Renewable Agriculture and Food Systems: 31(3); 185–190 doi:10.1017/S1742170515000022

Suppressing weed growth after wheat harvest with underseeded red clover in organic farming

Randy L. Anderson*

USDA-ARS, Brookings, 57006 South Dakota, USA.
*Corresponding author: randy.anderson@ars.usda.gov

Accepted 31 December 2014; First published online 5 March 2015 **Research Paper**

Abstract

Organic producers are seeking alternative tactics for weed control so that they can reduce their need for tillage. In this study, we examined cover crop strategies for suppressing weed growth after harvest of wheat. Three cover crop treatments, red clover (mammoth type), a mixture of oat and dry pea, and a control were compared. Treatments were established in both winter and spring wheat, resulting in six treatments arranged in a randomized complete block design. Red clover was underseeded in wheat by drilling in the spring, and the oat/pea mixture was planted in August. Oat was planted uniformly across all treatments in the following growing season. The red clover treatment effectively suppressed weeds, reducing post-harvest weed biomass, density of volunteer winter wheat, and seed production of downy brome by more than 99% compared with the control. Oat/pea was not effective for weed management, likely because of less fall growth and competition compared with red clover. Underseeding red clover did not affect winter wheat yield, but reduced spring wheat yield by 17%. Oat yield, however, was reduced by volunteer crop plants and downy brome infestations in all treatments. Underseeding clovers in winter wheat may effectively manage weeds and, if they winterkill, can replace the need for tillage to control weeds after wheat harvest.

Key words: cover crops, cultural tactics, downy brome, no-till, weed biomass

Introduction

In conventional agriculture, producers are restoring soil health with no-till systems[1]. No-till increases organic matter levels, improves soil structure and minimizes erosion[1,2]. Furthermore, microbial activity and resource-use-efficiency increase with no-till[2,3]. Hobbs[3] noted that integrating no-till with crop diversity will be critical for achieving sustainability in global agriculture.

Organic producers are interested in no-till, but they are concerned about controlling weeds without tillage. Cover crops are one option to replace tillage for weed control. With equipment such as the roller-crimper, cover crops can be terminated without needing to till[4]. This method has led to the concept of rotational tillage, where a no-till sequence is part of a longer tillage-based rotation[5]. However, results with the roller-crimper have been inconsistent[6]. A further concern is that continuous no-till is more beneficial for improving soil health[1]. Grandy et al.[7] noted that even a one-time tillage can severely restrict benefits gained from no-till in conventional agriculture.

We are seeking to develop a continuous no-till system for organic farming, and our initial effort for this research goal was devising a complex rotation to disrupt weed population dynamics. We proposed a 9-year rotation that consists of a corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] sequence followed by a 2-year interval of winter wheat (*Triticum aestivum* L.)–oat (*Avena sativa* L.), a 2-year sequence of soybean–corn, and then 3 years of a perennial legume[8]. This rotation was based on two critical factors of population-based weed management, crop diversity and no-till[9]. Weeds are managed more easily when rotations include crops with different life cycles, such as winter wheat and corn, and when these crops are arranged in 2-year intervals, i.e., two cool-season crops followed by two warm-season crops. No-till benefits weed management because weed seeds lose viability more rapidly when left on the soil surface. In herbicide-based no-till, some complex rotations have enabled producers to eliminate the need for herbicides in three crops out of four[10].

We are testing this 9-year rotation to validate its possible benefit for producers. The rotation includes a 2-year

Table 1. Cultural practices for establishing cool-season crops and cover crops.

Crop	Variety	Seeding rate (kg ha^{-1})	Planting date	
			Study 1	Study 2
Winter wheat	Darrell	140	September 13, 2011	September 12, 2012
Spring wheat	Briggs	135	April 5, 2012	May 3, 2013
Red clover	Mammoth: VNS	15	April 5, 2012	May 3, 2013
Oat–pea	Morton-Admiral	30:60	August 7, 2012	August 26, 2013
Oat	Shelby 427	110	May 3, 2013	April 21, 2014

VNS, variety not stated.

sequence of cool-season cereals to reduce density of warm-season weeds infesting corn and soybean[11]. It will be necessary to control weeds during the interval between winter wheat and oat to prevent extensive weed seed production otherwise weed density will increase in the following crops. A further concern is that density of winter annual weeds may escalate, which has occurred in conventional no-till cropland[12,13]. One species, downy brome (*Bromus tectorum* L.), is especially noteworthy as it commonly infests cool-season crops[9] and perennial legumes[14].

Organic producers in a no-till system may be able to control post-harvest and winter annual weeds with fall-planted cover crops that winterkill[15]. One option is planting cover crops after the harvest of the cereal grain[16]. This tactic may be effective, but a concern is weeds that are present before cover crops start growing which may not be effectively controlled. Another possibility is to underseed clovers in cool-season crops; clover would be established and growing at the time of harvest[17,18]. However, the competition for resources between clovers and cereal crops may reduce grain yield, especially in drier climates[18,19].

The objective of this study was to evaluate cover crops, either underseeded in wheat or planted after harvest, for controlling weeds during the interval between cool-season crops and their impact on yield of cereal grains. A second objective was to quantify the demographics of downy brome as affected by management treatments.

Materials and Methods

Study site

The study was established on a Barnes clay loam (Calcic Hapludoll) near Brookings, SD. The soil contained approximately 4% organic matter and had a soil pH of 6.9. Average yearly precipitation (30-year record) at the location is 584 mm. The cropping history of the site prior to the study was a corn–soybean–spring wheat rotation.

Experimental design

The study was a two-way factorial, with cover crop treatments and choice of wheat type as the two factors. Three treatments, red clover (mammoth type) underseeded in wheat, oat/pea mixture planted after wheat harvest and a no cover crop control, were evaluated. The three treatments were established in both winter and spring wheat (Table 1), resulting in six treatments. The study involved a 3-year interval, with winter wheat established in the first year, spring wheat and cover crops planted in the second year, and oat planted in the third year. The study was conducted twice, during 2011–2013 (Study 1) and 2012–2014 (Study 2). Crops were planted with a drill equipped with single disk openers. No fertilizers were used in the study. Treatments were arranged in a randomized complete block design with four replications; plot size was 7 by 10 m.

Data collection

Weed community and red clover biomass was measured in three 0.33 m^2 quadrats randomly placed in each plot, in mid-September following wheat harvest. Samples were oven-dried to a constant weight at 65°C. Number of volunteer winter wheat plants were recorded in early May of the third year in three 0.33 m^2 quadrats randomly placed in each plot that followed winter wheat.

Downy brome seedling emergence was recorded weekly in three permanent 0.33 m^2 quadrats randomly placed in each plot following wheat harvest. Counting started on August 1 and continued until June 1. After the weekly counting, seedlings were removed by hand. Crop volunteers and other weeds were also pulled and removed weekly. A second set of permanent quadrats was established on September 1 for the first study, and October 1 for the second study to assess downy brome seedling survival across time (referred to as demographic quadrats). Downy brome density was recorded on the day of quadrat establishment, November 1 (before winter dormancy), and at the end of winter dormancy in the spring. On June 21 of each year, seed-bearing plants in each quadrat were counted and then clipped at ground level. Weight of each sample was recorded after drying at 65°C until a constant weight, and seed number was counted from 5% of the seed heads in the sample. Viability of individual seeds was not determined. If crop volunteers or other weeds emerged in these quadrats, they were also removed by hand weekly.

https://doi.org/10.1017/S1742170515000022 Published online by Cambridge University Press

Grain yield of wheat and oat was determined by harvesting an area, 3 by 10 m, in each plot with a plot combine. Wheat and oat yield data were expressed at 15.5% moisture.

Statistical analysis

Data were analyzed as a factorial experiment arranged in a randomized complete block design. Data were initially examined for homogeneity of variance among years, and then subjected to analysis of variance to determine treatment effects and possible interactions among treatments and years. Main and interaction effects were considered significant at $P \leq 0.05$; treatment means were separated with Fisher's Protected LSD (0.05). Weed biomass and volunteer winter wheat data were averaged across quadrats within a plot before analysis.

Demographic data and emergence data for downy brome were analyzed with a repeated measures procedure. If interactions were found between treatment and date of sampling, data were analyzed within sampling date. The Fisher's Protected LSD was used for mean separation.

Results and Discussion

Data with cover crop treatments did not differ with type of wheat (winter or spring), therefore, data were pooled across wheat treatments. With weed assessments, if an interaction occurred between treatments and studies, data were shown individually by study.

Weed and cover crop biomass after wheat harvest

Red clover effectively suppressed weed growth after harvesting wheat. Weed biomass was almost 60 g m^{-2} in the control, but less than 1 g m^{-2} in the red clover treatment, a reduction of 98% (Fig. 1). Oat/pea did not suppress weed growth compared with the control. The weed community consisted primarily of green foxtail [*Setaria viridis* (L.) Beauv.], yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.], common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.). Red clover, being established when wheat was harvested, suppressed weeds because of its earlier growth compared with oat/pea planted after harvest. Biomass of red clover in mid-September was sixfold higher than oat/pea (Fig. 1).

A similar trend was observed with volunteer winter wheat density. In Study 1, more than 50 wheat plants m^{-2} were observed in the control and oat/pea treatments, but less than 1 plant m^{-2} was present in the red clover treatment (Fig. 2). In Study 2, volunteer wheat density differed among the three treatments. In total 48 volunteer wheat plants were established in the control, but only 31 plants were present in the oat/pea treatment. Due to dry conditions during Study 2, volunteer wheat did not germinate until late

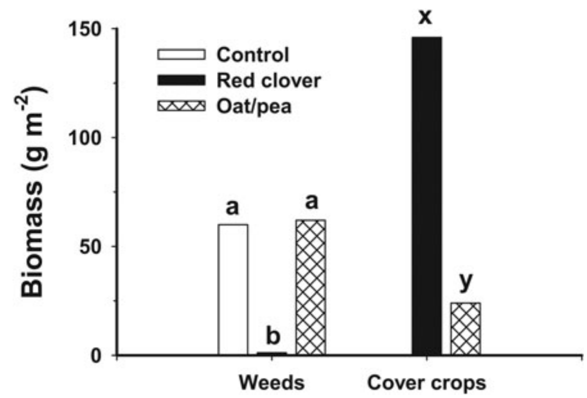

Figure 1. Biomass of the weed community and cover crops in mid-September, following wheat harvest. Cover crops were not planted in the control. Data were averaged across wheat treatments and studies. Weed and cover crop data were analyzed separately; bars within weeds or cover crops with the same letter are not significantly different as determined by the Fisher's LSD (0.05).

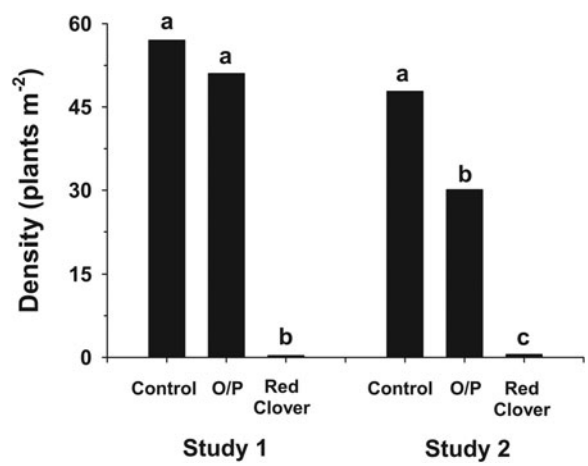

Figure 2. Volunteer winter wheat density in treatments, assessed in early spring of each study. Bars with the same letter within a study are not significantly different as determined by the Fisher's LSD (0.05). O/P, oat–dry pea mixture.

September. The earlier growth of oat/pea increased competition with volunteers and likely caused some seedling mortality. Less than 1 plant m^{-2} was present in the red clover treatment; red clover suppressed both weed biomass and volunteer wheat density by almost 98%.

Demographics of downy brome among cover crop treatments

A treatment by study interaction occurred with downy brome, because the downy brome time of emergence differed considerably between studies (Fig. 3a, b). Data are shown separately for each study.

Study 1. To further understand cover crop impact on weed growth, we monitored demographics of downy

https://doi.org/10.1017/S1742170515000022 Published online by Cambridge University Press

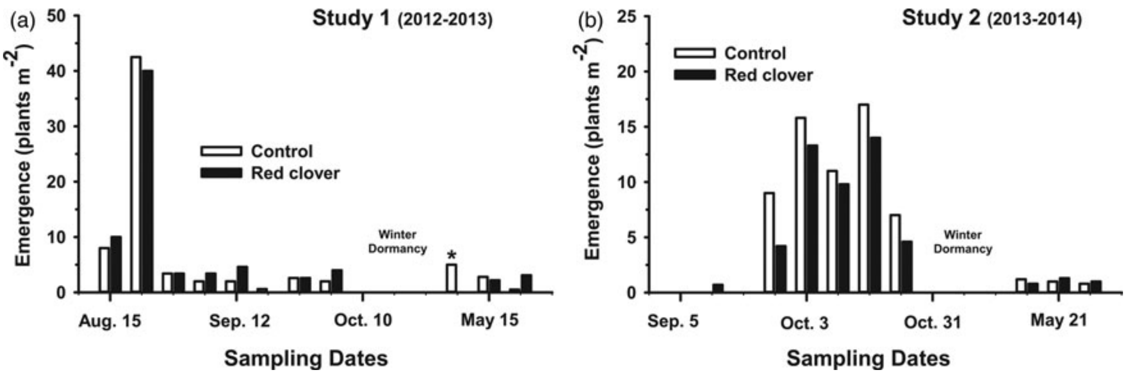

Figure 3. Seedling emergence of downy brome in underseeded red clover compared with the control, (a) Study 1, 2012–2013 and (b) Study 2, 2013–2014. Data were averaged across wheat treatments. An asterisk above a bar indicates that emergence at that date differed between the control and the red clover treatment at the 0.05 level of probability.

Table 2. Demographic data of downy brome as affected by cover crop treatments in Study 1 (2012–2013) and Study 2 (2013–2014).

	Cover crop treatment		
Parameter	**Red clover**	**Oat/pea**	**Control**
Study 1 (2012–2013)			
Density (plants m^{-2})			
September 1	72.0a	70.4a	65.4a
November 1	9.2b	49.2a	60.2a
May 1	0.3b	47.0a	55.6a
June 21	2.1b	50.2a	59.0a
Biomass (g m^{-2})	4b	486a	572a
Seeds (no. m^{-2})	38b	12,860a	14,740a
Study 2 (2013–2014)			
Density (plants m^{-2})			
October 1	23.1a	26.3a	25.4a
November 1	36.8b	51.6a	55.1a
April 15	0c	10.1b	18.4a
June 21	1.2c	11.7b	19.1a
Biomass (g m^{-2})	1c	77b	143a
Seeds (no. m^{-2})	8c	2340b	4180a

Data were averaged across wheat treatments. Means within a row followed by the same letter are not significantly different as determined by Fisher's LSD (0.05).

brome during the growing season. Cover crops did not affect seedling emergence of downy brome in the fall (Fig. 3a). Most downy brome seedlings emerged in August, with emergence not differing between red clover and the control at any sampling date. However, in the spring, downy brome emerged earlier in the control. Seedlings began emerging on May 8 in the control, but not until May 15 in the red clover treatment. This delay in seedling emergence likely occurred because of cooler soil temperatures due to dead red clover residues lying on the soil surface[20,21]. Emergence after May 15, however, did not differ between treatments because red clover residue had degraded by this time. Seedling emergence did not vary between oat/pea and the control at any sampling date throughout the assessment interval (data not shown).

Even though seedling emergence in the fall did not differ between the control and red clover, plant density varied across time in the demographic quadrats. On September 1, downy brome density was the same in both treatments, but on November 1, only nine downy brome plants m^{-2} were present in red clover, contrasting with 60 plants m^{-2} in the control (Table 2). We attribute this difference to seedlings dying because of competition by red clover. Lawley et al.[22] reported a similar trend with cover crops killing winter annual weed seedlings by competition rather than reducing seedling emergence. Reduced seedling growth of downy brome in red clover likely increased susceptibility to winterkill, as only 0.3 downy brome plants m^{-2} were present on May 1 compared with 56 plants m^{-2} in the control (Table 2). More than 99% of downy brome seedlings that emerged in red

https://doi.org/10.1017/S1742170515000022 Published online by Cambridge University Press

clover during the fall died before May 1, but very few plants died in the control. Downy brome density did not differ between oat/pea and control treatments at any sampling time.

The number of seeds m^{-2} produced by downy brome was 385-fold greater in the control compared with red clover (Table 2). Only 38 seeds were produced by plants in the red clover treatment compared with 14,740 seeds in the control. Seed production in red clover occurred mainly with plants emerging in the spring. However, several plants emerging in the spring did not vernalize and produce a seed head. Vernalization in downy brome is related not only to plant development and temperature, but also daylength[23]. Delay of emergence in the red clover treatment reduced seed production because longer daylengths suppressed vernalization. Downy brome seed production in the oat/pea treatment did not differ from the control.

Differences in downy brome biomass among treatments were similar to the trend found with seed production. Downy brome biomass was 572 g m^{-2} in the control but only 4 g m^{-2} in the red clover treatment, a reduction of more than 99%.

Study 2. Downy brome emerged later in Study 2 due to dry conditions in August and early September of 2013. The first flush of seedlings appeared on September 24, and continued through October (Fig. 3b). As found with study 1, seedling emergence in the fall did not vary between the control and red clover. The dense canopy of red clover did not suppress seedling emergence because downy brome germination does not require light[24]. Also, emergence did not differ between oat/pea and the other two treatments (data not shown). Emergence of downy brome in the spring did not vary with treatments, contrasting with results from Study 1. We attribute this difference to warmer temperatures in April in Study 2 favoring earlier breakdown and degradation of red clover residue. We speculate that lack of residue cover led to similar soil temperatures among treatments during the emergence period of downy brome.

In the demographic quadrats, downy brome density on October 1 was similar among red clover, oat/pea and the control (Table 2). However, plant density was 33% less in red clover than the control or oat/pea on November 1, because of competition from red clover killing seedlings. Winterkill of seedlings was high in all treatments and eliminated all seedlings in red clover. Less than 25% of the seedlings in the control or oat/pea treatment survived the winter, which we attributed to late emergence and lack of plant growth before winter dormancy started. Density also differed between oat/pea and control treatments on April 15 and June 21; fall competition likely favored winterkill of some downy brome seedlings in oat/pea.

Seed production of downy brome was reduced more than 99% in the red clover treatment compared to the control (Table 2); only 8 seeds were produced by downy brome in the red clover treatment. Similar to Study 1, several plants emerging in the spring did not vernalize, thus minimizing seed production of the spring cohort of plants. Downy brome biomass was suppressed by red clover similarly as seed production, with biomass being less than 1% of downy brome biomass in the control.

Grain yield of cool-season crops

Winter wheat yield did not vary among cover crop treatments, averaging 3080 kg ha^{-1} across studies. However, red clover reduced spring wheat yield by 17% compared with the control or oat/pea mixture. Spring wheat yielded 2230 kg ha^{-1} in the control, averaged across studies.

We were not able to accurately assess treatment effect on oat yield because of extensive interference by competing plants. First, some red clover plants survived the winter and infested 35 to 60% of the plot area to suppress oat growth. Secondly, downy brome and volunteer wheat interference reduced yield inconsistently in the control and oat/pea treatments. Oat yield varied from 300 to 2250 kg ha^{-1} across treatments.

Summary

Underseeding red clover effectively suppressed weeds, reducing post-harvest weed biomass, density of volunteer winter wheat and seed production of downy brome more than 99% compared with the control. Oat/pea was not effective for weed management because of less fall growth and competition compared with red clover.

We were concerned that downy brome density may escalate in no-till systems that included cool-season grain crops and perennial legumes[9,12,13]. However, underseeding red clover in winter wheat effectively suppressed downy brome, especially by favoring winterkill. Organic farmers can control downy brome seedlings that emerge in the spring with flaming, especially if downy brome is treated when plants have only 1 or 2 leaves[25,26]. Additionally, if row crops are grown the year following winter wheat, mowing downy brome at flowering will severely reduce seed production[27,28].

We were expecting that mammoth red clover would not survive the winter at this location. Because red clover persisted over winter, we are testing other clovers such as berseem clover (*Trifolium alexandrinum* L.) or crimson clover (*Trifolium incarnatum* L.) to replace red clover. These clovers are not as winter hardy as red clover and should winterkill[29]. If they are successful, then weeds can be managed during the interval between winter wheat and oat without volunteers reducing oat yield in our proposed 9-year rotation with no-till.

References

1 Triplett, G.B. Jr and Dick, W.A. 2008. No-tillage crop production: A revolution in agriculture! Agronomy Journal 100(Suppl.):S-153–S-165.

2 Peigne, J., Ball, B.C., Roger, E., Strand, J., and David, C. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use and Management 23:129–144.

3 Hobbs, P.R. 2007. Conservation agriculture: What is it and why is it important for future sustainable food production? Journal of Agricultural Science 145:127–137.

4 Van der Weide, R.Y., Bleeker, P.O., Achten, W.T., Lotz, L.A., Fogelberry, R., and Melander, B. 2008. Innovation in mechanical weed control in crop rows. Weed Research 48: 215–224.

5 Brainard, D.C., Haramoto, E., Williams, M.M. II, and Mirsky, S. 2013. Towards a no-till, no-spray future? Introduction to a symposium on nonchemical weed management for reduced-tillage cropping system. Weed Technology 27:190–192.

6 Creamer, N.G. and Dabney, S.M. 2002. Killing cover crops mechanically: Review of recent literature and assessment of new research results. American Journal of Alternative Agriculture 17:32–40.

7 Grandy, A.S., Robertson, G.P., and Thelen, K.D. 2006. Do productivity and environmental trade-offs justify periodically cultivating no-till cropping systems? Agronomy Journal 98:1377–1383.

8 Anderson, R.L. 2010. A rotation design to reduce weed density in organic farming. Renewable Agriculture and Food Systems 25:189–195.

9 Anderson, R.L. 2005. A multi-tactic approach to manage weed population dynamics in crop rotations. Agronomy Journal 97:1579–1583.

10 Anderson, R.L. 2008. Rotation design and no-till: Keys for pest management in the Great Plains. Weed Science 56: 141–145.

11 Anderson, R.L. 2009. A 2-year small grain interval reduces need for herbicides in no-till soybean. Weed Technology 23: 398–403.

12 Gibson, K.D., Johnson, W.G., and Hillger, D.E. 2005. Farmer perception of problematic corn and soybean weeds in Indiana. Weed Technology 19:1065–1070.

13 Werle, R., Bernards, M.L., Arkebauer, T.J., and Lindquist, J.L. 2014. Environmental triggers of winter annual weed emergence in the Midwestern United States. Weed Science 62:83–96.

14 Entz, M.H., Baron, V.S., Carr, P.M., Meyer, D.W., Smith, S. R. Jr, and McCaughey, W.P. 2002. Potential of forages to diversify cropping systems in the Northern Great Plains. Agronomy Journal 94:240–250.

15 Kruidhoff, H.M., Bastiaans, L., and Kropff, M.J. 2008. Ecological weed management by cover cropping: Effects on weed growth in autumn and weed establishment in spring. Weed Research 48:492–502.

16 Lawley, Y.E., Weil, R.R., and Teasdale, J.R. 2011. Forage radish cover crop suppresses winter annual weeds in fall and before corn planting. Agronomy Journal 103: 137–144.

17 Blaser, B.C., Gibson, L.R., Singer, J.W., and Jannick, J. 2006. Optimizing seeding rates for winter cereal grains and frost-seeded red clover intercrops. Agronomy Journal 98: 1041–1049.

18 Mutch, D.R., Martin, T.E., and Kosola, K.R. 2003. Red clover (*Trifolium pretense*) suppression of common ragweed (*Ambrosia artemisiifolia*) in winter wheat (*Triticum aestivum*). Weed Technology 17:181–185.

19 Thiessen Martens, J.R., Hoeppner, J.W., and Entz, M.H. 2001. Legume cover crops with winter cereals in southern Manitoba: Establishment, productivity, and microclimate effects. Agronomy Journal 93:1086–1096.

20 Teasdale, J.R. and Mohler, C.L. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85:673–680.

21 Teasdale, J.R. and Mohler, C.L. 2002. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Science 48:385–392.

22 Lawley, Y.E., Teasdale, J.R., and Weil, R.R. 2012. The mechanism for weed suppression by a forage radish cover crop. Agronomy Journal 104:205–214.

23 Finnerty, D.W. and Klingman, D.L. 1962. Life cycles and control studies of some weed bromegrasses. Weeds 10: 40–47.

24 Cici, S.Z. and Van Acker, R.C. 2009. A review of the recruitment biology of winter annual weeds in Canada. Canadian Journal of Plant Science 89:575–589.

25 Cisneros, J.J. and Zandstra, B.H. 2008. Flame weeding effects on several weed species. Weed Technology 22: 290–295.

26 Sivesind, E.C., Leblanc, M.L., Cloutier, D.C., Seguin, P., and Stewart, K.A. 2009. Weed response to flame weeding at different developmental stages. Weed Technology 23: 438–443.

27 Hulbert, L.C. 1955. Ecological studies of *Bromus tectorum* and other annual bromegrasses. Ecological Monographs 25:181–213.

28 Donald, W.W. 2007. Control of both winter annual and summer annual weeds in no-till corn with between-row mowing systems. Weed Technology 21:591–601.

29 Clark, A. 2012. Managing Cover Crop Profitably. 3rd ed. Sustainable Agriculture Research and Education Program Handbook Series: Book 9. Sustainable Agriculture Research and Extension Program (SARE), College Park, Maryland, USA. p. 116–188.