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Converting perennial legumes to organic cropland without tillage

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Abstract

Organic producers are interested in developing a no-till system for crop production. In this study, we examined management tactics to convert perennial legumes to annual crops without tillage. Our hypothesis was that reducing carbohydrate production in the fall by mowing would favor winterkill. Mowing treatments were imposed in the fall of the third year of alfalfa or red clover, and corn planted in year 4. The conventional practice of tillage to convert legumes to cropland was also included as a treatment. Mowing in autumn reduced red clover biomass 93% compared with alfalfa when measured 3 weeks after corn planting (WAP). Red clover biomass was still 75% less than alfalfa 6 WAP. Fall mowing suppressed red clover sufficiently to enable corn seedlings to establish, but corn seedlings did not survive in mowed alfalfa due to alfalfa competition. Corn grain yield following red clover was similar in the mowed and tilled treatments when weeds were present. Late season clover and weed growth reduced corn yields 46% compared with weed-free corn. Weed emergence in corn was three times higher after tillage compared with the mowed treatment. Converting red clover to annual crops with fall mowing will support a no-till system for organic farming.

Key words: corn, fall mowing, no-till, red clover, stand density, weed density

Introduction

Weeds are a main obstacle to cropping success in organic farming and require continuous effort to control (Sooby et al., 2007). Including perennial legumes, such as alfalfa (*Medicago sativa* L.), in the cropping sequence may help to reduce weed density in cropland because frequent harvesting of alfalfa suppresses establishment and seed production by weeds (Ominski et al., 1999). Also, weed seeds remain on the soil surface where they are less likely to survive (Anderson, 2005).

Impact of alfalfa on weed density in the Great Plains is related to the length of time it is grown. Weed assessments show that 3 or 4 yrs of alfalfa harvested for forage is most detrimental to weed population dynamics (Anderson, 2015). Density of weeds adapted to alfalfa management, such as dandelion (*Taraxacum officinale* Weber in Wiggers) and downy brome (*Bromus tectorum* L.), start invading alfalfa in the fourth and fifth year of production (Entz et al., 1995; Ominski et al., 1999; Anderson, 2015). Alfalfa competitiveness with weeds decreases in later years because stand density of alfalfa declines with time (Mesbah and Miller, 2005; Undersander et al., 2011).

Including alfalfa in the rotation will provide an additional benefit of a no-till interval. Organic producers till extensively to control weeds, which degrades soil health and reduces land productivity (Hobbs, 2007; Triplett and Dick, 2008). Therefore, organic producers are seeking cultural strategies for weed management that lessen the need for tillage, and are interested in no-till crop production (Sooby et al., 2007). The no-till interval of alfalfa will help both soil health (Triplett and Dick, 2008) and weed management (Ominski et al., 1999; Anderson, 2015).

In our research program, we are seeking to develop a continuous no-till system for organic farming. Our initial effort was to design a complex rotation that would disrupt weed dynamics, guided by principles for a population-based management approach in conventional agriculture that reduced weed density in cropland (Anderson, 2005). We proposed a 9 yr rotation that consists of 3 yrs of alfalfa followed by a 6 yr sequence of corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.]-winter wheat (*Triticum aestivum* L.)-oat (*Avena sativa* L.)-soybean-corn (Anderson, 2010). The complexity of crops with different life cycles aids producers in managing weeds with less inputs and tillage (Anderson, 2015).

An obstacle to a no-till system with this rotation, however, is converting alfalfa to annual crops without tillage. A possible technique to aid in conversion is fall mowing to reduce carbohydrates storage in the crown and roots, thus favoring winterkill of alfalfa (Haagenson et al., 2003). Scheaffer et al. (1988) noted that alfalfa can use 50% of its stored carbohydrates to survive the winter. A management recommendation is to avoid cutting from early September until the first frost to avoid winterkill and loss of stand (Sheaffer et al., 1988; Undersander et al., 2011). We hypothesized that mowing during this interval would reduce carbohydrate supply in crowns and roots and enhance winterkill, thus eliminating the need for tillage to convert alfalfa to annual crops. Another option that may enhance success with fall mowing is to grow red clover (*Trifolium pratense* L.) in place of alfalfa; red clover does not persist as long as alfalfa (Clark, 2012) and may be more vulnerable to fall mowing in the third year.

Therefore, the objective of this study was to evaluate impact of mowing in the third year of alfalfa and red clover on survival over winter and impact of this practice on corn planted into these stands the following year. These treatments will be compared with conversion by conventional tillage as commonly practiced by organic producers.

Materials and Methods

Study procedures

The study was established on a Barnes clay loam (Calcic Hapludoll) near Brookings, SD. The soil contained approximately 4% organic matter and had a pH of 6.9. Average yearly precipitation (30-yr record) is 584 mm. Cropping history of the site for the 6 yrs preceding the study was a corn-soybean-spring wheat rotation with conventional tillage.

The study was a two-way factorial experiment, with legume species and conversion treatments as the two factors. The legumes were either alfalfa or red clover. The study lasted for 4 yrs, with legumes established in the first year, conversion treatments imposed in the third year and corn planted uniformly across all treatments in the fourth year. Legumes were planted at 14 kg ha^{-1} and oat (as a companion crop) planted at 35 kg ha^{-1}. Varieties were Pioneer 54V54 alfalfa, medium red clover (variety not stated) and Stallion oat. Oat was planted first at 3 cm depth, followed by legumes planted at 1 cm depth on the same day (Table 1). Crops were planted with a no-till drill equipped with single disk openers. The site was no-tilled from spring wheat harvest to legume planting, and weeds were just starting to emerge at planting.

Forage yields in the first 3 yrs were collected when the legumes reached the 1/10 bloom stage. Forage yields were collected from 1 × 2 m^2 quadrats harvested by hand and oven-dried at 65°C until samples reached a constant weight. The remainder of the plot area was harvested with conventional equipment. The plots were harvested once in the first year (early August), and then three times in the second and third years. Harvest dates in the second and third years were approximately late May, early July and mid-August.

In the fall of year 3, three conversion treatments were established in each legume. One conversion method (referred to as no-till + mow) consisted of mowing legumes after September 1, when plants reached 15–20 cm in height (Table 1). A control treatment (referred to as no-till) was not mowed in the fall. The third treatment (referred to as till) included chisel plowing and disking in the fall and tilling once in the spring with a field cultivator before planting corn. The six treatments were arranged in a randomized complete block design with four replications; plot size was 7 × 20 m^2. The study was conducted two times, during 2010–2013 and 2011–2014, and established following spring wheat for each study.

Legume density was estimated by recording the number of 2.5 cm spaces in 1 m row occupied by a plant stem, thus providing a non-destructive assessment of stand density. Measurements were made at eight random locations in each plot in early June of each forage year and in corn during the fourth year.

In year 4, corn (DKC 48–37 RR) was planted at 62,000 seeds ha^{-1} (Table 1) across all treatments. Row spacing was 50 cm and no fertilizers were used. All conversion plots during the fourth year when corn was grown were randomly split into subplots. One subplot was maintained weed-free with two applications of glyphosate at 840 g a.i. ha^{-1} and hand weeding (referred to as weed-free). Weeds and legumes were allowed to grow in the second subplot (referred to as weed-infested). Subplot size was 7 × 10 m^2.

In the fourth year, legume biomass was determined from three 0.33 m^2 quadrats randomly located in each weed-infested subplot 3, 6 and 9 weeks after corn planting (WAP). Approximate corn development at time of sampling was two leaves fully exposed at the 3-week sampling, and five leaves and 11 leaves exposed at the 6- and 9-week samplings, respectively. Samples were oven-dried to a constant weight at 65°C. In addition, the weed community was assessed in the 9-week sampling quadrats to determine species, density and dry weight.

Weed dynamics were further assessed by recording weekly weed seedling emergence in corn in two 0.33 m^2 quadrats randomly located in each weed-free subplot. Counting started on the day of corn planting and continued for 8 WAP; after weekly counting, seedlings were removed by hand.

In each weed-free subplot, number of corn plants in 3 m of row was recorded at four random sites 5 WAP. Height of corn from the soil surface to the highest point of the plant was recorded 9 WAP, when corn had 11 leaves exposed. Corn grain yield in each subplot was determined

Table 1. Cultural practices for establishing legumes, mowing or tilling during the conversion year and establishing corn.

	Study 1	Study 2
Year 1		
Legume planting date	April 16, 2010	May 3, 2011
Year 3: Conversion		
First mowing	September 16, 2012	September 11, 2013
Second mowing	October 15, 2012	October 24, 2013
Fall tillage	September 26, 2012	September 27, 2013
Year 4		
Corn planting date	May 13, 2013	May 7, 2014

by harvesting an area, 2 × 10 m^2, with a plot combine. Reported corn yield were adjusted to 15.5% moisture level.

Statistical analysis

Data were analyzed as a two-way factorial in a randomized complete block design with Statistix 9 (Analytical Software, Tallahassee FL). Data were initially examined for homogeneity of variance among years, and then subjected to analysis of variance to determine treatments effects and possible interactions among treatments and studies. Conversion techniques and studies were considered fixed variables. Main and interaction effects were considered significant at $P \leq 0.05$. Data were pooled across studies when no significant treatments by study interactions were observed.

Plant frequency and plant biomass data were analyzed with the repeated measures procedure. Weed data were averaged across quadrats within a plot before analysis of weed emergence. Corn grain yield was analyzed as a split plot design with main treatments being conversion techniques and subplots being weed management treatments of weed-free and weed-infested. Treatment means were separated with Fisher's Protected Least Significant Difference [LSD (0.05)].

Results and Discussion

An interaction did not occur between the two studies therefore, data were averaged across studies. When an interaction occurred between choice of legume and conversion treatment, means were expressed for all treatments. An interaction was observed between treatments and sampling dates for legume biomass and frequency, so data were presented for each sampling date.

Biomass of legumes

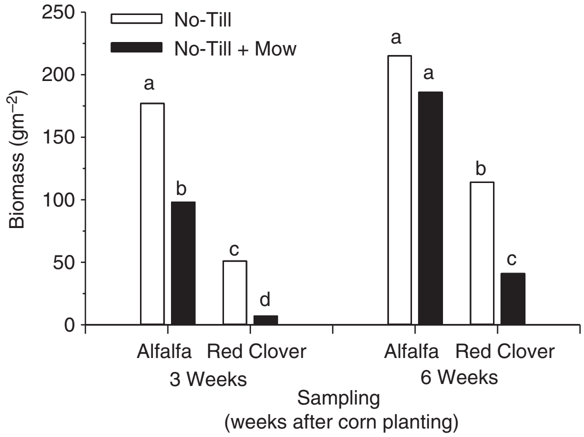

Figure 1. Biomass of legumes harvested 3 or 6 weeks after corn planting. Data averaged across studies. Bars with identical letters are not significantly different as determined by Fisher's LSD (0.05).

Fall mowing suppressed growth of both legumes in corn, but mowing was more effective with red clover. Biomass of red clover in corn 3 WAP was 7 g m^{-2} with fall mowing compared with 51 g m^{-2} in the non-mowed red clover treatment, an 86% reduction (Fig. 1). Fall mowing also reduced alfalfa biomass, but alfalfa still produced 100 g m^{-2}, 14 times greater than 7 g m^{-2} of biomass with mowed red clover.

Red clover biomass in the no-till + mow treatment was still significantly less than other treatments 6 WAP (Fig. 1). Only 41 g m^{-2} was recorded in this treatment, compared with 177 g m^{-2} of alfalfa biomass with no-till + mow and 114 g m^{-2} in the non-mowed treatment with red clover. Alfalfa biomass did not differ between no-till and no-till + mow treatments; alfalfa compensated for early growth suppression due to mowing.

Mowed red clover had less biomass than non-mowed red clover in part because of lower plant numbers. Mowed red clover occupied less than six spaces out of 40, whereas alfalfa in either no-till treatment occupied more than 34 spaces (Table 2). Alfalfa frequency did not differ between no-till treatments in any year, but red clover stand was declining by year 3. Even without mowing in no-till, red clover frequency was only 26.7, or 70% of alfalfa. This natural loss of stand density contributed to less biomass by red clover, and mowing accelerated stand loss.

Table 2. Plant occupancy and biomass (dry weight) of legumes and weeds. Plant frequency was measured in early June, whereas plant biomass was assessed 9 weeks after planting corn. Data averaged across studies. Means within a column followed by the same letter are not significantly different as determined by Fisher's LSD (0.05).

Treatment	Frequency by year of study			Biomass	
	2	3	4	Legume	Weeds
Alfalfa	no. m-row^{-1}			g m^{-2}	
No-till	39.1[1]	38.5[2]	38.4a	189a	1[3]
No-till + mow	38.8	38.0	34.3a	178a	4
Till[4]	39.3	38.3	6.5c	31c	113
Red clover					
No-till	38.7	31.8	26.7b	159a	5
No-till + mow	38.2	32.4	5.9c	90b	14
Till	38.4	32.2	0d	0d	152

[1] Means did not differ among treatments.

[2] An interaction was not observed between legumes and conversion techniques in year 3. Frequency for alfalfa, 38.3, differed significantly from red clover, 32.1.

[3] An interaction was not observed between legumes and conversion techniques. Averaged across legumes, weed biomass for till, 133 g m^{-2}, differed significantly from weed biomass for no-till and no-till + mow, 3 and 9 g m^{-2}, respectively.

[4] Tillage occurred in the fall of the third year and before planting corn.

At 9 WAP, biomass of red cover in the no-till + mow treatment was still 50% less than alfalfa biomass in the same treatment and 44% less than the no-till red clover treatment (Table 2). Even though fewer red clover plants were present in the no-till + mow treatment, these plants continued to grow and produce biomass. Producers, however, could suppress this growth with recently developed equipment. For example, Donald et al. (2001) designed a mower to control weeds between rows of corn and soybean, whereas other implements can remove weeds present in the crop row (Anderson, 2009; Forcella, 2012). These implements provide additional options to suppress red clover growth and may enable producers to convert a legume field to annual crops without tillage.

Corn establishment and grain yield

Corn germinated in all treatments, but few seedlings were able to survive in either no-till alfalfa treatments or the no-till red clover treatment because of legume competition. Corn seedlings survived in no-till + mow red clover because of delayed growth of red clover; density was similar to corn establishment in the till control (data not shown). Interfering weeds and red clover plants that survived mowing reduced corn yield by 46% in the no-till + mow treatment compared with the weed-free subplot (Fig. 2), yet weeds in the till control also reduced corn yield by 45%. Organic producers can control these weeds in corn with tillage in conventional systems, but producers in a no-till system also have control options (Donald et al., 2001; Forcella, 2012). Thus, tillage may not be needed to control weeds in corn following red clover.

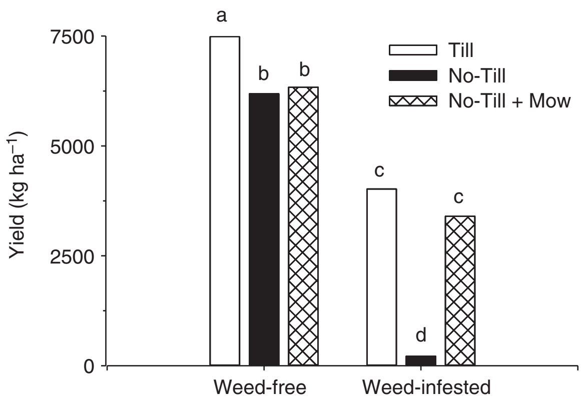

Figure 2. Corn grain yield in the red clover treatments. Weed-infested refers to both weeds and volunteer red clover; both categories of plants were controlled in weed-free. Corn yields were adjusted at the 15.5% moisture level; data averaged across studies. Bars with identical letters are not significantly different as determined by Fisher's LSD (0.05).

Weed dynamics in corn

Weed biomass in the tilled treatment with either legume was several-fold higher compared with no-till (Table 2). Weeds produced approximately 130 g m^{-2} in corn after tilling red clover and alfalfa, but 14 g m^{-2} or less in the no-till treatments. Averaged across no-till treatments, weed biomass was 95% less compared with the tilled treatments in both legumes. Prominent weeds were common lambsquarters (*Chenopodium album* L.), green foxtail [*Setaria viridis* (L.) Beauv.], yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.], and common sunflower (*Helianthus annuus* L.). Some alfalfa survived after tillage (frequency value of 6.5 compared with 0 for red

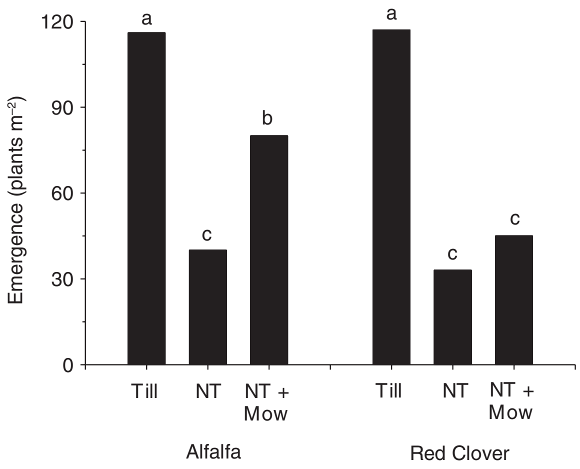

Figure 3. Sum of weed seedling emergence during the 8 weeks following corn planting. Data averaged across studies. Bars with identical letters are not significantly different as determined by Fisher's LSD (0.05). Abbreviation: NT, no-till.

clover, Table 2), which increased biomass of plants competing with corn. Tillage was more effective in controlling red clover than alfalfa.

Suppressing red clover with mowing did not lead to more weed growth. Weed biomass in the no-till + mow treatment was 14 g m^{-2}, or only 9% of weed biomass in the till control (Table 2). Competition from red clover may have suppressed weed growth in the no-till + mow treatment, but a second factor leading to low weed biomass was less weed emergence after corn planting. Almost 120 weed seedlings were recorded in the tilled red clover control, but only 40 seedlings emerged in no-till + mow (Fig. 3). This reduced weed emergence is similar to trends reported by Ominski et al. (1999), where tilling to convert perennial legumes to cropland increased weed density several-fold in the following annual crop compared with no-till conversion. Also, our results agree with a previous study at this location, where tilling after 2 yrs of no-till increased weed emergence five-fold compared with maintaining no-till for the third year of annual crops (Anderson, 2009).

Weed emergence was higher in the mowed alfalfa than in mowed red clover (81 versus 40 seedlings m^{-2}, Fig. 3), suggesting that alfalfa is less competitive with weeds than red clover. We speculate that some weeds were able to complete their life cycle and produce seeds during the forage phase of alfalfa.

Effect of tillage on emergence of specific weeds was consistent across all species, with fewer seedlings in no-till (data not shown). One striking trend was that common sunflower emerged primarily in the tilled treatment; seedlings were rarely observed in any no-till treatment. This stimulatory effect of tillage on common sunflower emergence and establishment has been shown in previous research at this location (Anderson, 2007).

Impact of tillage on corn yield in weed-free conditions

Corn yield in weed-free subplots differed between tilled and no-till treatments. Following red clover, corn yielded 7450 kg ha^{-1} with tillage, but only 6350 kg ha^{-1} when averaged across the two no-till treatments (Fig. 2). A similar trend between tillage treatments occurred with corn following alfalfa (data not shown). Corn density did not differ with tillage (data not shown), but corn height 9 WAP was approximately 24% higher in the tilled treatments compared with no-till treatments (130 versus 105 cm, averaged across legumes; data not shown).

Several factors likely are involved with this difference. Tillage may increase available nitrogen (Mohr et al., 1992), whereas soil temperature in the spring may have been cooler in no-till due to residue cover on the soil surface (Vetsch and Randall, 2002). Also, no-till treatments may have had less soil water due to red clover and alfalfa growth before corn planting. Tillage in the fall removed legume plants in the tilled treatment and eliminated water use.

Forage yield of alfalfa and red clover

Forage yield did not differ between alfalfa and red clover, yielding approximately 8 Mg ha^{-1} summed across 3 yr (data not shown). Red clover produced more forage than alfalfa in the second year, but less in the third year due to the gradual loss of plant stand across time (Table 2).

Summary

Mowing red clover in the fall may enable producers to include this legume in their rotation without needing tillage for conversion to annual crops. Corn yield was similar on tilled and mowed red clover when weeds were present (Fig. 2). A further benefit of mowed red clover is lower weed density (Fig. 3). This study demonstrates the potential for integrating a perennial legume into a no-till system.

A primary goal of any viable production system is protecting soil health (Hobbs, 2007). No-till will help organic producers achieve this goal (Triplett and Dick, 2008). Because red clover can be converted to annual crops with fall mowing, organic producers may be able to increase the complexity of their rotations to further suppress weed population dynamics (Anderson, 2010, 015). This mowing technique with red clover provides an initial step towards developing a no-till system for organic farming. Furthermore, perennial legumes in the rotation can increase crop yield, soil aggregation and nutrient cycling (Karlen et al., 2006). A no-till system, if successful, will lead to more sustainable cropping systems for organic farming (Hobbs, 2007).

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