latter option will be effective, economically feasible or environmentally desirable.

Our objective was to compare higher than average input level combinations with lower input level combinations to determine if canola seed yield and oil concentrations could be increased relative to current production practices. We also wanted to determine which input combinations increased canola seed and oil yields the most.

MATERIALS AND METHODS

Direct-seeded (no-till) experiments were conducted in western Canada from 2008 to 2010 at Beaverlodge, AB (lat. 119.4°W, long. 55.2°N); Brandon, MB (lat. 99.9°W, long. 50.0°N); Edmonton, AB (lat. 113.6°W, long. 53.7°N); Indian Head, SK (lat. 103.7°W, long. 50.5°N); Lacombe, AB (lat. 113.7°W, long. 52.5°N); Lethbridge, AB (lat. 112.8°W, long. 49.7°N); Melfort, SK (lat. 104.6°W, long. 52.8°N); and Swift Current, SK (lat. 107.7°W, long. 50.3°N). All plots were established on no-till fields previously sown to wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). Prior to seeding, a single pre-seeding glyphosate application (450 to 900 g a.e. ha^{-1}) was applied to the entire plot area to control emerged weeds.

A combination of 12 factorial treatments and three additional treatments were arranged in a randomized complete block design with four replications (Table 1). In the factorial treatment set ($2 \times 2 \times 3$), two canola seeding rates (75 or 150 seeds m^{-2}) were combined with two nitrogen rates (100 or 150% of soil test recommendation) and three nitrogen form-fungicide (prothioconazole) combinations (uncoated urea-no fungicide, uncoated urea-fungicide, and 50% polymer-coated urea-fungicide). The factorial treatment set was a canola-wheat-canola rotation (2008–2009–2010) and the three additional treatments were continuous canola (Table 1). Herbicides [glyphosate on glyphosate-resistant (RR) cultivars, glufosinate+clethodim on glufosinate-resistant (InVigor) cultivars, and sethoxydim+ethametsulfuron+clopyralid on Westar] were applied at labelled rates to weeds before canola reached the four-leaf stage to ensure that weeds did not reduce canola yield potential. Disease infestation levels were monitored and recorded at all sites. Insecticides (depending on insect pest species) were applied as required to prevent significant insect damage to canola.

In 2008, hybrid spring canola cultivars (except Westar – open pollinated) were seeded from late April to mid May using hoe or knife openers on 20- to 30-cm row spacings at a depth of 1 cm at 75 or 150 seeds m^{-2}. Fertilizer (N, P_2O_5, K_2O, S) was side-banded during planting 2 cm beside and 3–4 cm below the seed row at recommended levels based on soil tests and yield targets [nitrogen was applied as indicated in the list of treatments (Table 1)]. Soil cores for soil test recommendations were taken from 10 bulked samples (0-cm to 30-cm depth) across experimental areas prior to the first year of the experiment, and from single 0-cm to 30-cm-depth

Table 1. Experimental treatment listing, coding description and crop rotation

Treatment	Treatment coding[z]	2008 (canola)	2009 (wheat and canola)	2010 (canola)
1	75–1 ×–Un–No	InVigor 5440	Wheat[y]	72-55RR
2	75–1 ×–Un–Fn	InVigor 5440	Wheat	72-55RR
3	75–1 ×–Co–Fn	InVigor 5440	Wheat	72-55RR
4	75–1.5 ×–Un–No	InVigor 5440	Wheat	72-55RR
5	75–1.5 ×–Un–Fn	InVigor 5440	Wheat	72-55RR
6	75–1.5 ×–Co–Fn	InVigor 5440	Wheat	72-55RR
7	150–1 ×–Un–No	InVigor 5440	Wheat	72-55RR
8	150–1 ×–Un–Fn	InVigor 5440	Wheat	72-55RR
9	150–1 ×–Co–Fn	InVigor 5440	Wheat	72-55RR
10	150–1.5 ×–Un–No	InVigor 5440	Wheat	72-55RR
11	150–1.5 ×–Un–Fn	InVigor 5440	Wheat	72-55RR
12	150–1.5 ×–Co–Fn	InVigor 5440	Wheat	72-55RR
13	75–1.5 ×–Co–Fn	71-45RR	InVigor 5440	72-55RR
14	150–1.5 ×–Co–Fn	71-45RR	InVigor 5440	72-55RR
15	150–1.5 ×–Un–Fn	Westar	Westar	72-55RR

[z] Treatment coding (applies only in 2008 and 2010): first value = seeding rate (seeds m^{-2}), second value = nitrogen rate (1 × is soil test recommendation), third value = uncoated nitrogen (Un) or 50% polymer coated nitrogen (Co), fourth value = no fungicide (No) or fungicide (Fn). InVigor 5440 is glufosinate-resistant, hybrid canola. 71-45RR and 72-55RR are glyphosate-resistant hybrid canola. Westar is an old, open-pollinated canola cultivar.

[y] Spring wheat was a locally adapted cultivar at each site.

cores in each plot prior to 2010. Canola yield targets for all years were 2.2 Mg ha^{-1} for Swift Current, 2.8 Mg ha^{-1} for Beaverlodge and Lethbridge, 3.0 Mg ha^{-1} for Brandon, 3.4 Mg ha^{-1} for Indian Head, and 3.9 Mg ha^{-1} for Edmonton, Lacombe and Melfort. Plot size was 4 by 12–15 m at all locations.

In 2009, the factorial treatment set was planted to wheat and the remaining three treatments were planted to canola again (Table 1). However, neither wheat nor canola plots were subjected to different seed rate, nitrogen rate, nitrogen form or fungicide treatments; 2009 was designated as a simple rotation treatment (wheat or canola).

In 2010, all plots were seeded to a single glyphosate-resistant hybrid canola cultivar (72-55RR) and subjected to the same seed rate, nitrogen rate, nitrogen form or fungicide treatments as in 2008 (Table 1).

Crop emergence (80%) dates were determined by visual inspection every 2 to 3 d after seeding. Emergence density was determined by counting plants in two, side-by-side, 1-m rows at two representative places in each plot 2 to 3 wk after crop emergence. The three most-dominant weed species in each plot were recorded and weed cover proportions were visually estimated for each species from two 0.5-m^{-2} quadrats at pre-spray and post-spray (3 to 4 wk after final herbicide application) intervals. Canola was harvested with plot combines and yield was corrected to 8.5% moisture content. Canola seed oil concentration (8.5% moisture basis) was determined using a near infrared reflectance spectrometer (Foss Model 6500, FOSS NIRSystems Inc., Silver Spring, MD). Immediately after harvest, 30 random canola stem-root samples were collected from each plot and assessed for root maggot damage (categorically scored 0 to 5, where 0 = no visible damage and 5 = severe damage).

Site and environmental data were recorded at each site. Weather stations were available at all sites, but were not necessarily immediately adjacent to the experiment. Soil organic matter content, pH, and textures were determined to a depth of 30 cm. The following data were included in the statistical analyses to help explain site and treatment effects: latitude, longitude, percent soil organic matter, soil pH, soil percent sand, soil percent silt, soil percent clay, days to canola emergence (from seeding), crop density, pre- and post-spray weed density, days to canola maturity (from seeding), May to August accumulated precipitation, May to August average temperature, May to August growing degree days (0°C base), June to August minimum temperature, June to August maximum temperature, June to August days > 30°C, and root maggot damage ratings.

Statistical Analyses

Data were analyzed with the PROC GLIMMIX procedure of SAS (SAS Institute, Inc. 2005; Littel et al. 2006). Replicate and site effects and their interactions with fixed effects were considered random, and crop input (nitrogen, seeding rates, nitrogen coating, fungicide) and rotation treatment effects were considered fixed. In many agronomic studies, given the objective of making treatment inferences at many untested locations, it is appropriate to consider location effects and their interactions with fixed effects as random (Yang 2010).

A Gaussian error distribution (with the default identity link function) was used for crop variable analyses. Exploratory analysis indicated the possibility of heterogeneous variances among sites. The corrected Akaike's Information Criterion (AICC) was used to confirm the benefit of modeling variance heterogeneity. For 2008 oil concentration data, however, we found that it was not beneficial to model heterogeneous variances among sites.

Variance components were derived using a restricted maximum likelihood estimation method. Preplanned contrasts were constructed between the highest (treatment 12) or lowest (treatment 1) input combinations and all of the remaining treatments (Table 1). Another contrast comparing all fungicide treatments that were combined with uncoated nitrogen was constructed to determine fungicide effects. Treatment effects were declared significant at $P < 0.05$.

Next, we determined the effect of site and environment indicators on canola seed yield and oil concentration using the partial least squares (PLS – also known as projection to latent structures PLS) method. The purpose of this analysis was to determine which site and environmental indicators had the greatest influence on canola seed yield and oil concentration. Data for the PLS analysis consisted of a matrix with each site as a row, and site means for canola seed yield and oil concentration as well as the site/environment indicators as columns. The PLS analysis was performed using the PROC PLS procedure of SAS (Tobias 1995; SAS Institute, Inc. 2004). Initially, all site and environment indicators measured in the study were included as predictor variables in the PLS model.

Latent variable (LV) values reflect a composite weighting of all measured or recorded site and environmental conditions that potentially influenced canola seed yield or oil concentration. Low LV1 scores (negative) are generally associated with sites that have positive associations with low predictor values (e.g., low soil organic matter, low days to maturity, etc.) or negative associations with high predictor values, but the association weakens for predictors with relatively low variable importance in the projection (VIP) values. Site and environment indicators (predictors) with the greatest influence in explaining canola seed yield and oil concentration variability were then selected based on the VIP being > 0.8 (Wold 1994). The five site and environment indicators with the highest VIP were ranked and presented. X loadings represent the correlation between site and environment predictors and each LV score. When LV covariable by treatment interactions were significant, treatment means were estimated for the sites with the lowest and highest LV scores (i.e., the sites with environments that deviated from the ‘‘average site’’ the most).

RESULTS AND DISCUSSION

Canola Seed Yield

The location by treatment interaction for canola yield, although significant, only accounted for a minor portion ($<1\%$) of the total variance associated with location effects (Table 2). In addition, in the PLS analysis, treatment effects did not differ across the gradient of LV1 scores across locations [LV covariate by treatment interactions were not significant, $P = 0.080$ (2008), $P = 0.228$ (2010)]. The latter finding, in conjunction with the low variance ($<1\%$) associated with the site by treatment interaction, indicates that treatment differences observed across locations were stable even with notable average yield and site-environmental condition differences among locations.

Seeding rate main effects were significant in 2008 and 2010 (Table 2). High (150 seeds m^{-2}) versus low (75 seeds m^{-2}) seeding rates increased canola yields by 0.16 and 0.07 Mg ha^{-1} in 2008 and 2010, respectively (Table 3). Other research confirms canola seed yield increases at relatively high seeding rates (Harker et al. 2003; Brandt et al. 2007; Hanson et al. 2008). However, Brandt et al. (2007) suggested that canola yield responses to seeding rate were dependent upon relatively high nitrogen rates. Our research suggests that seeding rate effects on yield were not dependent on nitrogen rate.

Nitrogen rate main effects also were significant in 2008 and 2010 (Table 2). Higher than recommended nitrogen rates (150%) increased canola yields by 0.12 and 0.25 Mg ha^{-1} in 2008 and 2010, respectively (Table 3). Previous studies indicated that hybrid canola yields are often optimized at higher than ‘‘normal’’ rates of nitrogen (Cutforth et al. 2009; Smith et al. 2010; Blackshaw et al. 2011).

Yield targets related to nitrogen rates can be dubious and difficult to accurately meet. Depending on yield target philosophy (how conservative and attainable researcher/grower ambitions are) and how target yield is determined, even the same laboratory will recommend different nitrogen rates for the same target. In addition, a lower yield target at a low soil organic matter site may require more applied nitrogen than at higher yield target site with high soil organic matter content (see 2010, Lethbridge versus Lacombe – Table 4). Furthermore, there are undoubtedly many biotic and abiotic factors other than nitrogen that influence crop yields.

Most sites did not meet yield targets; Edmonton and Lacombe were notable exceptions (Table 4). Because most actual yields were below target yields, the 100% nitrogen rate applied to obtain target yields at those sites was in excess of that required for the actual yield. Therefore, the consistent yield response to extra nitrogen at those sites suggests a response to nitrogen even above 150% of the recommended nitrogen rate. At Edmonton and Lacombe, where actual yields were well above target yields, it was not surprising that canola responded to more than 100% of the recommended nitrogen rate.

No fixed effect treatment interactions were significant (Table 2). It is important to note that, in this study, we controlled weeds before canola reached the four-leaf stage; post-spray weed populations were not substantial enough to reduce yields at any site (data not shown). Early weed removal is essential to protect canola yield

Table 2. Analysis of variance for canola seed yield and oil concentration fixed effects

	Canola seed yield				Oil concentration			
	2008		2010		2008		2010	
Effect/Contrast[z]	*F* value	*P* value[y]	*F* value	*P* value[z]	*F* value	*P* value[z]	*F* value	*P* value[z]
Treatment (T)	15.8	<0.001	5.5	<0.001	8.9	<0.001	8.9	<0.001
Seeding rate (S)	25.0	**<0.001**	4.8	**0.031**	0.6	0.450	6.3	**0.014**
Nitrogen rate (N)	13.8	**<0.001**	53.0	**<0.001**	16.3	**<0.001**	45	**<0.001**
Nitrogen coating (C)	0.4	0.525	7.1	**0.010**	0.6	0.442	1	0.311
Fungicide (F)	0.1	0.779	5.0	**0.020**	0.1	0.817	2.5	0.120
S × N	1.5	0.227	0.0	0.859	0.2	0.650	1.3	0.251
S × C	0.4	0.524	0.1	0.758	0.1	0.750	0.3	0.592
S × F	0.2	0.632	0.3	0.567	0.3	0.596	0.1	0.796
N × C	3.4	0.071	0.9	0.353	<0.1	0.842	0.4	0.537
N × F	0.1	0.779	0.3	0.594	0.5	0.473	0.3	0.574
S × N × F	2.4	0.126	0.6	0.438	0.3	0.570	0.7	0.417
	Var. est[x]		Var. est[y]		Var. est[y]		Var. est[y]	
Location (L)	1.748		1.150		198		107	
L × T	0.007	0.031	0.009	0.031	42	0.003	22	0.005
% L[w]	0.4		0.8		18		17	

[z] Due to the unbalanced nature of the treatment list (nitrogen coating only in combination with fungicide – see Table 1), some interactions were difficult to interpret or their contrasts could not be generated. Therefore, those interactions are not shown in this Table. Treatments 13–15 (Table 1) were not included in the Table 2 ANOVA. A specific contrast was constructed to determine fungicide effects when combined with uncoated nitrogen.

[y] Bolded main effect P values are statistically significant ($P < 0.05$).

[x] Variance estimate.

[w] Percent values reflect variance associated with the location by treatment interaction expressed as a percentage of the total variance associated with location effects.

potential (Clayton et al. 2002; Harker et al. 2003, 2008; Martin et al. 2001).

Polymer-coated nitrogen main effects were significant only in 2010 (Table 2). In a blend with uncoated urea, polymer-coated nitrogen increased canola yields in 2010 by 0.10 Mg ha^{-1} (3%) (Table 3). Blackshaw et al. (2011) reported that polymer-coated nitrogen increased hybrid canola yield in five of twenty possible site-years. Our rather positive results with a 50:50 mixture of coated and uncoated urea suggest that it may be prudent to have at least some of the applied nitrogen in a form that is readily available to the crop, particularly if available soil nitrogen is very low.

Table 3. Canola seed yield as influenced by treatment main effects[z]

Main effect	Level	2008	2010
		(Mg ha^{-1})	
Seeding rate (seeds m^{-2})	75	2.96	3.19
	150	**3.12**	**3.26**
N fertilizer rate (× recommended)	1×	2.98	3.10
	1.5×	**3.10**	**3.35**
N fertilizer coating	No	3.03	3.19
	Yes	3.05	**3.29**
Fungicide	No	3.03	3.14
	Yes	3.04	**3.24**
SED[y]		0.04	0.04
DDF[y]		77	71

[z] Bolded values are significantly greater than the low main effect level according to the ANOVA (Table 2).

[y] SED, standard error of the difference between means; DDF, denominator degrees of freedom.

Fungicide treatment main effects were only significant in 2010 (Table 2). Fungicide treatment increased canola yields in 2010 by 0.10 Mg ha^{-1} (Table 3). The fungicide effect, although minor, was somewhat surprising given that stem rot [*Sclerotinia sclerotiorum* (Lib.) deBary] levels at all sites were low (<5%), and neither stem rot nor any other disease infestation was judged (by plant pathologists) to be serious enough to reduce canola yield at any of the sites. Brandt et al. (2007) reported no canola production benefit from fungicide applications. In contrast, Kutcher and Wolf (2006) did observe a benefit of fungicide application in canola, but in their case, stem rot levels ranged from 30 to over 50% incidence in untreated plots. Consistent responses from stem rot fungicides usually occur when there is a moderate to high level of disease. Therefore, we cannot explain the 2010 canola yield response to fungicide treatment.

A major objective of this study was to evaluate different input combinations. The highest input combination treatment (treatment 12) led to numerically greater yields than any other treatment in 2008 and 2010 (Table 5). It is notable and supportive of the main effect results discussed above, that 63 and 88% of the treatments in the same statistical group as treatment 12 in 2008 and 2010 included the 150 seed m^{-2} seeding rate and the 150% nitrogen rate, respectively. It is also evident that InVigor 5440 had greater inherent yield capacity than 71-45RR; in 2008, both 71-45RR treatments (13, 14) yielded less than their corresponding InVigor 5440 treatments (6, 12) with the same input levels. Westar

Table 4. Target yields, fall soil test nitrogen levels, 100 and 150% applied nitrogen levels for yield targets, and actual yields for canola at eight western Canada locations

		2008					2010				
	Yield target	Fall soil test	Applied nitrogen		Actual yield		Fall soil test	Applied nitrogen		Actual yield	
Location	100%	nitrogen	100%	150%	100%	150%	nitrogen	100%	150%	100%	150%
	($Mg\ ha^{-1}$)	($kg\ ha^{-1}$)			($Mg\ ha^{-1}$)		($kg\ ha^{-1}$)			($Mg\ ha^{-1}$)	
Beaverlodge	2.80	51	67	101	2.34	2.46	47	79	114	2.63	2.81
Brandon	3.00	41	78	128	2.11	2.29	19	100	150	2.10	2.40
Edmonton	3.90	99	119	178	4.98	5.06	125	82	123	4.78	4.97
Indian Head	3.40	34	89	144	2.82	2.98	16	100	165	2.37	2.75
Lacombe	3.90	25	158	237	5.17	5.31	21	150	222	4.57	4.62
Lethbridge	2.80	30	119	178	2.05	2.20	20	158	237	3.50	3.80
Melfort	3.90	31	63	86	2.70	2.81	24	126	185	2.93	3.32
Swift Current	2.20	20	46	81	1.73	1.73	14	37	80	2.10	2.32

canola (old cultivar, open-pollinated) with relatively high inputs yielded much lower (0.60 Mg ha^{-1}) than the lowest input treatment for InVigor 5440 (treatment 1) in 2008.

Yield-reducing effects of canola following canola also were evident. In 2010, the highest input treatment following wheat yielded more (3.50 Mg ha^{-1}) than the same high input treatment when canola followed canola (3.22 Mg ha^{-1}) (Table 5). Yield reductions in canola following canola versus canola in rotation with other crops have been reported previously (Christen and Sieling 1995; Sieling et al. 1997; Johnston et al. 2005; Cathcart et al. 2006; Kutcher and Brandt 2008).

Two LVs (LV1 and LV2) explained 91 to 94% of the variation for crop yield, and 60 to 72% of the variation for the predictor (site and environment) variables (Table 6). The ANOVA of PLS scores for LV3 would not come to a stable solution.

Site and environment predictor variables with the greatest influence in explaining LV1 values (and by association, canola yield) in 2008 and 2010 were soil organic matter content and days to maturity (Table 6: VIP 1.67–1.77 and 1.45–1.54, respectively). Both soil organic matter content and days to maturity were positively associated with LV1 values [(Table 6: XLoad (LV1) 0.25–0.30 and 0.31–0.33, respectively]. It is not clear whether the positive organic matter effects on yield were more related to organic matter-influenced water and nitrogen availability than to organic matter content per se. Harker et al. (2011) also found positive associations of canola yield with soil organic matter.

High temperature conditions were negatively associated with canola yields in both years (Table 6). June to August days > 30°C, May to August average temperature, May to August growing degree days and June to August maximum and minimum temperatures were all important predictor variables for canola yield in 2008 or 2010. Negative associations of canola yield with temperature have been reported in several other studies (Polowick and Sawhney 1988; Nuttall et al. 1992; Young et al. 2004; Kutcher et al. 2010; Harker et al. 2011).

The only other top-five predictor variable for the LV1 association with canola yield was soil clay content in 2010 (Table 6). Although soil clay content had a relatively high VIP value (1.25), an almost neutral XLoading (-0.05) made it difficult to suggest clay content associations with LV1, and therefore, crop yield. The remaining site and environmental predictors including latitude, longitude, soil percent sand, soil percent silt, precipitation, days to crop emergence, crop density, pre- and post-spray weed density, and root damage ratings (from root maggots) did not rank as one of the top-five predictor variables or had VIP values below 0.8 (Wold 1994).

Overall, results from the PLS analysis suggest that canola yields best on high organic matter soils when conditions permit a long growing season and not too

Table 5. Ranked canola seed yields averaged across sites with contrasts for low and high input treatments

2008					2010				
		Yield	Contrasts[z]				Yield	Contrasts[z]	
Trt. no.	Treatment[y]	(Mg ha^{-1})	vs. **1**	vs. **12**	Trt. no.	Treatment[y]	(Mg ha^{-1})	vs. **1**	vs. **12**
12	**150–1.5 ×–Co–Fn**	**3.23**	**		**12**	**150–1.5 ×–Co–Fn**	**3.50**	**	
8	150–1 ×–Un–Fn	3.16	**		6	75–1.5 ×–Co–Fn	3.37	**	
10	150–1.5 ×–Un–No	3.15	**		5	75–1.5 ×–Un–Fn	3.37	**	
11	150–1.5 ×–Un–Fn	3.11	*		11	150–1.5 ×–Un–Fn	3.36	**	
6	75–1.5 ×–Co–Fn	3.08	*		15[x]	150–1.5 ×–Un–Fn	3.34	**	
7	150–1 ×–Un–No	3.06	*	*	10	150–1.5 ×–Un–No	3.30	**	*
5	75–1.5 ×–Un–Fn	3.04		*	14[x]	150–1.5 ×–Co–Fn	3.22	**	**
9	150–1 ×–Co–Fn	3.01		**	13[x]	75–1.5 ×–Co–Fn	3.20	*	**
14[x]	150–1.5 ×–Co–Fn	3.00		**	4	75–1.5 ×–Un–No	3.20	*	**
4	75–1.5 ×–Un–No	2.99		**	9	150–1 ×–Co–Fn	3.17	*	**
1	**75–1 ×–Un–No**	**2.90**		**	8	150–1 ×–Un–Fn	3.17		**
3	75–1 ×–Co–Fn	2.89		**	3	75–1 ×–Co–Fn	3.11		**
2	75–1 ×–Un–Fn	2.85		**	7	150–1 ×–Un–No	3.08		**
13[x]	75–1.5 ×–Co–Fn	2.83		**	2	75–1 ×–Un–Fn	3.06		**
15[x]	150–1.5 ×–Un–Fn	2.30	**	**	**1**	**75–1 ×–Un–No**	**3.00**		**
	SED[w]	0.08					0.09		
	DDF[w]	77					71		
	LSD (0.05)	0.16					0.17		

[z] Statistical significance for comparison with listed contrast is indicated as follows: * = 0.05 ≥ P value ≥ 0.01; and ** = P value < 0.01. Contrasts are against the lowest (**Trt. 1**) and highest (**Trt. 12**) input treatments.

[y] Treatment coding: first value = seeding rate (seeds m^{-2}), second value = nitrogen rate (1× is soil test recommendation), third value = uncoated nitrogen (Un) or polymer coated nitrogen (Co), fourth value = no fungicide (No) or fungicide (Fn). With the exception of treatments 13–15, all treatments are in a canola-wheat rotation.

[x] Treatments are continuous canola (see Table 1).

[w] SED, standard error of the difference between means; DDF, denominator degrees of freedom.

many high temperature days. Soil pH had lower impact (VIP) than most of the other top five predictors, but greater yields were often associated with lower pH sites. As noted above, the PLS analysis confirmed that treatment rankings for canola yield did not interact with location effects (LV covariate by treatment interactions were not significant).

Seed Oil Concentration

Of the fixed effects, only main effects were significant for canola seed oil concentration (Table 2). In 2008, nitrogen rate was the only significant treatment effect. The recommended nitrogen rate led to greater seed oil concentration than the 1.5 × nitrogen rate in 2008 and 2010 (Table 7). Previous researchers have also reported that oil concentration is reduced at relatively high nitrogen rates (Brandt et al. 2007; Malhi et al. 2007; May et al. 2010). Jackson (2000) suggested that optimum seed and oil yields occurred at a relatively high nitrogen rate (200 kg N ha^{-1}). Given our substantial and consistent seed yield response to extra nitrogen, total oil yields were increased at 150% of the recommended nitrogen rate (multiply respective nitrogen effect values in Tables 3 and 7).

In 2010, the higher than normal seeding rate also increased oil concentration. Brandt et al. (2007) reported that increasing canola seeding rate resulted in a small increase in canola seed oil concentration. The lack of an oil concentration response to polymer-coated nitrogen is consistent with the findings of Blackshaw et al. (2011).

Combinations of agronomic treatments did influence canola oil concentration, but optimal combinations for oil concentration were not the same as those that led to the highest canola yields. Seed oil concentration was influenced by cultivar, nitrogen rate and seeding rate (Table 8). When three different cultivars were seeded (2008) (see Table 1), the RR cultivar (71-45RR) (treatments 13 and 14) had the highest oil concentration while Westar (treatment 15) had the lowest oil concentration. InVigor 5440 oil concentrations were all intermediate to 71-45RR and Westar. Seed oil concentration differences among canola cultivars are common (Vera et al. 2007).

Some input treatment combinations were more influential on seed oil concentration than others (Table 8). Higher than average nitrogen rate reduced oil concentration. Among the LL cultivar treatments in 2008 and 2010, all normal nitrogen rate treatments (1×) had numerically greater oil concentrations than treatments at the 1.5 × nitrogen rate. The consistency of nitrogen rate effects on canola oil concentration for a single cultivar was rather remarkable for all combinations of agronomic treatments. However, it is important to remember that total oil yields continued to increase with more than the recommended nitrogen rate (Tables 3 and 7). Higher than normal seeding rates also tended

Table 6. Canola seed yields in 2008 (top) and 2010 (bottom) ranked according to latent variable 1 (LV1) showing site characteristics ranked (left to right) according to variable importance in projection (VIP)

2008 Location	LV1^z	LV2	Yield (Mg ha^{-1})	Soil organic matter (%)	Days to maturity (d)	No. days >30°C June to Aug. (#)	Ave. temp. May to Aug. (°C)	GDD May to Aug. (Σ°C >0)
Lethbridge, AB	−3.21	0.57	2.08	3.0	100	11	15.8	1942
Swift Current, SK	−2.38	−0.81	1.69	3.4	94	10	15.2	1867
Brandon, MB	−1.74	0.94	2.13	5.0	90	7	15.4	1895
Indian Head, SK	−0.45	−0.50	2.80	3.2	98	6	14.5	1779
Melfort, SK	0.95	−0.49	2.70	9.0	102	4	14.7	1800
Edmonton, AB	1.61	1.18	4.93	13.0	101	5	14.6	1798
Beaverlodge, AB	1.87	−1.92	2.39	5.4	102	7	13.7	1681
Lacombe, AB	3.35	1.03	5.10	8.3	120	4	13.7	1688
VIP				1.77	1.54	1.40	1.18	1.17
XLoad^y (LV1)				0.30	0.33	−0.37	−0.40	−0.39
XLoad (LV2)				0.37	0.17	−0.17	0.27	0.30

2010 Location	LV1	LV2	Yield (Mg ha^{-1})	Soil organic Matter (%)	Days to maturity (d)	Max. temp. June to Aug. (°C)	Soil clay content (%)	Min. temp. June to Aug. (°C)
Brandon, MB	−4.02	1.04	2.24	5.0	93	33.5	33.0	3.1
Swift Current, SK	−1.81	−2.31	2.24	3.4	106	32.8	18.2	0.7
Lethbridge, AB	−0.88	2.40	3.65	3.0	118	33.4	33.0	3.3
Melfort, SK	−0.15	−0.74	3.17	9.0	101	28.1	44.0	1.8
Indian Head, SK^x			2.42	3.2		30.5	21.4	0.8
Beaverlodge, AB	1.34	−2.27	2.63	5.4	109	29.2	22.0	0.7
Edmonton, AB	2.42	1.23	4.88	13.0	113	27.9	36.5	2.3
Lacombe, AB	3.10	0.66	4.63	8.3	127	29.7	21.0	−1.6
VIP				1.67	1.45	1.25	1.25	1.10
XLoad (LV1)				0.25	0.31	−0.31	−0.05	−0.24
XLoad (LV2)				0.10	0.16	0.12	0.25	0.25

[z] LV1 and LV2 explained 60 and 31% of the variation for 2008 crop yield variability and 63 and 31% of the variation for 2010 crop yield variability. LV1 and LV2 also explained 59 and 13% of the variation for 2008 predictor (site and environment) variables and 39 and 21% of the variation for 2010 predictor variables.

[y] XLoad(ing) is similar to a correlation coefficient of mean canola yields with respective LV scores.

[x] LV1 and LV2 could not be estimated at Indian Head where days to maturity was not determined.

Table 7. Canola seed oil concentration as influenced by treatment main effects[z]

Main effect	Level	2008	2010
		($g\ kg^{-1}$)	
Seeding rate (seeds m^{-2})	75	430	464
	150	431	**467**
N fertilizer rate (× recommended)	1×	**433**	**468**
	1.5×	428	461
N fertilizer coating	No	430	465
	Yes	431	466
Fungicide	No	430	464
	Yes	430	466
SED[y]		2	1
DDF[y]		84	94

[z] Bolded values are significantly greater than the low main effect level according to the ANOVA (Table 2).

[y] SED, standard error of the difference between means; DDF, denominator degrees of freedom.

to increase canola oil concentration, but this effect was less consistent than the nitrogen rate effect as noted above.

In contrast to yield data, the highest input combination treatment (treatment 12) did not favour high canola seed oil concentration (Table 8). Indeed, when there was only one cultivar to compare (2010), three treatment combinations (treatments 7–9) led to greater oil concentration than treatment 12. All of the former treatments were at the high seeding rate and the low nitrogen rate. Therefore, oil concentration was not associated with overall "high" or "low" input levels (treatments 1 and 12 were not different in either year); it was most closely linked with cultivar and nitrogen rate. It is also interesting to note that the three treatments with the numerically lowest oil concentration (treatments 13–15) were the only treatments that were preceded by canola rather than wheat.

The location by treatment interaction (random effects) for canola oil concentration accounted for a substantial portion (17–18%) of the total variance associated with location effects (Table 2). In addition, the LV covariate by treatment interactions for canola oil concentration in the PLS analyses were significant [$P <$ 0.001 (2008), $P = 0.038$ (2010)]. Therefore, it is important to examine the influence of site conditions on oil concentration treatment effects.

Site and environment predictor variables with the greatest influence in explaining LV1 values (and by association, canola oil concentration) in 2008 were soil texture, pH and maximum June to August temperatures (Table 9). When conditions such as high soil silt, low soil pH, high maximum temperatures and low soil clay were similar to Swift Current (lowest LV1 score and lowest average oil concentration), low nitrogen rate led

Table 8. Ranked canola seed oil concentration averaged across sites with contrasts for low and high input treatments

2008					2010				
		Oil	Contrasts[z]				Oil	Contrasts[z]	
Trt. no.	Treatment[y]	($g\ kg^{-1}$)	vs. **1**	vs. **12**	Trt. no.	Treatment[y]	($g\ kg^{-1}$)	vs. **1**	vs. **12**
14[x]	150–1.5 ×–Co–Fn	443	**	**	8	150–1 ×–Un–Fn	471		**
13[x]	75–1.5 ×–Co–Fn	438		**	9	150–1 ×–Co–Fn	471		**
9	150–1 ×–Co–Fn	435			7	150–1 ×–Un–No	469		**
1	**75–1 ×–Un–No**	**434**			2	75–1 ×–Un–Fn	467		
8	150–1 ×–Un–Fn	434			3	75–1 ×–Co–Fn	467		
7	150–1 ×–Un–No	434			**1**	**75–1 ×–Un–No**	**467**		
3	75–1 ×–Co–Fn	433			6	75–1.5 ×–Co–Fn	463		
2	75–1 ×–Un–Fn	430			11	150–1.5 ×–Un–Fn	463		
12	**150–1.5 ×–Co–Fn**	**429**			**12**	**150–1.5 ×–Co–Fn**	**462**		
6	75–1.5 ×–Co–Fn	428			5	75–1.5 ×–Un–Fn	462		
5	75–1.5 ×–Un–Fn	428			10	150–1.5 ×–Un–No	461		
11	150–1.5 ×–Un–Fn	427			4	75–1.5 ×–Un–No	458	**	
4	75–1.5 ×–Un–No	427	*		15[x]	150–1.5 ×–Un–Fn	457	**	*
10	150–1.5 ×–Un–No	427	*		14[x]	150–1.5 ×–Co–Fn	456	**	*
15[x]	150–1.5 ×–Un–Fn	412	**	**	13[x]	75–1.5 ×–Co–Fn	454	**	**
	SED[w]	4					4		
	DDF[w]	84					98		
	LSD (0.05)	6					6		

[z] Statistical significance for comparison with listed contrast is indicated as follows: * = 0.05 ≥ P value ≥ 0.01; and ** = P value < 0.01. Contrasts are against the lowest (**Trt. 1**) and highest (**Trt. 12**) input treatments.

[y] Treatment coding: first value = seeding rate (seeds m^{-2}), second value = nitrogen rate (1 × is soil test recommendation), third value = uncoated nitrogen (Un) or polymer coated nitrogen (Co), fourth value = no fungicide (No) or fungicide (Fn). With the exception of treatments 13–15, all treatments are in a canola-wheat rotation.

[x] Treatments are continuous canola (see Table 1).

[w] SED, standard error of the difference between means; DDF, denominator degrees of freedom.

Table 9. Canola seed oil concentration in 2008 (top) and 2010 (bottom) ranked according to latent variable 1 (LV1) showing site characteristics ranked (left to right) according to variable importance in projection (VIP)

2008 Location	LV1[z]	LV2	Oil (g kg^{-1})	Soil silt content (%)	pH	Max. temp. Jun. to Aug. (°C)	Soil clay content (%)	Soil sand content (%)
Swift Current, SK	−2.62	−2.34	404	50.4	6.5	36.3	18.2	31.4
Indian Head, SK	−1.67	1.39	425	65.0	7.6	34.1	21.4	13.6
Beaverlodge, AB	−0.36	1.18	426	47.4	6.5	32.2	22.0	30.6
Melfort, SK	0.23	−0.28	430	40.0	6.4	35.7	44.0	16.0
Edmonton, AB	0.34	1.03	430	40.5	7.6	33.8	36.5	23.0
Brandon, MB	0.79	1.50	446	33.0	8.1	33.2	33.0	34.0
Lacombe, AB	1.39	0.24	442	33.0	6.4	31.1	21.0	46.0
Lethbridge, AB	1.90	−2.73	441	30.0	8.0	36.6	33.0	37.0
VIP				2.06	1.34	1.34	1.21	1.17
XLoad[y] (LV1)				−0.57	0.20	−0.16	0.33	0.32
XLoad (LV2)				0.15	0.06	−0.44	0.02	−0.18

2010 Location	LV1	LV2	(g kg^{-1})	Precipitation May to Aug. (mm)	Pre-spray weed density (no. m^{-2})	Soil sand content (%)	Root maggot damage rating (1–5)	Latitude
Lacombe, AB	−3.32	−0.60	451	460	19	46.0	4.03	52.5
Swift Current, SK	−1.61	−0.32	457	412	16	31.4	1.92	50.3
Lethbridge, AB	−1.01	1.55	466	347	66	37.0	3.00	49.7
Indian Head, SK[x]			452	307		13.6	1.18	50.6
Brandon, MB	0.38	0.11	463	336	95	34.0	2.31	50.0
Edmonton, AB	1.57	−1.76	466	246	27	23.0	1.44	53.7
Beaverlodge, AB	1.91	2.01	479	168	81	30.6	1.08	55.2
Melfort, SK	2.08	−1.00	471	300	117	16.0	3.08	52.8
VIP				2.03	1.58	1.34	1.24	1.13
XLoad (LV1)				−0.44	0.32	−0.41	−0.30	0.25
XLoad (LV2)				−0.21	0.22	0.27	−0.14	−0.04

[z] LV1 and LV2 explained 84 and 8% of the variation for 2008 crop yield variability and 77 and 20% of the variation for 2010 crop yield variability. LV1 and LV2 also explained 51 and 17% of the variation for 2008 predictor (site and environment) variables and 21 and 26% of the variation for 2010 predictor variables.

[y] XLoad(ing) is similar to a correlation coefficient of mean canola yields with respective LV scores.

[x] LV1 and LV2 could not be estimated at Indian Head where pre-spray weed density was not determined.

Table 10. Ranked canola seed oil concentration as influenced by composite site and environmental conditions with means estimated according to LV1 score extremes (conditions deviating from the "average site" the most)

2008						2010					
Lowest LV1 score (-2.6)			Highest LV1 score (1.9)			Lowest LV1 score (-3.3)			Highest LV1 score (2.1)		
No.	Treatment[y]	Oil	No.	Treatment[z]	Oil	No.	Treatment[z]	Oil	No.	Treatment[z]	Oil
		(g kg^{-1})			(g kg^{-1})			(g kg^{-1})			(g kg^{-1})
8	150–1 ×–Un–Fn	418	14	150–1.5 ×–Co–Fn	467	8	150–1 ×–Un–Fn	458	7	150–1 ×–Un–No	483
7	150–1 ×–Un–No	416	13	75–1.5 ×–Co–Fn	459	1	75–1 ×–Un–No	458	9	150–1 ×–Co–Fn	480
3	75–1 ×–Co–Fn	416	9	150–1 ×–Co–Fn	448	9	150–1 ×–Co–Fn	456	8	150–1 ×–Un–Fn	480
9	150–1 ×–Co–Fn	415	1	75–1 ×–Un–No	447	3	75–1 ×–Co–Fn	456	2	75–1 ×–Un–Fn	475
1	75–1 ×–Un–No	415	7	150–1 ×–Un–No	447	2	75–1 ×–Un–Fn	455	1	75–1 ×–Un–No	475
2	75–1 ×–Un–Fn	414	3	75–1 ×–Co–Fn	446	5	75–1.5 ×–Un–Fn	452	3	75–1 ×–Co–Fn	475
12	150–1.5 ×–Co–Fn	412	8	150–1 ×–Un–Fn	445	11	150–1.5 ×–Un–Fn	452	6	75–1.5 ×–Co–Fn	474
5	75–1.5 ×–Un–Fn	411	12	150–1.5 ×–Co–Fn	443	13	75–1.5 ×–Co–Fn	452	12	150–1.5 ×–Co–Fn	473
6	75–1.5 ×–Co–Fn	410	10	150–1.5 ×–Un–No	443	7	150–1 ×–Un–No	452	5	75–1.5 ×–Un–Fn	473
14	150–1.5 ×–Co–Fn	409	11	150–1.5 ×–Un–Fn	442	6	75–1.5 ×–Co–Fn	451	10	150–1.5 ×–Un–No	473
13	75–1.5 ×–Co–Fn	409	2	75–1 ×–Un–Fn	442	12	150–1.5 ×–Co–Fn	449	11	150–1.5 ×–Un–Fn	472
4	75–1.5 ×–Un–No	408	6	75–1.5 ×–Co–Fn	441	4	75–1.5 ×–Un–No	448	4	75–1.5 ×–Un–No	467
11	150–1.5 ×–Un–Fn	407	4	75–1.5 ×–Un–No	441	10	150–1.5 ×–Un–No	447	14	150–1.5 ×–Co–Fn	467
10	150–1.5 ×–Un–No	405	5	75–1.5 ×–Un–Fn	440	14	150–1.5 ×–Co–Fn	447	15	150–1.5 ×–Un–Fn	466
15	150–1.5 ×–Un–Fn	381	15	150–1.5 ×–Un–Fn	434	15	150–1.5 ×–Un–Fn	446	13	75–1.5 ×–Co–Fn	462
	SED[y]	6			5			5			4
	DDF[y]	84			82			70			70
	LSD (0.05)	14			11			9			7

[z] Treatments 13–15 are continuous canola (see Table 1).

[y] SED, standard error of the difference between means; DDF, denominator degrees of freedom.

to the highest oil concentration despite cultivar effects (Table 10). Conversely, at high average oil concentration levels, when conditions were similar to those in Lethbridge (highest LV1 score: low soil silt, high pH, etc.), cultivar effects were again prominent and the glyphosate-resistant cultivar (71-45RR: treatments 13 and 14) had greater oil concentration than any other treatment despite their 1.5 × nitrogen rate. High seed oil concentration is generally associated with relatively cool growing conditions (Canadian Grain Commission 2010); associations with soil texture and soil pH reported here have not been reported previously.

In 2010, a new set of site and environmental predictors were associated with oil concentration levels (Table 9). In addition to soil sand content, precipitation, pre-spray weed density, root maggot damage, and latitude all tended to influence oil concentration. When conditions were similar to Lacombe (lowest LV1 score and low average oil concentration) such as relatively high precipitation and low pre-spray weed density, oil concentration was generally high when nitrogen rates were low (Table 10). Given conditions similar to Melfort (high average oil concentration, highest LV1 score) such as high pre-spray weed density, low soil sand content and relatively high latitude, high oil concentration was again associated with low nitrogen rate. The trend for oil concentration to be relatively low when canola was the previous crop was apparent in 2010 when means were estimated for the lowest and highest LV1 scores (treatments 13–15).

CONCLUSIONS

Canola oil concentration varied among canola cultivars, but was consistently lower when nitrogen rates were high (150% of recommended). The nitrogen effect had a greater influence than the cultivar effect when site conditions included relatively high levels of soil silt and low soil pH; the cultivar effect was greater than the nitrogen effect when soil silt content was low and soil pH was high. Higher than normal seeding rates led to high canola seed oil concentration in some cases, but the effect was inconsistent.

Crop input treatment effects on canola yield were similar across all sites, years and conditions. High average canola yields across all treatments were positively associated with soil organic matter and growing season length, and negatively associated with high temperatures. Inputs such as fungicides and polymer-coated nitrogen may enhance canola yield in some cases, but their effects were inconsistent. High-yielding canola on the Canadian prairies is likely to be grown in rotation with other crops, with more nitrogen than is currently recommended from soil tests, and with more than 75 seeds m^{-2}. Given the consistently strong yield response to relatively high rates of nitrogen, it would be interesting to determine the influence of legume crops seeded prior to canola. Using higher than normal inputs on 6.5 million hectares of prairie canola could increase average production by 0.50 Mg ha^{-1} and supply more than 3 million additional Mg of canola annually.

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