# Integration of cultural weed control enhances weed control in organic cropping systems

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## Introduction

Modern agriculture depends on the use of synthetic herbicides to control weeds. Alternative farming strategies are being developed due to increase risk of overuse of synthetic  pesticides and fertilizers and their effect on the environment (Mason et al. 2007b). Organic farming is one form of sustainable agriculture where crop production occurs without the use of synthetic inputs such as fertilizers and pesticides. Of all the organic field crops grown in Canada, oat has the second highest acreage next to wheat. Saskatchewan has the largest organic crop production in Canada accounting for 54% of cultivated organic land (Canadian Organic Growers 2010). Due to many challenges, organic crop production is less attractive among farmers. The low grain yields compared to conventional systems (Kitchen et al. 2003; Ryan et al. 2004) can be the main reason for low adoption of organic crop production. The greater abundance of weeds compared to conventional systems (Leeson et al. 2000; Entz et al. 2001), and lack of efficient weed control strategies (Leeson et al. 2000; Bond and Grundy 2001; Entz et al. 2001) may be responsible for low yields.

In sustainable weed management, an ideal weed management system should minimize weed emergence, reduce growth and fecundity, and finally minimize crop interference (Lovette and Knights 1996; Blackshaw 2008). Therefore, in organic cropping systems, the weed management tactics consist of long term strategies such as crop rotations, cover crops, green manure crops as well as short term cultural and mechanical weed management strategies such as high density planting, growing competitive genotypes, narrow row planting, harrowing, and hoeing.

The primary goal of cultural weed control is to reduce weed competition through the enhancement of crop CA (Melander et al. 2005). Crop competitive ability can be enhanced by numerous cultural methods, such as competitive genotypes (Lemerle et al. 1996; Mason et al.

2007a), narrow crop row spacing (Koscelny et al. 1990; Fanadzo et al. 2007) and high crop seeding rates (O'Donovan et al. 1999; Olsen et al. 2004). Mechanical weed control reduces the weed density and weed biomass and thereby provides a competitive advantage for the crop. In-crop mechanical weed control such as harrowing and hoeing are the most widely used direct weed control methods in organic crop production (Rasmussen 2004). Specifically, post-emergence harrowing is effective in controlling weeds in cereals (Kirkland 1995; Velykis 2009).

Multi-tactic approaches that prevent weed seed germination, enhance crop competition and control weeds can be more important than single tactics (Rasmussen et al. 2000). Therefore, integration of cultural and mechanical weed control methods is valuable as it provides both preventive and therapeutic measures in weed management (Jordan 1993). Post-emergence harrowing provided better results when it was a part of a weed management system that included cultural weed control methods such as fertilizer management, high seeding rate, and competitive crop genotypes (Melander et al. 2005). Combining competitive genotypes with high seeding rates and early weed removal reduced weed biomass and increased yield by 41% (Harker et al. 2003). Similarly, Anderson (2005) reported the use of narrow row spacing, increased plant density and delayed planting in sunflower reduced weed biomass by only 5-10% when used individually. When two and three of these practices were combined, weed biomass was reduced by 20-25%, and up to 90%, respectively.

Combining several weed control strategies may not always provide additive weed control as they may interact with each other. In spring wheat, genotypes that have greater CA at low crop densities may not be competitive when seeded at high densities (Weiner et al. 2001). Similarly, the effect of narrow row planting on weed biomass in wheat was reduced at high crop density (Olsen et al. 2004). Furthermore, the effectiveness of each cultural method and their additive or synergistic effect varies depending on the growing environmental conditions (O'Donavan et al. 1999; Rasmussen et al. 2009).

Most of the attempts to integrate weed control tactics were done in conventional cropping systems with herbicides as a weed control option (Harker et al. 2003; Anderson 2005; Harker et al. 2009). The interactions and additive effects from combining cultural and mechanical weed control methods are less known in organic cropping systems. Therefore, this study hypothesise that integrating cultural and mechanical weed control strategies could enhance the crop CA and thereby enhance the weed control in organic cropping systems. The objective of this study was to determine the individual and combined effect of crop genotype, crop density, row spacing and post-emergence harrowing on weed biomass, weed density as well as crop yield under organic conditions. To do this we used organic oat production as a model system.

## Materials and methods

### Experimental design and location

Field experiments were carried out at two locations; the Kernen Research Farm (52° 09' N, 106° 33' W) Saskatoon, SK, and Vonda Commercial Organic Farm (52° 19' N, 106° 05' W) near Vonda SK. The Kernen and Vonda farms were under organic management for 19 and 14 years respectively. Both sites have black clay loam soil.

The experiment was a factorial design with four levels (oat genotype, crop density, row spacing and post-emergence harrowing), each having two treatments. The field layout was a randomized complete block design with four replicates and a plot size of 4 x 6 m. The oat genotypes were Ronald (Mitchell et al. 2003) and CDC Baler (Rossnagel and Scoles 1998). Ronald is a high yielding semi-dwarf type oat genotype expected to be low in competitive ability. CDC Baler is a tall broad leaved genotype expected to be competitive (Wildeman 2004). The two crop densities used were 250 plants $m^{-2}$ (recommended) and 500 plants $m^{-2}$ (2X recommended). The two row spacings were 11.5 cm (narrow) and 23 cm (standard). The mechanical weed control treatment was post-emergence harrowing and a non-harrowed control.

### Experimental procedure

Oat seed was obtained from Crop Development Center Saskatchewan. The seeding rates were calculated based on the targeted planting density by using thousand kernel weight, germination percentage, and estimated mortality (5%) for each genotype. The seeding was done on 21$^{st}$ May in Vonda and 23$^{rd}$ May in Kernen 2008. In 2009, Vonda was seeded on May 11$^{th}$ and Kernen was seeded on 18$^{th}$ May.

The post-emergence harrowing treatment was applied when oat seedlings were at 2-3 leaf stage. An Einbock spring tine weed harrower (Einbock) with 7 mm x 490 mm long tines and 4 m overall width was used, and one pass was done over the selected plots. At locations with high weed density, two passes were carried out sequentially. Plant counts were taken for crop and weeds at the 2-3 leaf stage of the crop. A 0.25$m^2$ quadrat was placed in random positions on both the front and back of each plot. Quadrats were placed parallel to the crop row to include three crop rows within the quadrat. The number of weeds within the quadrat was recorded by species.

Oat shoot biomass and weed shoot biomass were taken using 0.25 $m^2$ quadrat from both the front and back of every plot at the soft dough stage (Zadoks 85). The samples were oven dried in paper bags for 48 hours at 60 $^{o}$C. At maturity (Zadoks 90), the crop was harvested using a plot combine harvester with 1.6m width. Length of the harvested plot was reduced to 6 m and edges of either side of the plot were kept un-harvested to reduce the edge effect. The harvested grains were air dried for 2-3 days until a constant moisture condition was obtained. Each harvested grain sample was cleaned using a dockage tester (Carter Day International, Inc.). The cleaned samples were weighed and yield per plot was recorded. A 1 kg of sample was taken and stored in paper bags for subsequent quality evaluation.

Grain quality parameters such as test weight, thousand kernel weight, percentage of thin kernels and percentage of plump kernels were determined using the 400 g sub-sample. Thousand kernel weight was measured by weighing 200 seeds and multiplying by five. The test weight was determined by the specifications of the Canadian Grain Commission's Official Grain Grading Guide (2009). The percentage of plump kernels was determined by the proportion of grain sample retained after sieving through a slotted sieve of 2.15 mm x 8.33 mm, and the thins were that proportion passed through a 1.95 mm x 8.33 mm sieve.

## Data analysis

All the data for the four site-years were combined, and analysis of all the data was performed using Analysis of Variance (ANOVA) with SAS Mixed models (SAS Institute Inc., 2008). The treatments were considered as fixed effect while replicates (blocks) and environment (site-year) and all the site-year by treatment interactions were considered random. The non-significant covariance parameters were eliminated from the model according to AIC values for better model fit (Littell et al. 2005). Preliminary analysis of variance indicated a high degree of variation in naturally occurring weeds in Vonda 2008. A spatial covariance analysis was done when the data were analyzed by site-year, to eliminate the spatial variability of weed density in Vonda 2008. Before the analysis, data were log and square root transformed based on the Levenes test for homogeneity of variance and inspecting residuals. Means were separated using Fisher's protected Least Significant Difference (LSD) at $P < 0.05$.

## Results and Discussion

### Grain yield

There was no significant genotype effect on grain yield ($P > 0.05$) (Table 1), indicating that there was no difference between CDC Baler and Ronald. These results mirror those observed in chapter 3 as CDC Baler and Ronald had similar grain yield. However, the average grain yield varied from a high of 4540 kg ha$^{-1}$ at Kernen 2008 and to a low of 1380 kg ha$^{-1}$ at Vonda in 2008. The low weed density at Kernen in 2008 and the high weed density at Vonda in 2008 is probably the main reason for the yield difference.

Increasing the crop density increased the grain yield ($P < 0.01$) (Table 1). Oat planted at higher crop density (500 plants m$^{-2}$) had an 11% yield increase compared to normal crop density (250 plants m$^{-2}$) (Figure 1). Similarly, May et al. (2009) found that increasing oat seeding rate from 150 seeds m$^{2}$ to 350 seeds m$^{2}$ increased oat grain yield. Mason et al. (2007a) observed a similar yield increase by doubling the seeding rate in organic wheat and barley. Crop density did not interact with other cultural practices; thus, increasing crop density always increased grain yield independent of other treatments used in this study. In general, increased seeding rate is often associated with increase in grain yield in most cereals such as wheat (Lemerle 2004), barley (Barton et al. 1992) and oat (Peltonen-Sainio and Jarvinen 1995) in conventional cropping systems.

There was no row spacing effect observed for grain yield (*P* = 0.18) indicating that reducing crop row spacing from 23 cm to 11.5 cm does not increase grain yield. Previous studies suggest that reduction in row spacing had no effect on grain yield (Kolb et al. 2010), had an inconsistent effect (Puricelli et al. 2003), or resulted in reduced grain yield (Fanadzo et al. 2007).

**TABLE 1** ANOVA for grain yield, oat biomass, weed density and weed biomass as affected by genotype (G), crop density (CD), spacing (SP), and harrowing (H) assessed in Kernen and Vonda in 2008 and 2009.

| Source | Yield‡ | Oat Biomass | Weed Density§ | Weed Biomass‡ |
|---|---|---|---|---|
| | kg ha$^{-1}$ | kg ha$^{-1}$ | Plants m$^{-2}$ | kg ha$^{-1}$ |
| Genotype (G) | 0.4665 | 0.0988† | 0.7607 | 0.0452* |
| Crop Density (CD) | 0.0104* | 0.0225* | 0.2387 | <.0001*** |
| Spacing (SP) | 0.1827 | 0.2427 | 0.6558 | 0.1713 |
| Harrowing (H) | 0.0028** | 0.155 | 0.1301 | 0.4516 |
| G x CD | 0.9406 | 0.9357 | 0.2052 | 0.9645 |
| G x SP | 0.4588 | 0.1875 | 0.3332 | 0.1103 |
| CD x SP | 0.3287 | 0.4165 | 0.3265 | 0.7706 |
| SP x H | 0.3324 | 0.1713 | 0.0253* | 0.1643 |
| G x H | 0.7981 | 0.2304 | 0.6924 | 0.8537 |
| CD x H | 0.6149 | 0.8118 | 0.2835 | 0.0952† |
| G x CD x H | 0.8485 | 0.4868 | 0.7158 | 0.6059 |
| G x CD x SP | 0.2086 | 0.4548 | 0.8572 | 0.997 |
| G x SP x H | 0.9595 | 0.5151 | 0.763 | 0.9841 |
| CD x SP x H | 0.7455 | 0.4293 | 0.9121 | 0.9155 |
| G x CD x SP x H | 0.9938 | 0.766 | 0.257 | 0.2359 |

*,**,***, denote significant at the 0.05,0.01,0.001 probability levels respectively.
† denotes significant at 0.1 level.
‡ Data were square root transformed for analysis.
§ Data were $\log_{10}$ transformed for analysis.

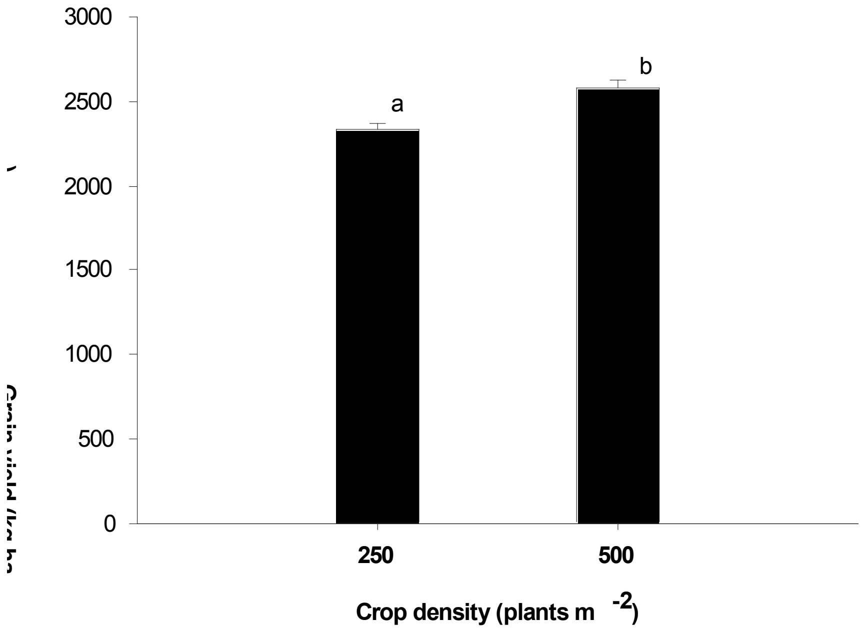


**FIGURE 1** Effect of crop density on grain yield assessed in Kernen and Vonda in 2008 and 2009. Least squares means are back transformed. Error bars represent the standard errors of the least squares mean. Comparisons made between treatments with similar letters indicating no significant difference at LSD $_{0.05.}$

Post-emergence harrowing resulted in 13% increase in grain yield compared to the non-harrowed treatment (Figure 2). However, previous studies have revealed no consistent yield increase in cereals with harrowing (Rasmussen and Svenningsen 1995; Rydberg 1994). Yield advantage of harrowing can be obtained if the predominant weed is sensitive to harrowing, weed density is high and the application is timely (Mohler 2001). In the present study, the yield advantage observed could be due to high weed density and timely application.

Despite the individual effect of harrowing and high crop density, combining these two cultural strategies were able to increase the grain yield up to 25%; thus, indicate that these two cultural practices are additive in nature to enhance grain yield.

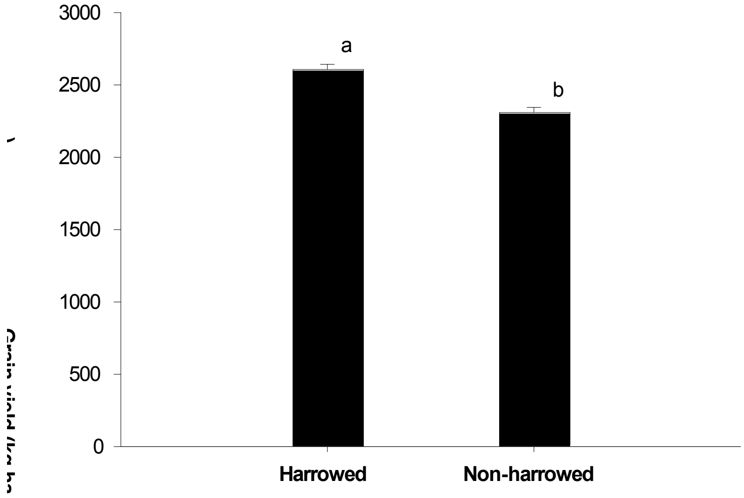


**FIGURE 2** Effect of harrowing on grain yield assessed in Kernen and Vonda in 2008 and 2009. Least squares means are back transformed. Error bars represent the standard errors of the least squares mean. Comparisons made between treatments with similar letters indicating no significant difference at LSD $_{0.05}$.

### Weed density

Harrowing was effective at reducing weed density at sites with high weed densities. Even though there were no site-year by harrowing interaction, data analyzed within site-years clearly suggests that harrowing was highly effective ($P < 0.001$) in reducing weed density among 3 site-years out of 4 (Figure 3).

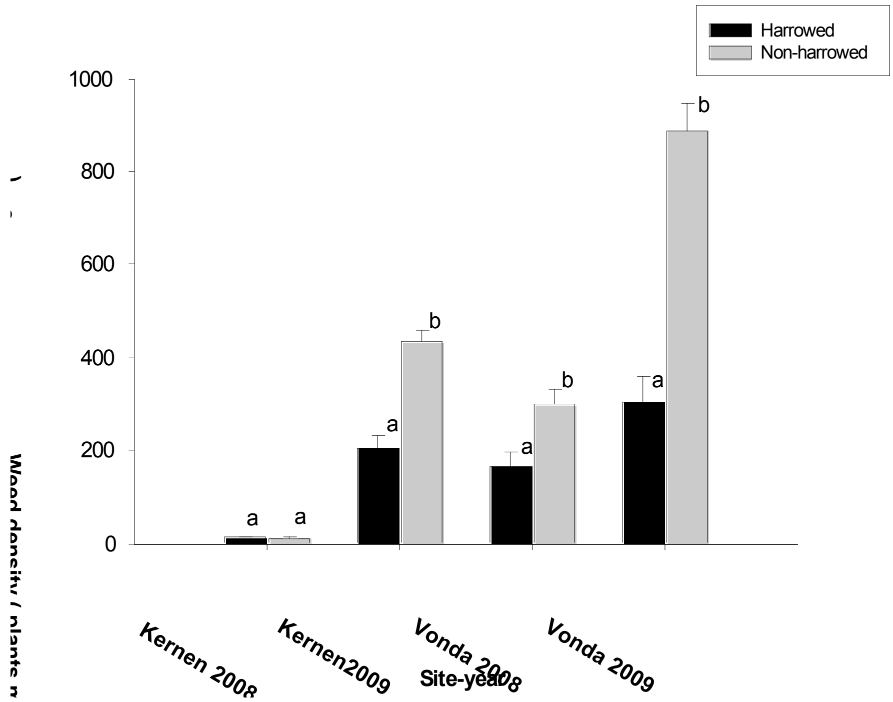


**FIGURE 3** Effect of harrowing on weed density assessed in each individual site-year. Error bars represent the standard errors of the least squares mean. Comparisons made between treatments with similar letters indicating no significant difference at LSD $_{0.05.}$

### 4.3.5 Weed biomass

CDC Baler had less weed biomass ($P < 0.05$) than Ronald (Figure 4) and therefore can be considered to be more competitive than Ronald. The higher competitive ability of CDC Baler could be due to plant height and higher crop biomass compared to Ronald. Genotype differences in competitive ability have often identified in conventional cropping systems (Lemerle et al. 1996; Watson et al. 2006). However, competitive genotypes in conventional systems not often tested under organic conditions. The results indicated that genotype competitive ability does not depend on the other cultural practices used as there was no interaction with genotype and other treatments (Table 1).

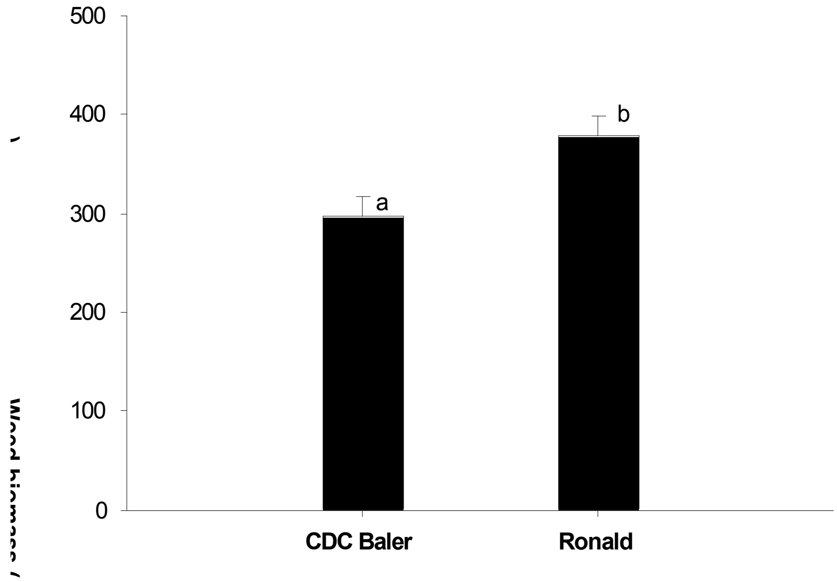


**FIGURE 4** Effect of oat genotype on weed biomass assessed in Kernen and Vonda in 2008 and 2009. Least squares means are back transformed. Error bars represent the standard errors of the least squares mean. Comparisons made between treatments with similar letters indicating no significant difference at LSD $_{0.05.}$

Increasing crop density to 500 plants m$^{-2}$ reduced weed biomass by 52% compared to 250 plants m$^{-2}$ (Figure 5). Similarly, in organically grown wheat and barley, doubling the seeding rate reduced weed biomass by 28% (Mason et al. 2007a). In the present study, doubling the crop density found to be more effective than growing competitive genotypes. This is in accordance with many other studies which revealed greater weed biomass reduction by increasing the crop density compared to other cultural practices (Scursoni and Satorre 2005; Chengci chen et al. 2008; Mason et al. 2007b). Furthermore, crop density and crop genotype were additive in nature as the combination of competitive genotype (CDC Baler) with high cropping density (500 plants m$^{-2}$) could reduce weed biomass by 63% compared to a non-competitive genotype (Ronald) with standard cropping density (250 plants m$^{-2}$).

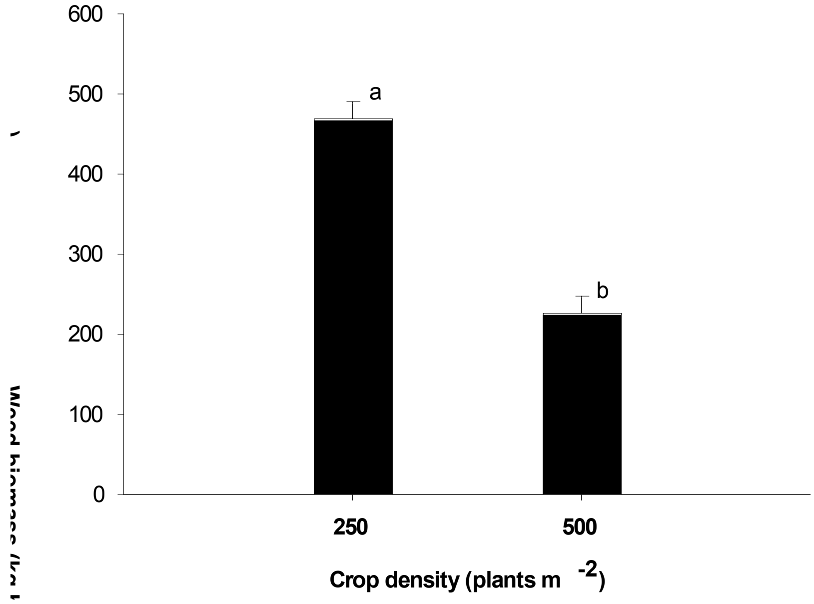


**FIGURE 5** Effect of crop density on weed biomass assessed in Kernen and Vonda in 2008 and 2009. Least squares means are back transformed. Error bars represent the standard errors of the least squares mean. Comparisons made between treatments with similar letters indicating no significant difference at LSD $_{0.05.}$

There was a significant (*P* = 0.09) crop density by harrowing interaction for weed biomass. Harrowing for weed management was most effective when oat was planted at higher densities. The lowest weed biomass were observed when harrowing was done to the crop planted with 500 plants $m^{-2}$ density treatment (Figure 4). Similarly, studies of Rasmussen and Rasmussen (2000) revealed significant weed biomass reduction by harrowing.

There was 65% less weed biomass in harrowed high crop density treatment compared to that of non-harrowed low density treatment. This interaction highlights the importance of combining the two cultural practices. Moreover, the combination of competitive genotype, high crop density and post-emergence weed harrowing was able to reduce weed biomass by 71 % which was far greater than their individual effects.

### 4.6 Conclusions

In organic cropping systems, weed control using cultural and mechanical practices are highly effective. Increasing the cropping density from 250 plants $m^{-2}$ to 500 plants $m^{-2}$ and post-emergence weed harrowing was able to increase oat grain yield. Genotype and row spacing did not affect grain yield. However, the competitive genotype, CDC Baler was able to suppress weeds better than Ronald. Increasing the crop density was the most effective individual strategy for greater weed suppression and increased grain yield. No negative interactions were observed when cultural and mechanical weed control tactics when combined; thus most of them were additive in nature. When high crop density, competitive genotype and post-emergence harrowing were combined, weed biomass was reduced by 71%. Similarly, grain yield was increased by 25%, when high crop density and harrowing was combined. Therefore, these results clearly indicate the importance of combining several cultural and mechanical weed control strategies than using them alone for better yield and greater weed suppression.

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