

Evaluation of Harvest Aids Application Timing for Lentil Dry Down

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Abstract:

Harvesting stage is a critical step for lentil producers to maintain high seed yield and good quality. Desiccating lentil with desiccants/harvest aids can dry down lentil evenly and quickly, and control late-growing green weeds, which enhances lentil harvest efficiency and allows early harvesting. Since the harvest aids are applied at a late growth stage, high herbicide residue in seeds may cause commercial issues with marketing lentil. Application timing of harvest aids is critical for producers. Improper application timing may reduce yield and thousand seed weight, but increase herbicide residue in seeds. Therefore, the objective of the harvest aids application timing (% seed moisture) trial was to evaluate the responses of lentil to different herbicide application timings at Saskatoon and Scott, Saskatchewan, over 2 years (2012 and 2013). For this trial, glyphosate (900 g a.e. ha⁻¹), saflufenacil (50 g a.i. ha⁻¹), and the combination of glyphosate plus saflufenacil (900 g a.e. ha⁻¹ and 36 g a.i. ha⁻¹) were applied when seed moisture content was 60%, 50%, 40%, 30% and 20%. Apart from these herbicide treatments, there was also an untreated control, which is desiccated naturally. Significant relationships between evaluated variables and application timing on the basis of seed moisture content were detected. Also, this trial indicated that early application timing (60% application seed moisture) could result in reductions in lentil yield and thousand seed weight. Glyphosate residue in seeds was less than 4 mg kg⁻¹ when glyphosate was applied alone at 30% and 20% average seed moisture. Glyphosate residue decreased when adding saflufenacil to glyphosate. Saflufenacil residue consistently increased with earlier application timing of the harvest aids.

Introduction:

Lentil (*Lens culinaris L.*) belongs to the legume family, and its seeds contain higher protein, carbohydrate, and energy compared to other legume family members (Solanki et al., 2007). Lentil has been considered as a health-conscious diet to improve human health and to lessen risks of illness for a long time (Solanki et al., 2007).

Lentil seed yield, seed quality, and efficiency of harvesting are the main concerns for lentil growers. There might be reductions in seed yield and quality at harvest stage due to uneven maturity caused by its indeterminate habit, the presence of late-season green weeds, or uncertain adverse environmental conditions such as frost (Saskatchewan Pulse Growers, 2011). Also, the efficiency of lentil harvesting can be adversely influenced by immature lentil and green weed plants (Bond and Bollich, 2006; Alberta Pulse Growers, 2013).

Therefore, desiccants have been widely used as harvest aids to improve crop dry down and

shorten harvest interval, which is a period of time between physiological maturity and harvesting stage. Shortening harvest interval can assist in preventing mature pods losses, and improving weed control (Miller et al., 2010). Riethmuller et al. (2005) cited lentil yield was lower without desiccants than that with the aid of a desiccant. Although desiccants can contribute to crop harvest efficiency, their application timing is critical, as the seed yield and quality can be reduced with improper application timing (Bennet and Shaw, 2000; Baig et al., 2003). Furthermore, some studies have shown that applying combined pre-harvest herbicides have better influences on desiccating plants than using specific herbicides alone. Although glyphosate is not a true desiccant, it helps to control wide-spectrum weedy plants. Thus, it is common to see glyphosate was applied with true desiccants to improve weed control. However, the maximum residue levels (MRLs) of glyphosate and saflufenacil can be the big issues for Canadian producers who export lentil seeds to some countries with low MRLs of both herbicides.

Materials and Methods:

Application timing trial was conducted at Saskatoon and Scott, Saskatchewan in 2012 and 2013 to investigate the responses of lentil to three pre-harvest herbicide treatments at a series of five various application timings based on seed moisture content. However, the desiccant timing trial at Scott in 2012 was destroyed due to hail damage. Thus, the data from Scott in 2012 will not be further analyzed. The soil types were silt loam at Saskatoon in 2012 and 2013, and silty loam at Scott in 2013. The pH value and organic matter content were 7.5 and 4.5% at Saskatoon in 2012 and 2013, and 5.3 and 2.6% at Scott in 2013, respectively. Individual plot sizes in the application timing trial at Saskatoon were 2.25 by 6 meters in 2012 and 2013, and 2 by 5 meters at Scott in 2013, respectively.

All plots were set up as a 2-way factorial experiment on a randomized complete block design including a non-treated control (no herbicide) for comparison. The first factor was three herbicide treatments, and the second factor was five different application timings based on seed moisture content. All treatments were replicated four times. CDC Maxim, a small red lentil cultivar, was the only lentil cultivar used in application timing trial and potential new desiccants trials. This cultivar was chosen because it is able to resistant to group 2 herbicides, which are widely used for weed control in Saskatchewan (Saskatchewan Ministry of Agriculture, 2010). The three herbicide treatments evaluated in the timing trials were foliar applied. The details of the herbicides are: glyphosate, saflufenacil and the combination of the two herbicides. Their application timings are listed in Table 1. The application dates are shown in Table 2. The series of herbicides application timings based on seed moisture contents were chosen because glyphosate as a pre-harvest aid is recommended to apply when grain moisture is around 30% or less (Saskatchewan Ministry of Agriculture, 2013).

Before seeding, lentil seeds were inoculated with a Liquid Nodulator application of 2.76ml/kg at Saskatoon in 2012, and with Tag Team Granular at Saskatoon and Scott in 2013. Lentil was drill-seeded with a small plot grain drill on 17 May 2012 and 12 May 2013 at Saskatoon, and on 21 May 2013 at Scott. The target density at Saskatoon in 2012 and 2013 and at Scott in 2013 was 130 plants per square meter with a seeding depth of 3 cm. Prior to pre-harvest applications, some plants from 2 border plots were pulled and bulked to create a composite sample to determine seed moisture content. Three desiccant treatments were applied to lentil with seed moisture

contents of about 60%, 50%, 40%, 30% and 20%, respectively. Crop moisture contents and desiccation visual rating from each plot were recorded at 7, 14 and 21 days after each herbicide application (DAA). Lentil yield, thousand seed weight, harvest seed moisture content, harvest straw moisture content and dockage data were collected at 21 DAA. Harvest straw moisture and dockage data were not investigated at Saskatoon in 2012. Seed samples from each treatment containing glyphosate in the first three replications were sent to ALS labs for maximum residue level (MRL) analysis. Each sample was collected at 7 DAA, and weights over 250 grams for glyphosate residue analysis. Saflufenacil seed residue samples, weighted to 75 grams, were also sent to the laboratory of Dr. Mueller Thomas in the University of Tennessee for saflufenacil residue analysis.

All data were analyzed using the Mixed Procedure (SAS, 2003). Herbicide treatments and application timings were considered as fixed effects, while site-year (environmental effects), replications nested within site-year, and all interactions including either of these factors were regarded as random effects. Since application timing factor based on per cent seed moisture content were quantitative data in the timing trials, they were analyzed using regression. In this trial, type III statistics were used to test all fixed factors. The significances of random effects were analyzed by Z-tests of variance estimate. Proc Univariate and Levenes test were used to test field data for normality and homogenous variance. All treatment factors were compared using LSD method at the 0.05 significance level. Additionally, all letter groupings were done by PDMIX800 macro in SAS (Saxton, 1998).

Table 1 Herbicide treatments and application timings for each herbicide treatment evaluated in timing trials at Saskatoon and Scott, Saskatchewan in 2012 and 2013.

Herbicide	Rate	Application Timing (seed moisture content)
Control		
Glyphosate	900 g AE/ha	60% 50% 40% 30% 20%
Saflufenacil+Merge	50 g AI/ha + 1 L/ha	60% 50% 40% 30% 20%
Glyphosate+Saflufenacil+Merge	36 g AI/ha+900 g AE/ha+0.5 L/ha	60% 50% 40% 30% 20%

Table 2 Dates of application timings for each treatment in timing trials at Saskatoon and Scott, Saskatchewan in 2012 and 2013.

Application timing (seed moisture content)	Saskatoon		Scott	
	2012	2013	2012	2013
60%	August 17	August 9	NA	August 20
50%	August 20	August 14	NA	August 23
40%	August 28	August 16	NA	August 29
30%	August 30	August 19	NA	September 3
20%	September 6	August 23	NA	September 12

NA: not applicable (timing trial at Scott, Saskatchewan in 2012 was destroyed by hail damage)

Results:

Seed yield

For the timing trial conducted at Saskatoon in 2012 and 2013, and Scott 2013, Saskatchewan, yield data were adjusted to 13% harvest moisture based on harvested moisture content. Also, these data were analyzed for investigating site-year effects considered as random factor. After statistical analysis, yield data did not have similar patterns with application seed moisture; then, they were analyzed separately within site-year.

For the yield data of Saskatoon 2012, there was a significant interaction between harvest aid treatment and application timing (Table 3). For glyphosate herbicide, no significant regression of herbicides at various application timings was detected (Figure 1). When using saflufenacil as a harvest aid, quadratic responses of lentil yield were detected (Figure 1). For saflufenacil herbicide, when it was applied between 40% and 30% average seed moisture content, lentil yield could reach its peak point around 3400 kg ha⁻¹ (Figure 1). When applying the tank mix of glyphosate and saflufenacil, a significant linear relationship was observed (Figure 1). Lentil yield decreased with higher seed moisture content for application (Figure 1). At 20% application seed moisture, yield was about 3300 kg ha⁻¹ (Figure 1). Then, the number of yield declined rapidly to 2300 kg ha⁻¹ at 60% application seed moisture (Figure 1). Compared to untreated control, yield was significantly affected by saflufenacil and the tank mixture when it was applied at 60% seed moisture content (Figure 1).

At Saskatoon in 2013, there was no interaction between harvest aid treatment and application timing (Table 3). So yield responses had similar patterns along with application timings. A quadratic relationship between seed yield and application timing was found for harvest aid treatments (Figure 2). Similar to Saskatoon 2013 (Figure 2), harvest aids applied at 60% seed moisture significantly reduced yield compared to control.

At Scott in 2013, application timing had significant effects on yield, but the harvest aid treatment and interaction between harvest aid treatment and application timing were not significant (Table 3). Therefore, yield data were averaged across three herbicides when using regression analysis. There was no significant regression was found for harvest aids at this site-year. Compared with untreated control, yield was not impacted by herbicide treatments at five application timings but 30% seed moisture content. Yield arrived at its lowest point at approximately 2000 kg ha⁻¹ when

herbicides were applied at 30% seed moisture content (Figure 3)

Table 3 P-values derived from analysis of variance illustrating fixed effects for lentil yield and thousand seed weight (TSW) at Saskatoon in 2012 and 2013, and at Scott in 2013.

Source	P values			
	Yield			TSW
	Saskatoon 2012	Saskatoon 2013	Scott 2013	Combined
Herbicide (H)	0.0345*	0.0107*	0.0495	0.7601
Timing (T)	<.0001***	0.0197*	0.0068**	<.0001***
H x T	0.0020**	0.2081	0.8468	0.4289

*, **, *** , significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

^a Thousand-seed weight data were averaged across Saskatoon 2012, Saskatoon 2013, and Scott 2013.

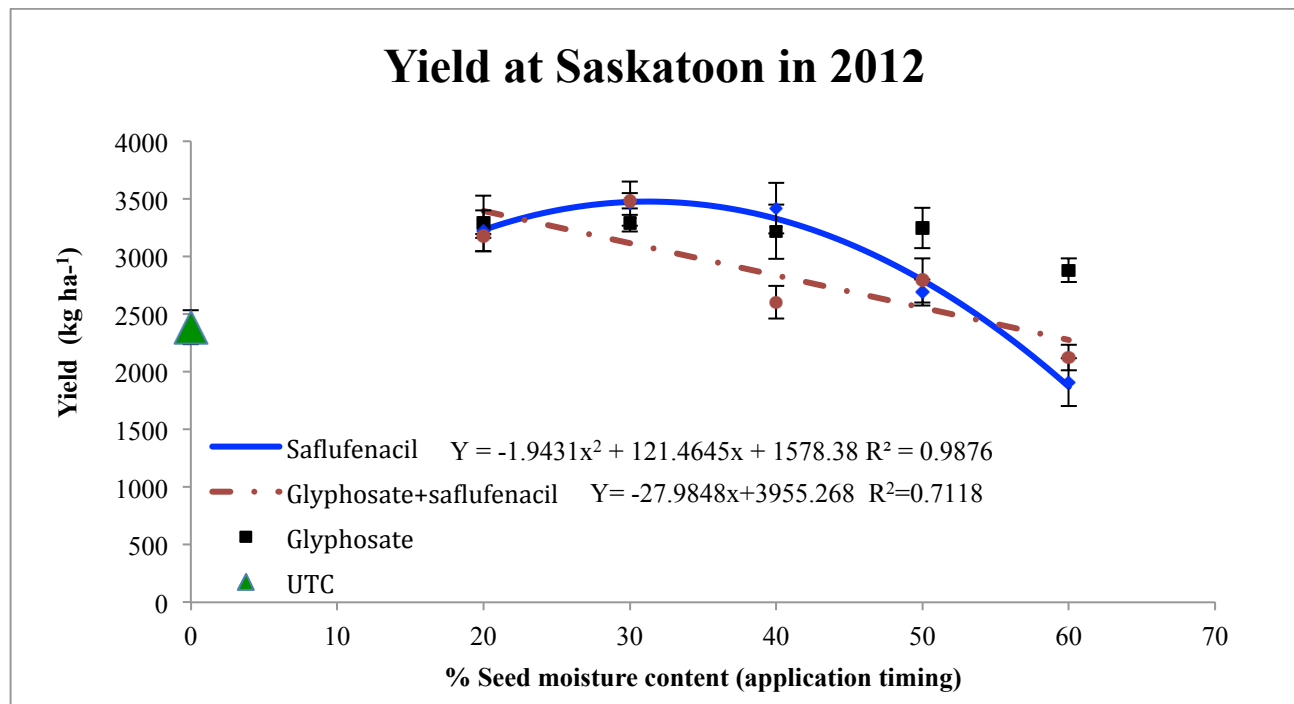


Figure 1 Relationship between yield and application timing (% seed moisture content) for each harvest aid treatment at Saskatoon in 2012. Two regression curves in this chart represent two herbicide treatments (saflufenacil and combination of glyphosate and saflufenacil). No significant relationship was observed for glyphosate.

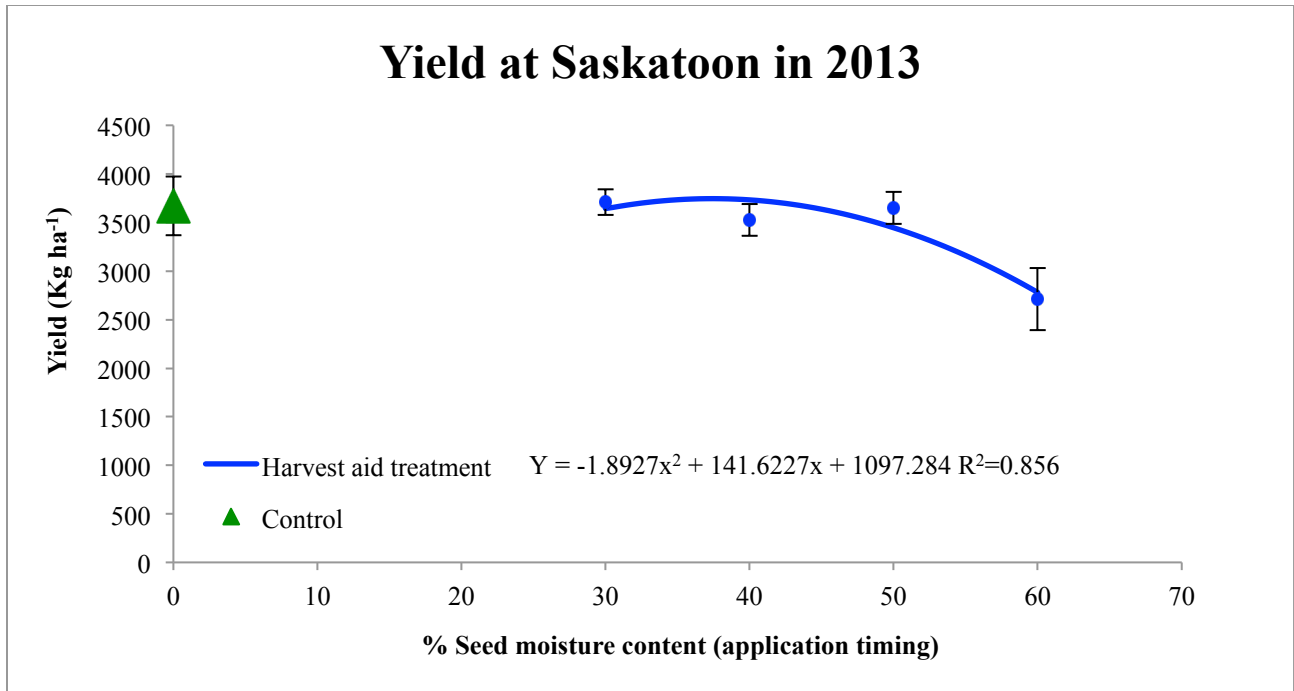


Figure 2 Relationship between yield and application timing (% seed moisture content) at Saskatoon in 2013. Yield data represent a main trend line for herbicide treatments.

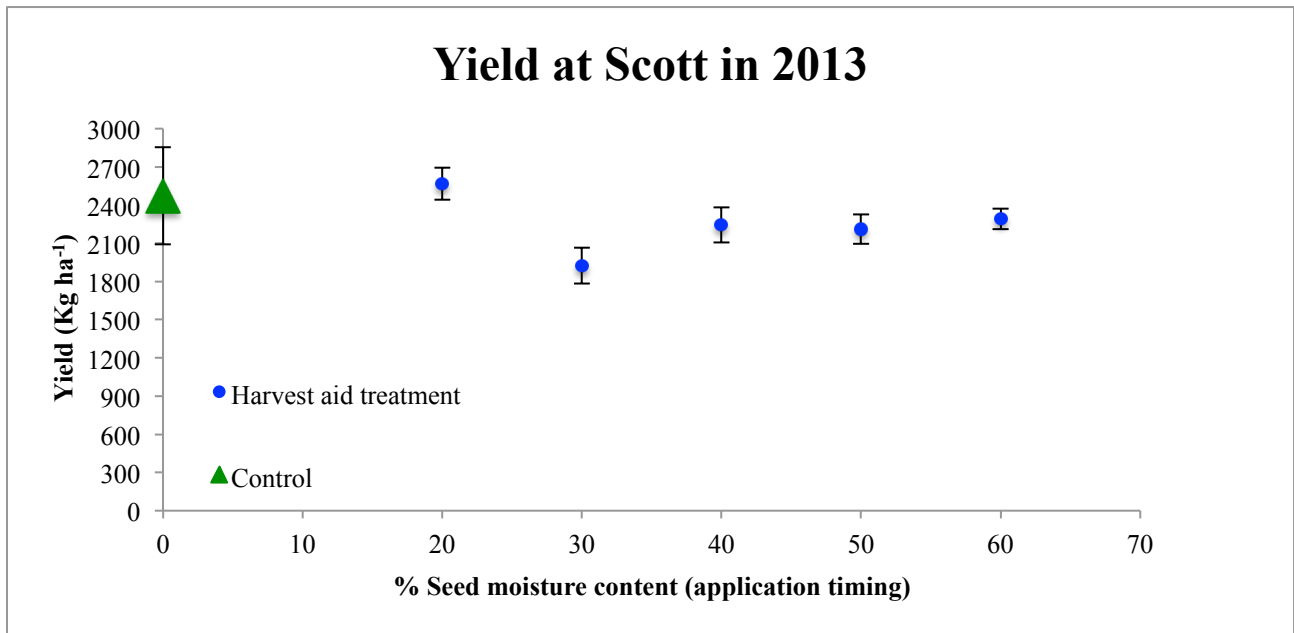


Figure 3 Relationship between yield and application timing (% seed moisture content) for harvest aid treatments at Scott in 2013.

Thousand seed weight

For thousand seed weight data, the interactions between site-year and main treatment factors including herbicide treatments and application timings were not significant. Therefore, all thousand seed weight data were averaged across site-year. As demonstrated in Table 3, thousand seed weight data were not affected by the interaction between application timing and herbicide treatments, nor the herbicide treatments. But they were significantly influenced by application timing (Table 3). So data were averaged across three herbicide treatments when analyzing regression.

Linear response was observed for thousand seed weight data (Figure 4). Apparently, thousand seed weight could reach its highest point at 41 grams when herbicides applied at 20% seed moisture content (Figure 4). Then, there was a straight decreased trend with higher application seed moisture content, reaching the lowest point of 37.5 grams (Figure 4). Additionally, thousand seed weight was adversely influenced by harvest aid treatments compared to control but 20% and 30% seed moisture content (Figure 4).

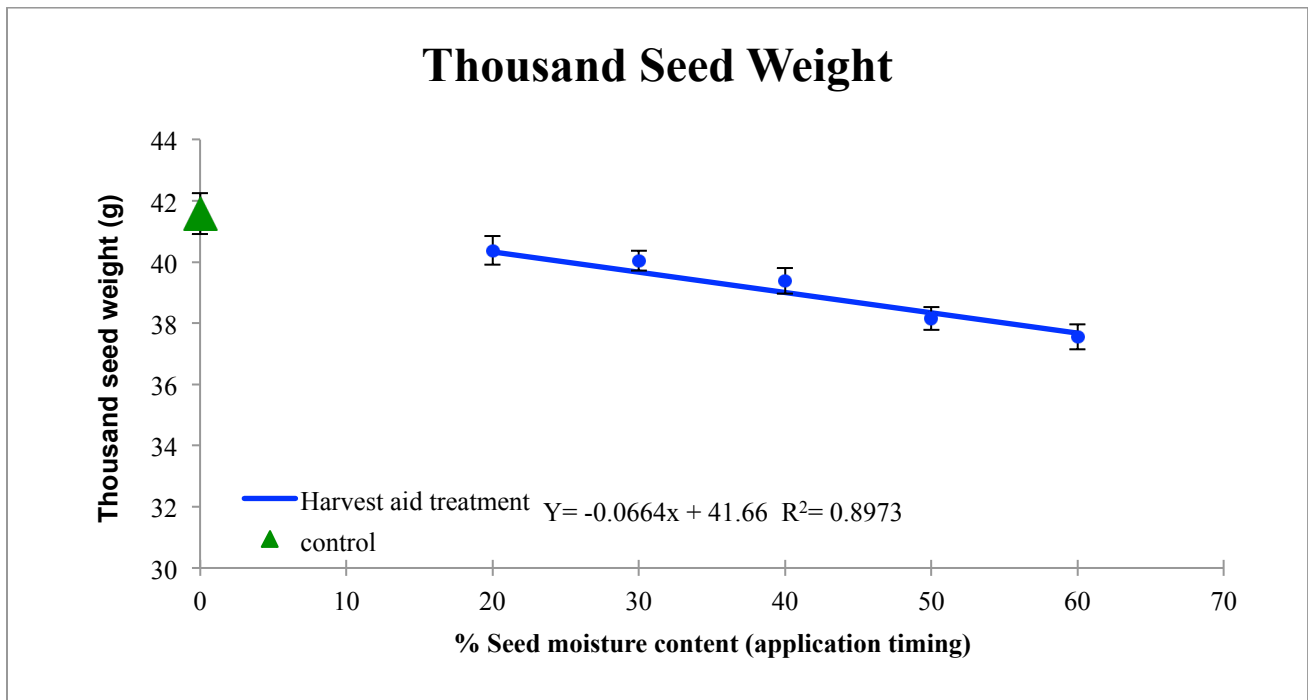


Figure 4 Relationship between thousand seed weight tested by number 10 sieve, and application timing (% seed moisture content). Data were averaged across Saskatoon 2012, Saskatoon 2013, and Scott 2013. Also, data were pooled together across three herbicide treatments

Saflufenacil residue

Saflufenacil residue data were analyzed separately based on site-years because there was a significant difference in saflufenacil residue patterns across three site-years. In order to meet the two basic assumptions for variance analysis, a logarithmical transformation was used in analyzing data from Saskatoon 2012.

For Saskatoon 2012, a significant harvest aid treatment by application timing interaction was not present (Table 4), which means the two harvest aids followed similar patterns with application seed moisture. For both harvest aids, saflufenacil residue increased with higher application timing.

At Saskatoon in 2013, there was a significant interaction between harvest aids and application timing with both treatments having linear relationships between saflufenacil residue and application timing (Figure 6). Again, the higher saflufenacil residue was detected at earlier application timing.

Although saflufenacil residue in lentil seeds increased with higher application seed moisture, all the saflufenacil residue data were less than 0.3 ppm for both years at Saskatoon. Not surprisingly, saflufenacil residue was higher than control due to the fact that no saflufenacil applied to control plots (Figure 5 and 6) at Saskatoon in both 2012 and 2013 (Saflufenacil residue for control was close to zero, so data for control was not shown in figures). Also, saflufenacil residues applied with the combination (glyphosate plus saflufenacil) were almost half less than saflufenacil applied alone (Figure 6) for the two site-years.

For Scott 2013, different results were detected. A significant interaction between harvest aid and application timing was not found (Table 4), nor the significant relationship between herbicide residue and application seed moisture. Saflufenacil residue was only influenced by application timings (Table 4). Saflufenacil residue was much higher at 50% seed moisture than the other four seed moisture contents (Figure 7). Besides, saflufenacil residue treated by tank mixture did not reduce compared to saflufenacil applied alone (Figure 7).

Table 4 P-values derived from analysis of variance illustrating fixed effects for saflufenacil residue and (S_residue) and glyphosate residue (G_residue) in lentil seed at Saskatoon in 2012 and 2013 and at Scott in 2013.

Source	P values					
	S_residue			G_residue		
	Saskatoon 2012	Saskatoon 2013	Scott 2013	Saskatoon 2012	Saskatoon 2013	Scott 2013
Herbicide (H)	<.0001***	0.0025**	0.2509	0.0006***	NA	NA
Timing (T)	<.0001***	0.0003***	<.0001***	<0.0001***	NA	NA
H x T	0.2448	0.0484*	0.6567	0.5151	NA	NA

*, **, *** , significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

^a Thousand-seed weight data were averaged across Saskatoon 2012, Saskatoon 2013, and Scott 2013.

NA: not applicable (timing trial at Scott, Saskatchewan in 2012 was destroyed by hail damage)

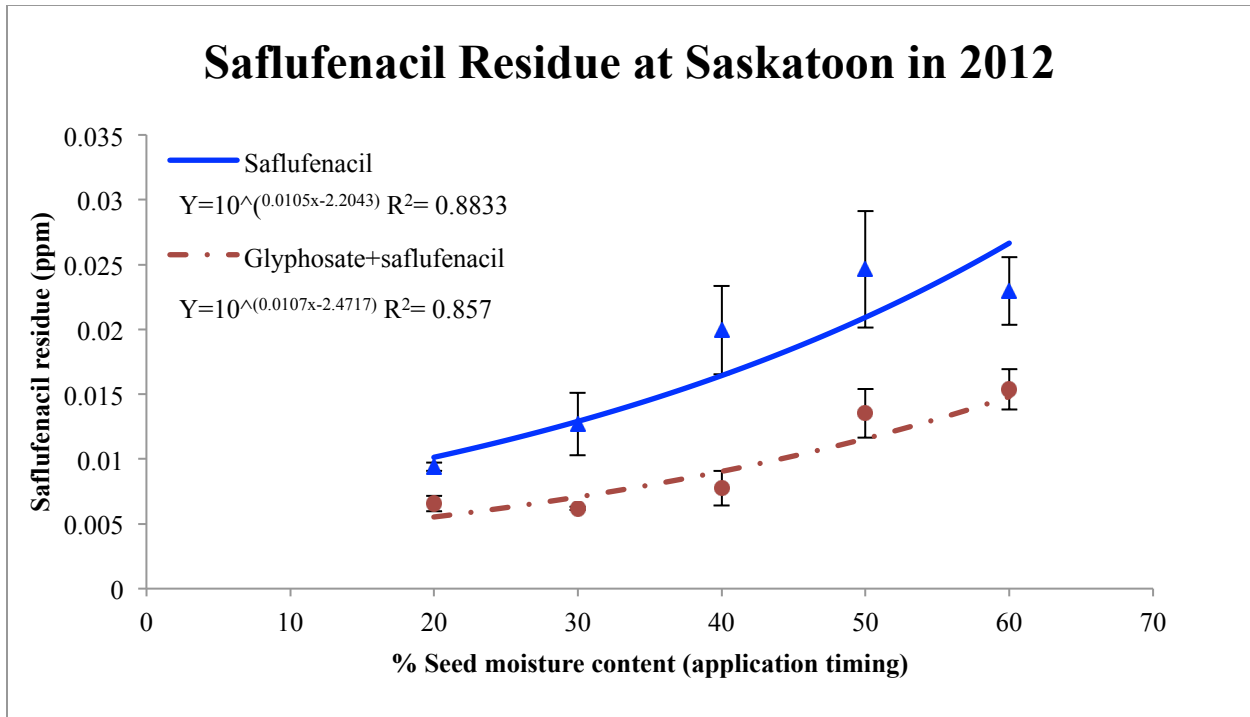


Figure 5 Relationships between saflufenacil residue and application timing (% seed moisture content) for Saskatoon 2012.

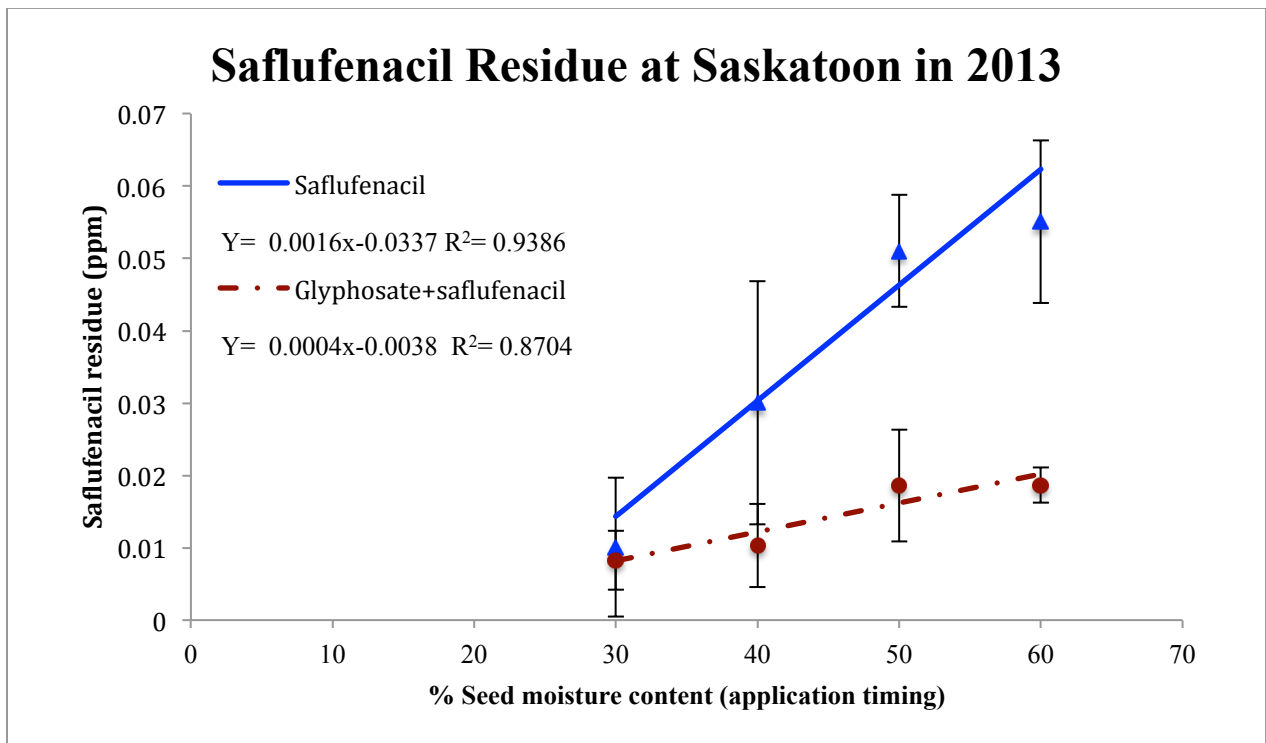


Figure 6 Relationships between saflufenacil residue and application timing (% seed moisture content) for Saskatoon 2013.

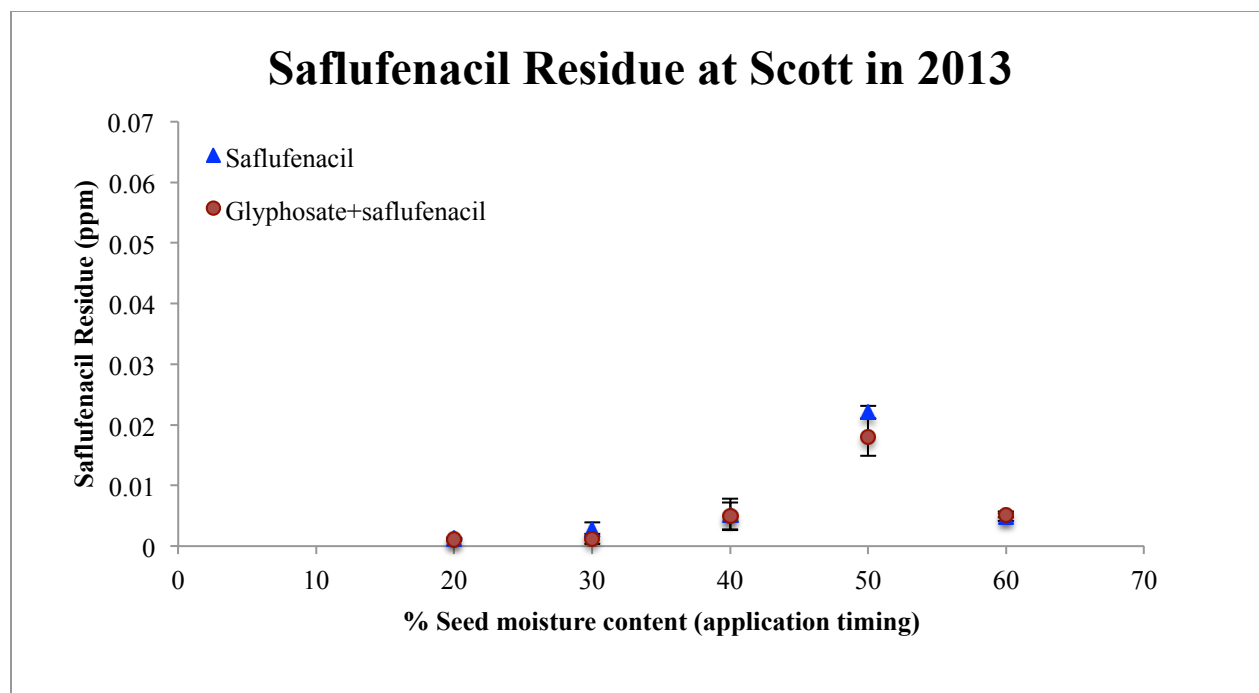


Figure 7 Relationships between saflufenacil residue and application timing (% seed moisture content) for Scott 2013.

Glyphosate residue

Seed samples treated with glyphosate residue at the first three replications were sent to ALS lab for herbicide residue test. To fulfill the two assumptions of variance analysis, glyphosate residue data were transformed logarithmically at Saskatoon in 2012. The interaction between herbicide treatments and application timing was not significant. A significant linear relationship between glyphosate residue on a logarithmic scale and application timing was observed (Figure 8). Glyphosate residue increased constantly with higher application seed moisture (Figure 8). According to the results, glyphosate residue would not go over 4 ppm until application seed moisture equal or more than 40% for both harvest aid treatments. When the harvest aids were applied at around 25% seed moisture content, glyphosate residue was less than 2 ppm. What is more, glyphosate residue significantly decreased when applied tank mixture (Figure 8).

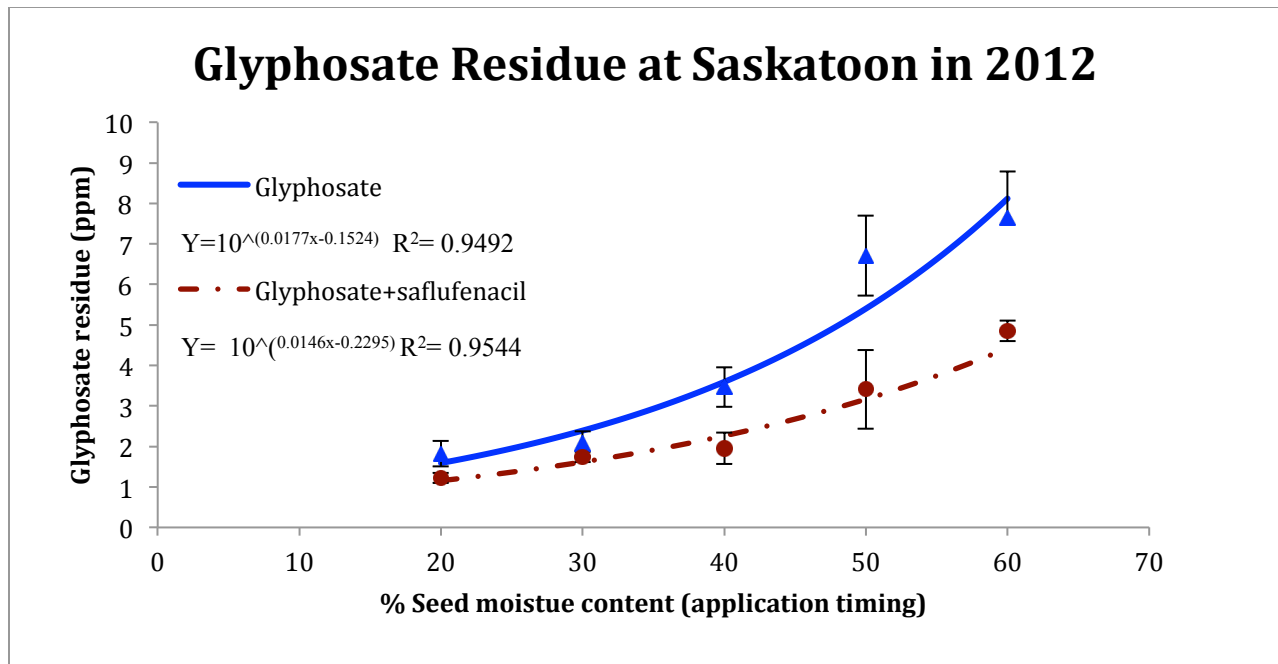


Figure 8 Relationships between glyphosate residue and application timing (% seed moisture content) at Saskatoon in 2012.

2.7 Discussion:

Saskatoon 2012 and Saskatoon 2013 had similar yield results (Figure 1 and Figure 2). Lower yield was found when application seed moisture content ranged from approximately 55% to 60% compared to control (Figure 1 and Figure 2). These results indicated that some young lentil pod had not reached their physiological maturity when the harvest aids applied at early application timing. Similar results show that too early an application timing (ranging from 60% to 50% application seed moisture content) can reduced crop yield due to fewer crop seeds getting chance to become mature were also reported in rice and soybean (Bond and Bollich, 2007; Griffin and Boudreaux, 2011).

At Scott in 2013, yield was not affected by harvest aids treatments (Figure 4). No significant regression was detected. At 30% application seed moisture, yield data were lower than the other application timings, which was different from results at Saskatoon (2012 and 2013). This could be resulted from high relative humidity (RH) application conditions. Lentil cannot tolerate high moisture conditions (Saskatchewan Pulse Growers, 2011). So high RH at 30% application timing might make lentil become more susceptible to herbicide treatments, resulting in yield reductions compared to other application timings. These results demonstrated that both application timing and environmental conditions for herbicide application were critical. For lentil growers, warm and moderate moist conditions are good to spray harvest aids (Saskatchewan Ministry of Agriculture, 2013).

Apparently, compared to control, thousand seed weight was badly affected when using harvest aid treatments at 50% and 60% application timings. As mentioned above, young pods might have

not entered the maturity stage when harvest aids were applied at these timings. So, for these immature lentil pods, they had less time at seed development, leading to the decreased thousand-seed weight. Griffin and Boundreau (2011) also found seed weight reductions with 50% and 60% application seed moistures.

Saflufenacil possessed xylem mobility in plant and can destroy plant phloem quickly (Hall and Ashigh, 2010), and its residue can be found in lentil seeds in this field study. Saflufenacil residue in lentil seeds decreased with delayed harvest aid application at Saskatoon in both 2012 and 2013 years (Figure 5 and Figure 6). As was expected, lower herbicide residue was also observed when using tank mix treatment (Figure 5 and Figure 6), because the rate of saflufenacil applied alone (50 g ai ha^{-1}) is higher than that in tank mixture (36 g ai ha^{-1}). However, different responses of saflufenacil residue to harvest aids were detected at Scott in 2013. 50% application timing had the highest herbicide residue among all timings. The climate data showed that the temperature at 50% was higher than the other timings (Government of Canada, 2013). The activity of saflufenacil herbicide might be limited by the low temperature environment conditions. Lower saflufenacil residue was detected at the other four application seed moistures but not the 50% application timing. Some countries have maximum residue limit (MRL) for saflufenacil. These MRL values vary in countries. So far, for lentil, the international codex of MRL is 0.3 ppm (FAS online, 2014). Based on the three site-years data, all treatments will not make high saflufenacil residue than 0.3 ppm.

For glyphosate residue results, at Saskatoon in 2012. The data of glyphosate residue demonstrated that earlier application might result in higher glyphosate residue in lentil seed. Glyphosate is a systemic herbicide, which translocates slowly in phloem and move with nutrients to seed during (Government of Alberta, 2009). At early stage of lentil seed development, a lot of organic nutrients will be sent to seeds (Government of Alberta, 2009). Therefore, more glyphosate will enter seeds with other nutrients when harvest aid treatment applied too early. Less glyphosate residue was detected in combination treatment compared with glyphosate applied alone (Figure 8). As mentioned previously, saflufenacil, as a contact like herbicide, can destroy plant phloem where glyphosate translocates. So glyphosate has fewer chances to go up through phloem and enter lentil seeds when tank mixed with saflufenacil. Similar results were observed by Hall and Ashigh (2010) on buckwheat, cabbage and canola. As mentioned previously, high glyphosate herbicide in lentil seeds may result in commercial issue. The MRLs in Canada is 4 ppm which is lower than that in United State (8 ppm), European countries (10 ppm) (Fasonline, 2014). For some countries, which have not set MRLs for lentil will follow international codex (5 ppm) (Fasonline, 2014). But MRL is 2 ppm in Japan (Fasonline, 2014). According to the one site-year data, around 25% application seed moisture did not cause huge damage on seed yield and quality depending on the three site-years data. But the label of the three herbicides state 30% seed moisture content is safe to apply these harvest aids (Saskatchewan Ministry of Agricultural, 2013).

Reference:

- Alberta Pulse Growers, 2013. Swathing and desiccating your lentils. Accessed from: <http://www.pulse.ab.ca/producers/varieties-management/lentils/swathing-desiccation/>
- Baig, M.N., Darwent, A.L., Harker, K.N., O'Donovan, J.T., 2003. Preharvest applications of glyphosate affect emergence and seedling growth of field pea (*Pisum sativum*). *Weed Technol.* 17, 655–665.
- Bennett, A.C., Shaw, D.R., 2000. Effect of preharvest desiccants on group IV Glycine max seed viability. *Weed Sci.* 48, 426–430.
- Bond J. A. and Bollich P. K. 2006. Effects of pre-harvest desiccants on rice yield and quality. *ScienceDirect Crop Production* 26 (2007) 490-494
- Fasonline. 2014. Pesticide MRL Database. Accessed from: <http://www.mrldatabase.com/results.cfm>
- Government of Canada, Daily data report for August 2013. Accessed from: http://climate.weather.gc.ca/climateData/dailydata_e.html?timeframe=2&Prov=SASK&StationID=3259&dlyRange=1911-05-01|2014-03-16&Year=2013&Month=8&Day=01
- Griffin J. L. and Boudreaux J. M. 2011. Application timing of harvest aid herbicides affects soybean harvest and yield. *Weed technology* 25:38-43.
- Hall J. C. and Ashigh J. 2012, Bases for interaction between saflufenacil and glyphosate in plant. *J. Agric. Food Chem.* 58: 7335-7343.
- Miller D.K., Griffin J.L. and Boudreaux J. M. 2010. Herbicides as Harvest Aids. *Weed Science* 58:355–358
- Riethmuller G. et al., 2005. Successful Lentil Harvesting. Agriculture Western Australia. Accessed from: http://www.agric.wa.gov.au/objtwr/imported_assets/content/fcp/lp/lent/cp/f09999.pdf
- Pulse Canada. 2014. Lentil (*Lens culinaris*). Accessed from: <http://www.pulsecanada.com/about-us/what-is-a-pulse/lentil>
- Saskatchewan Ministry of Agriculture. 2010. Lentils in Saskatchewan. Accessed from: <http://www.agriculture.gov.sk.ca/Default.aspx?DN=c5993bcc-009f-4031-b936-c52c992b9e7d>
- Saskatchewan Ministry of Agriculture, 2013. Guide to Crop Protection
- Saskatchewan Pulse Growers, 2011. Lentil Production Manual.
- [SAS] Statistical Analysis Systems. 2003. SAS 9..1. Cary, NC: SAS Institute.

Saston, A. M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed.

Solanki, I.S., Yadav, S.S. and Bahl, P.S. (2007) Varietal adaptation, participatory breeding and plant type. In: Yadav, S.S., McNeil, D.L. and Stevenson, P.C. (eds) *Lentil: an Ancient Crop for Modern Times*. Springer, Dordrecht, The Netherlands, pp. 255–274.