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Niger Tolerance to Flucarbazone

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Niger is a potential crop for the Northern Great Plains, but not until volunteer canola can be controlled. A study at Indian Head, SK, was conducted from 2007 to 2009 to determine the tolerance of niger to flucarbazone, a herbicide that controls volunteer canola. The tolerance was determined by applying three rates of flucarbazone (19, 28.5, and 38 g ai ha^{-1}) at four application stages (two, four, six, and eight-leaf stage). Mean injury did not exceed 22% for any year by treatment combination. Injury was most prominent in 2007, and dissipated as the growing season progressed. Increasing the rate of flucarbazone increased crop injury depending on the year, application timing, and evaluation timing. Injury under 20% in 2007 and under 10% in 2008 and 2009 was observed at the start of flowering when flucarbazone was applied at the two, four, and six-leaf stage. Injury from applications at the two, four, and six-leaf stage decreased as the growing season progressed. When the labelled rate of flucarbazone for wheat (19 g ha^{-1}) was applied at the two, four, or six leaf stage, injury was below 10%. Injury when flucarbazone was applied at the eight-leaf stage was highest during seed filling. Volunteer canola was controlled by flucarbazone. The application of flucarbazone relative to a weedy control increased yield by about 50% (138 to 213 kg ha^{-1}) in 2008 and 2009. Flucarbazone rate did not affect niger yield except in 2007 where yield was about 100 kg ha^{-1} less with the two highest rates. Delaying flucarbazone application decreased niger yield, especially in the year (2007) with most niger injury. Flucarbazone application at the two- or four-leaf niger stage at a rate of 19 g ha^{-1} provided a good balance of weed control and crop tolerance.

Nomenclature: Flucarbazone; volunteer canola, *Brassica napus* L.; niger, *Guizotia abbysinica* (L.f.) Cass.; wheat, *Triticum aestivum* L.

Key words: Application rate, application stage, crop removal, injury, tolerance

Níger es un cultivo potencial para las Grandes Planicies del Norte, pero esto dependerá del control la colza voluntaria. En Indian Head, Saskatchewan, se realizó un estudio entre 2007 y 2009, para determinar la tolerancia de níger a flucarbazone, un herbicida que controla la colza voluntaria. La tolerancia se determinó aplicando tres dosis de flucarbazone (19, 28.5, y 38 g ai ha^{-1}) en cuatro estadios de crecimiento (dos, cuatro, seis, y ocho hojas). El daño promedio no excedió 22% en ninguno de los años para cualquiera de las combinaciones de tratamientos. El daño fue más prominente en 2007, y se disipó conforme la temporada de crecimiento avanzó. El incremento en la dosis de flucarbazone aumentó el daño en el cultivo dependiendo del año, el momento de aplicación, y el momento de evaluación. Niveles de daño por debajo de 20% en 2007 y de 10% en 2008 y 2009, fueron observados al inicio de la floración cuando flucarbazone fue aplicado en los estadios de dos, cuatro, y seis hojas. El daño generado por aplicaciones en los estadios de dos, cuatro, y seis hojas disminuyó al avanzar la temporada de crecimiento. Cuando se aplicó la dosis de etiqueta de flucarbazone para trigo (19 g ai ha^{-1}) en los estadios de dos, cuatro, o seis hojas, el daño fue inferior a 10%. El daño de flucarbazone aplicado en el estadio de ocho hojas fue más alto durante el llenado de la semilla. La colza voluntaria fue controlada por flucarbazone. La aplicación de flucarbazone, en relación al testigo con malezas, aumentó el rendimiento en cerca de 50% (138 a 213 kg ha^{-1}) en 2008 y 2009. La dosis de flucarbazone no afectó el rendimiento del níger, excepto en 2007 cuando el rendimiento fue cerca de 100 kg ha^{-1} menor con las dos dosis más altas. El retrasar la aplicación de flucarbazone disminuyó el rendimiento del níger, especialmente en el año (2007) con mayor daño en el cultivo. La aplicación de flucarbazone en los estadios de dos o cuatro hojas a una dosis de 19 g ai ha^{-1} brindó un buen balance entre el control de malezas y la tolerancia del cultivo.

Crop diversification can be an important management tool for farmers. Crop diversity enhances the management of plant disease and insect pests. In addition, crop diversity can mitigate economic risk because global market forces do not necessarily impact the profitability of all crops similarly in any given year. Niger, also known as niger thistle, Nyjer™, noog, and ramtil, is an open-pollinated oilseed crop that has been cultivated in Ethiopia and India for several thousand years, accounting for 50% of the Ethiopian and 3% of the Indian oilseed production (Getinet and Sharma 1996). It is thought that Ethiopia is the centre of origin and

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that niger was taken to India in the third millennium BC. Niger is imported and used as bird feed in Europe and North America. Approximately 50,000 tonnes of niger were imported into the USA in 2003 (Lin 2005).

Recently, a private plant breeder in Minnesota developed several cultivars of niger that will mature and produce seed on the northern Great Plains of North America. The yield potential of niger in Saskatchewan ranges from 200 to 1000 kg ha^{-1} (May et al. 2011). Niger growth is slow in early stages, which means it allows weeds to emerge and develop. Volunteer canola is a major weed in western Canada and is ranked as the 14th most common weed in the early 2000's by Leeson et al. (2005). Volunteer canola has been observed as a major weed in niger in early herbicide screening trials (May et al. 2008), probably because canopy closurer does not occur until the middle of July because niger has slow initial growth; therefore, volunteer canola control is a major limitation to niger yields in western Canada.

Preliminary studies have been conducted on the tolerance of niger to several herbicides. Kandel and Porter (2002) reported that niger was severely injured by bentazon, bromoxynil, dicamba, fomesafen, thifesulfuron, clopyralid, imazamethabenz, imazamox, nicosulfuron, acetochlor, isoxaflutole, and flumetsulam. They also reported that niger had good tolerance to ethafluralin, trifluralin, EPTC, and sulfentrazone. In addition, May et al. (2008) reported that niger tolerated ethafluralin, trifluralin flucarbazone and sulfentrazone. Flucarbazone is the only herbicide niger tolerates that also controls volunteer canola (Saskatchewan Ministry of Agriculture 2013).

A better understanding of the appropriate application parameters for flucarbazone to control weeds such as volunteer canola is required before flucarbazone can be recommended for use with niger. The main objective of this research is to determine the tolerance of niger to flucarbazone across a range of stages and flucarbazone rates .

Materials and Methods

Site Description and Experimental Design. A field experiment was conducted on sites with heavy clay soils (Orthic Vertisol or Haplocryert) at Indian Head (50.55°N, 103.64°W; elevation 579 m), Saskatchewan, Canada in 2007, 2008 and 2009. The sites were established on wheat stubble in 2007 and 2008 and on barley stubble in 2009.

The experiment design was a factorial arrangement of two factors and two checks arranged in a randomized complete block design with four replications. The first factor included three rates of flucarbazone (Everest; 66% dry granular, Arysta Life Sciences Canada, http://www.arystalifescience.ca): 19, 28.5, and 38 g ha^{-1}. The second factor was crop stage at which flucarbazone was applied: two-, four-, six-, and eight-leaf stage of niger. The treatment design also included a hand-weeded and weedy control (no weeds were controlled during the rating period). Plot size was 10.7 m long by 4.0 m wide.

Glyphosate was applied before seeding at a rate of 900 g ae ha^{-1}. Herbicides were applied using a tractor sprayer, equipped with 110015 pre orifice nozzles (Airmix) with a pressure of 275 kPa. A non-ionic surfactant, LI 700® was always used at 0.25% v/v. The sprayer was calibrated to deliver a carrier volume of 111 L ha^{-1}. Plots were sown with a no-till drill with hoe openers designed by Conserva Pak. The hoe openers were spaced 30.5 cm apart. The niger cultivar, Early Bird was sown on May 28 in 2007 and 2009 and on May 22 in 2008 at a rate of 6.5 kg ha^{-1} and at a depth of 1.5 to 2 cm below the soil surface. Nitrogen fertilizer was applied as urea, monoammonium phosphate and ammonium sulphate. Urea, phosphorous (monoammonium phosphate), potassium (potassium chloride) and sulphur (ammonium sulphate) were applied in a side band placed 2 to 3 cm to the side and 7 to 8 cm below the seed at the following rates: 30 kg N ha^{-1}, 20 kg PO_4^{3-} ha^{-1}, 10 kg K_2O ha^{-1}, and 10 kg SO_4^{2-} ha^{-1}.

Data Collection. Plant counts were done approximately three weeks after seeding. Two 1-m sections of crop row within each plot were selected at random and counted. Niger tolerance to flucarbazone was rated at the following stages: (1) 1% of the plants were flowering; (2) 100 % of the plants were flowering; (3) 100% of the plants were in seed development. The control of volunteer canola was visually estimated when 100% of the niger plants were in seed development. Niger was swathed after first frost and then harvested. Seed yield was expressed on a clean seed basis.

Statistical Analyses. Data were analyzed with the GLIMMIX procedure of SAS (Littell et al. 2006).

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Table 1. Summary of climatic conditions at Indian Head, Saskatchewan from 2007 through 2009.

Year	Precipitation				% of long term average	Temperature				% of long term average
	May	June	July	August		May	June	July	August	
	(mm)					(C)				
2007	46	46	51	63	81	10	15	20	16	95
2008	21	60	90	47	86	9	14	17	18	92
2009	15	60	59	77	83	8	14	14	15	81
Long-term average	56	79	67	53		11	16	18	18	

The effect of replicate was considered random, and the effects of year and the applied treatments were considered fixed. Data were analyzed with a Gaussian error distribution, and the analyses accounted for heterogeneous residual variances among years; a corrected Akaike's information criterion confirmed benefit of modeling variance heterogeneity. Density and yield data analysis considered the factorial combinations flucarbazone rate and application stage, and the untreated and weed-free checks as a single factor. Linear and quadratic contrasts were included to assess the factorial portion of the treatment design; i.e., portion of treatment design not including the two checks.

Results and Discussion

Climatic Conditions and Pant Density. Conditions over the course of the study at Indian Head generally were slightly drier and cooler than normal (Table 1). In fact, precipitation in May 2008 and 2009 was considerably drier than normal. Exceptions to these trends were a wetter than normal July, 2008 and slightly warmer than normal July, 2007. Niger plant density for individual treatments ranged from 107 to 165 plants m^{-2} when averaged over the three years.

Niger Tolerance. Maximum average niger injury response to any one of the different flucarbazone treatment combinations did not exceed 25% for any given year and the rate labelled for control of broadleaf weeds, 19 g ha^{-1}, had injury responses that were all below 10%. Niger injury was greatest in 2007 and least in 2009 (Table 2). Furthermore, all flucarbazone treatments caused injury in 2007, whereas, a number of treatments caused minimal average injury in 2008 and especially in 2009 (Table 3). One important aspect of niger growth and development when interpreting visual injury ratings on niger is it's indeterminate growth habit; the niger developed 10 leaves and then initiated reproductive development by producing buds followed by flowering while vegetative growth continued.

The analysis of variance revealed that all main effects were significant and that all three way interactions were significant ($P < 0.005$), rating stage by application stage by flucarbazone rate, year by rating stage by flucarbazone rate and year by rating stage by application stage. The three way interactions are used to explain niger injury. Another commonality from the analysis was that the non-linear effect of flucarbazone rate on injury was not statistically significant ($P > 0.05$); the only exception was a significant non-linear rate effect in 2007 for applications at the four-leaf stage (Figure 1).

The rating stage by application stage by flucarbazone rate interaction was caused by the following differences. When injury was rated at 1% flowers emerged, niger injury occurred with increasing flucarbazone rates applied at the two- and four-leaf stages (Table 4 and Figure 1). Injury from flucarbazone applied at the six-leaf stage and especially at the eight-leaf stage was not observable at 1% flower because of the short period of time between eight-leaf stage and 1% flower. Later in the growing season (100% flowers emerged and 100% seed filling), injury increased with flucarbazone rate

Table 2. Mean niger injury responses from flucarbazone at three rating stages at Indian Head, Saskatchewan in 2007 to 2009.

Year	Flowers formed		Seed filling	LSD0.05
	1%	100%	100%	
	(% injury)			
2007	15.2	13.2	9.9	1.8
2008	7.7	5.0	4.0	1.4
2009	4.1	4.3	1.5	1.4

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Table 3. The effect of year, rating stage, and application stage of flucarbazone on niger injury at Indian Head, Saskatchewan.

Year	Rating stage	Application stage 2	4	6	8	Linear	Non-linear
		Injury (%)					
2007	1% flowers	14.4	19.3	21.8	5.5	**< 0.001**[a]	**< 0.001**
	100% flowers	9.2	11.6	12.7	19.3	**0.017**	**< 0.001**
	Seed filling	7.8	11.1	6.8	13.9	**< 0.001**	0.071
2008	1% flowers	1.6	7.8	21.3	0.1	0.051	**< 0.001**
	100% flowers	0.4	0.1	2.8	16.5	**< 0.001**	**< 0.001**
	Seed filling	0.1	0.1	1.8	13.9	**< 0.001**	**< 0.001**
2009	1% flowers	5.8	6.8	3.8	0.1	**< 0.001**	0.092
	100% flowers	0.1	1.1	1.4	14.5	**< 0.001**	**0.031**
	Seed filling	0.1	0.1	0.1	5.5	**< 0.001**	**< 0.001**

[a] Bold indicates significance.

only for the six- and eight-leaf application stages. At the same time the visible injury caused from flucarbazone when applied at the two- and four-leaf stages decreased as niger continued to develop (indeterminate growth habit).

A year by rating stage by flucarbazone rate was observed (Table 4 and Figure 1). Progressively greater flucarbazone rates increased niger injury when applied at the two-, four-, and six-leaf stages in 2007, eight-leaf stage in 2008, and four-leaf stage

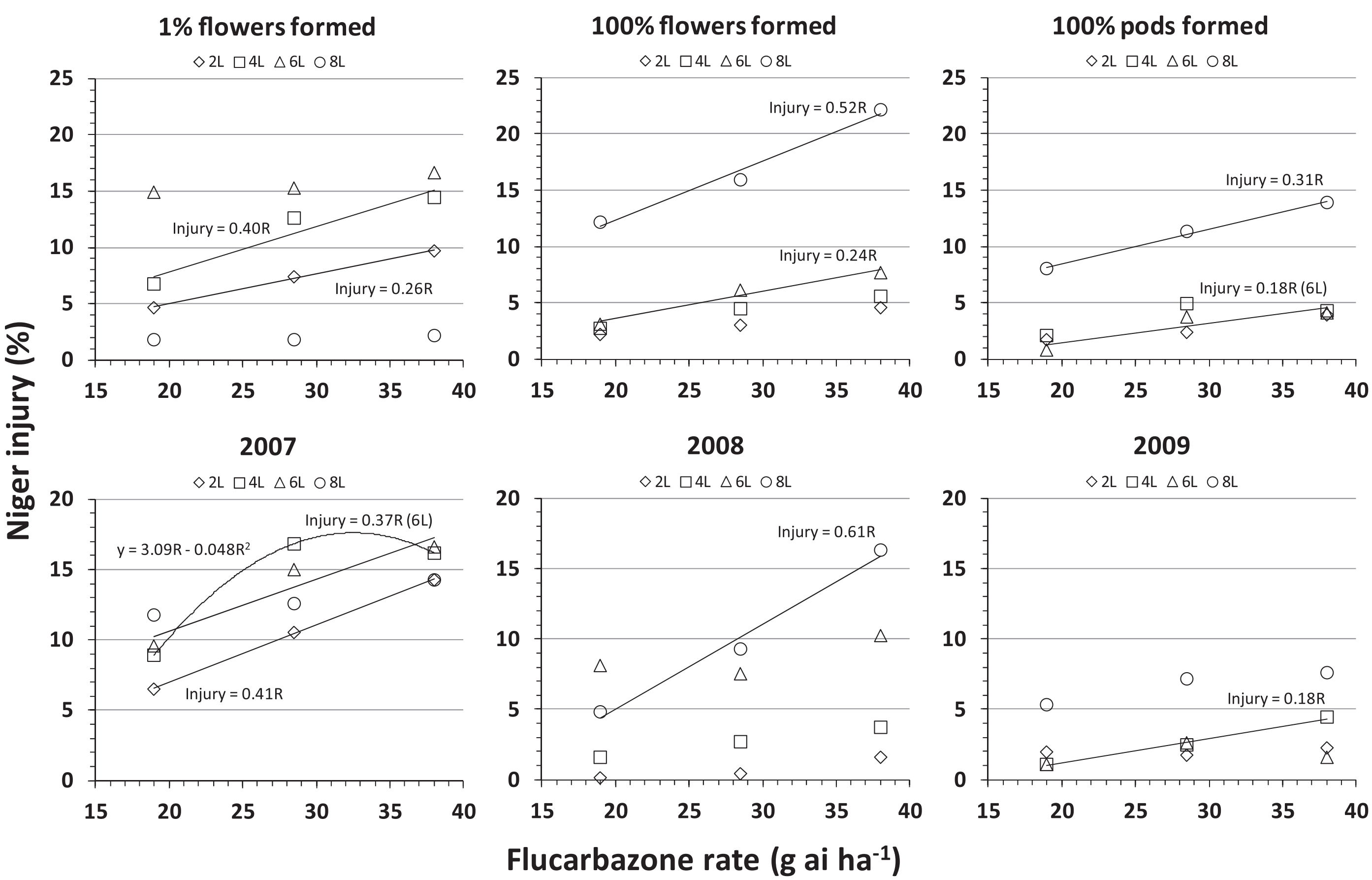

Figure 1. Mean niger injury responses to flucarbazone rate (R) at Indian Head, Saskatchewan in 2007 to 2009. Top charts are for different times of applications (L represents leaf stage) and rating stage. Bottom charts are for different times of applications and for three years. Regression equations (do not include intercept) and trend lines are included only for significant trends.

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Table 4. Contrast analysis for niger injury data from flucarbazone collected at Indian Head, Saskatchewan in 2007 to 2009.

	Rating stage		
Interaction	Flowers formed		Seed filling
R x S x F[a]	1%	100%	100%
Application Stage	(P value)		
2LF	**0.002**[b]	0.155	0.141
4LF	< **0.001**	0.171	0.074
6LF	0.269	**0.036**	**0.004**
8LF	0.792	**0.000**	< **0.001**
Y × R × F[a]	2007	2008	2009
Application Stage	(P value)		
2LF	< **0.001**	0.306	0.817
4LF	< **0.001**	0.156	**0.022**
6LF	< **0.001**	0.140	0.728
8LF	0.172	< **0.001**	0.119

[a] Abbreviations: Y, year; R, rating stage; S, application stage; F, flucarbazone rate, linear effect; LF, leaf stage.

[b] Bold indicates significance.

in 2009. These results indicate that injury can vary between years and the effect of increasing injury as the flucarbazone rate increase is more likely to occur when overall injury is higher. Injury was below 10% in each year, when the labelled rate of flucarbazone (19 g ha^{-1}) was applied at the two-, four-, or six-leaf stage.

Niger injury responses to application stage varied among rating stages and years (Table 3). Niger injury response at the beginning of flowering was at a maximum when applications were made at the four-leaf or six-leaf stage. Flucarbazone applied at progressively later growing stages increased (linear and non-linear) average niger injury at 100% flowers and seed filling. Therefore, the later applications, especially at eight leaves, caused the most injury that persisted through the entire growing season.

It is not easy to relate weather conditions to differences in injury among the three years. July temperatures in 2007 were above the long term average while they were below the long term average in 2008 and 2009 (Table 1). This temperature difference in July may have contributed to the differences in niger injury among the years.

Volunteer Canola Control. Flucarbazone treatments almost always controlled more than 80% of volunteer canola. Year by treatment interactions for volunteer canola control responses were detected with significant ($P < 0.05$) year by application stage and year by flucarbazone rate interactions. In 2008, volunteer canola control was above 97% for all flucarbazone treatments (Figure 2). In 2009, 87% of volunteer canola was controlled at a rate of 19 g ha^{-1} and increased to over 92% for the two highest flucarbazone rates. Volunteer control responses to time of flucarbazone application were significant in 2009, but did not follow a typical linear or quadratic trend (Figure 2).

Although weed control was only assessed two years, results indicated that control close to or in excess of 90% will be achieved at any rate or

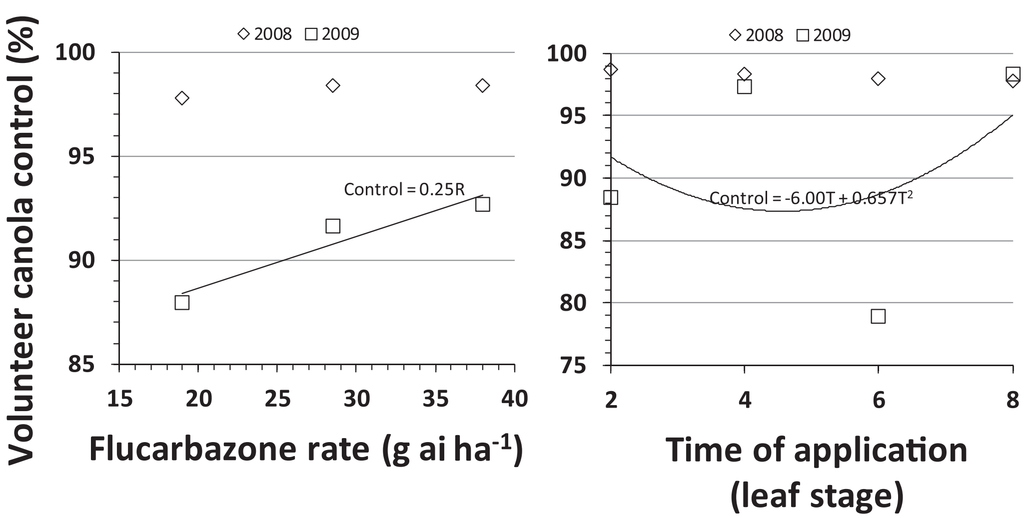

Figure 2. Visual estimates of volunteer canola responses to flucarbazone rate (R) and application stage (T) at Indian Head, Saskatchewan in 2008 to 2009. Regression equations (do not include intercept) and trend lines are included only for significant trends.

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Table 5. Mean niger yield responses for all treatment combinations at Indian Head, Saskatchewan in 2007 to 2009.

Application stage/ Flucarbazone rate (g ai ha^{-1})	2007	2008	2009
		kg ha^{-1}	
Nontreated check	816	301	415
2-leaf stage			
19	771	534	753
28.5	751	552	791
38	663	542	722
4-leaf stage			
19	761	430	747
28.5	676	518	833
38	616	485	758
6-leaf stage			
19	493	393	525
28.5	505	458	641
38	434	394	619
8-leaf stage			
19	251	339	412
28.5	213	330	418
38	146	299	311
Hand-weeded check	870	671	766
LSD0.05	134	86	142

application stage for flucarbazone. These results confirm that that flucarbazone adequately controls volunteer canola in niger stands.

Grain Yield. Application stage had a bigger effect on niger yield than the flucarbazone rate. Year by application stage and year by flucarbazone rate were significant; however, the hand-weed check and the untreated check treatments are also important when the yield data is interpreted. Therefore, all treatments are presented by year (Table 5). In 2007 with no major infestation of weeds present, the untreated check and hand-weeded check have similar yields. The 19 g ha^{-1} rate at the two- and four-leaf and the 28.5 g ha^{-1} rate at the two-leaf stage were similar to both checks. The grain yield of niger rapidly declined as the application stage was delayed to six and eight leaves (Table 5). At the four-leaf stage in 2007 the flucarbazone rate had an effect on seed yield. At the other leaf stages in 2007 and all leaf stages in 2008 and 2009, altering the rate of flucarbazone did not affect the grain yield of niger. In 2007, niger had good tolerance to flucarbazone when applied at the labeled rate at the two- and four-leaf stage.

In 2008, the hand-weeded check had a greater grain yield than all the flucarbazone treatments and the untreated check (Table 5). In addition all flucarbazone rates applied at the two-, four-, and six-leaf stages had a higher grain yield than the untreated check and applications at the two- and four-leaf stages tended to out yield an application at the eight leaf stage. The 2008, results indicate that flucarbazone may reduce the yield of niger, but uncontrolled volunteer canola will reduce niger grain yield by an even larger amount.

In 2009, the hand-weeded check and flucarbazone applications at the two and four leaf stages had a higher grain yield than the untreated check (Table 5). The similar grain yield between the hand-weeded check and flucarbazone applications at the two and four leaves indicates that niger had good tolerance to flucarbazone at those application stages. The 81% yield increase from an application of flucarbazone at the two leaf stage compared to the untreated check indicates how important it is to control volunteer canola in a niger crop. Progressively later times of flucarbazone application decreased yield; niger yield was approximately 700 kg ha^{-1} for the two-leaf and four-leaf stages of application and approximately 300 kg ha^{-1} for the eight-leaf stage of application when data were averaged across other factors (Figure 3). On a by-year basis, yield reduction associated with delayed flucarbazone application was greater and more non-linear in nature for 2007 and 2009 compared with 2008.

Injury and yield results indicate that an application of flucarbazone at the two- or four-leaf growth stage increased grain yield when volunteer canola was present. Niger develops slowly early in the season, which means that the relatively open canopy allows weeds to emerge and develop, leaving niger susceptible to early-season weed interference. Early season competition is important in spring sown broadleaf crops (Harker et al. 2001; May et al. 2003). This may be the reason why time of flucarbazone application affected niger yield more than flucarbazone rate. Because this trial was not conducted under weed free conditions the grain yield data indicating the tolerance of niger to flucarbazone is confounded with niger tolerance to early season weed competition.

Future research should consider the effects of early season weed competition on niger and the control and competitive effects of other species. Furthermore, the benefits of integrating herbicide weed control with other management practices

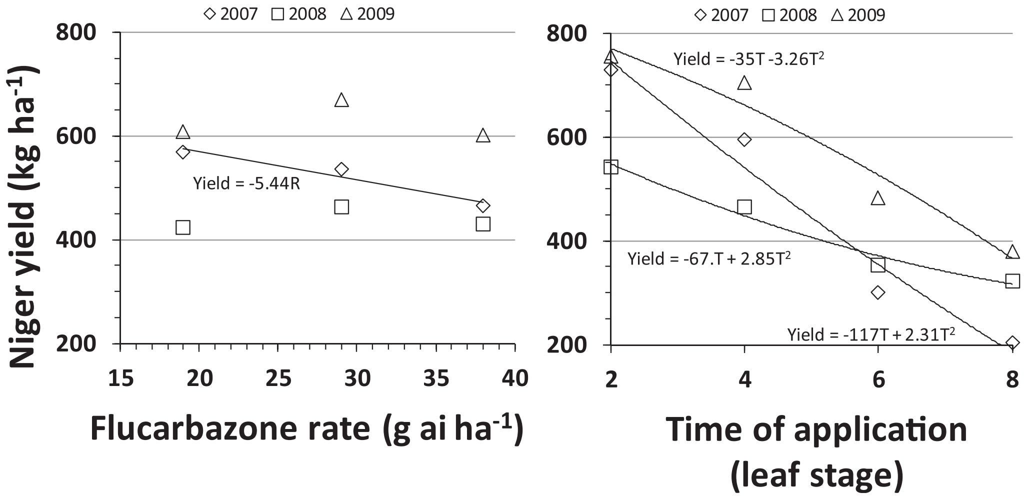

Figure 3. Mean niger yield responses to flucarbazone rate (R) and application stage (T) at Indian Head, Saskatchewan from 2007 through 2009. Regression equations (do not include intercept) and trend lines are included only for significant effects.

(greater seeding rates, seeding dates, etc.) should be investigated to provide efficient/effective weed management for niger. In conclusion, flucarbazone is a suitable herbicide for the control of volunteer canola in niger when the labelled rate, 19 g ha^{-1} is applied at the two- or four-leaf stage.

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