Weed Technology 2016 30:559–572

Spring- and Fall-Seeded Radish Cover-Crop Effects on Weed Management in Corn

Miriam F. Gieske, Donald L. Wyse, and Beverly R. Durgan*

Weeds often limit productivity of organic cropping systems. Radish is a fast-growing, potentially allelopathic cover crop that has the potential to improve weed management in organic systems. To evaluate the effect of radish on density, cover, and biomass of weeds in organically managed corn, 2-yr field experiments were conducted over 4 site years. Four cover-crop planting treatments (fall-only, spring-only, fall + spring, and no cover) were tested in factorial with three cultivation treatments (standard [three to four passes], false seedbed [standard with a false seedbed], and reduced [two passes]). All plots were tilled before planting. Shoot biomass averaged 3,057 kg ha^{-1} for fall-seeded radish and 385 kg ha^{-1} for spring-seeded radish. Radish cover crops generally did not improve management of weeds during the corn growing season. However, in the absence of a false seedbed, fall-seeded radish reduced field pennycress density from 9 to < 1 plant m^{-2} and horseweed density from 6 to 2 plants m^{-2} in spring in site years where these weeds were present. Fall-seeded radish also reduced cover of summer annual weeds during the fall cover-crop growing season from 4 to 0% in 1 site year, preventing these weeds from setting seed. Radish cover crops did not affect corn grain yield.
Nomenclature: Field pennycress, *Thlaspi arvense* L. THLAR; horseweed, *Conyza canadensis* [L.] Cronq. ERICA; radish, *Raphanus sativus* L.; corn, *Zea mays* L.
Key words: Brassica, ecological weed management, frost seeding, green manures, organic cropping systems.

Las malezas a menudo limitan la productividad de los sistemas de cultivos orgánicos. El rábano es un cultivo de cobertura potencialmente alelopático de rápido crecimiento que tiene el potencial de mejorar el manejo de malezas en sistemas orgánicos. Para evaluar el efecto del rábano sobre la densidad, cobertura, y biomasa de malezas en maíz manejado orgánicamente, se realizaron estudios de campo de dos años de duración en 4 sitios-años. Cuatro tratamientos de siembra de cultivos de cobertura (sólo otoño, sólo primavera, otoño + primavera, y sin cobertura) fueron evaluados en forma factorial con tres tratamientos de labranza (estándar [tres a cuatro pases], cama de siembra falsa [estándar con cama de siembra falsa], y reducida [dos pases]). Todas las parcelas fueron labradas antes de la siembra. La biomasa de la parte aérea promedió 3,057 kg ha^{-1} para el rábano sembrado en el otoño y 385 kg ha^{-1} para el rábano sembrado en la primavera. Los cultivos de cobertura de rábano generalmente no mejoraron el manejo de malezas durante la temporada de crecimiento del maíz. Sin embargo, en ausencia de la cama de siembra falsa, el rábano sembrado en el otoño redujo la densidad de *Thlaspi arvense* de 9 a < 1 planta m^{-2} y la densidad de *Conyza canadensis* de 6 a 2 plantas m^{-2} en la primavera, en sitios-años en los que estas malezas estuvieron presentes. El rábano sembrado en el otoño también redujo la cobertura de malezas anuales de verano durante la temporada de crecimiento del cultivo de cobertura de 4 a 0% en 1 sitio-año, previniendo así que estas malezas produjeran semillas. Los cultivos de cobertura de rábano no afectaron el rendimiento de grano del maíz.

Organic field crop producers in Minnesota and throughout the United States consistently cite weed management as a major concern (Minnesota Department of Agriculture 2007; Moynihan 2010; Walz 1999). Organic farmers manage weeds through a combination of mechanical tillage and ecological weed management strategies (Bond and Grundy 2001). Ecological weed management focuses on redesigning cropping systems to reduce weed recruitment, increase crop competitiveness, and reduce the size of the weed seedbank (Bastiaans et al. 2008). Reliance on mechanical tillage for weed control is inherently risky, because effective mechanical weed control requires multiple precisely timed cultivations, which can easily be disrupted by wet weather (Cavigelli et al. 2008; Mohler 2001; Porter et al. 2003; Posner et al. 2008). By reducing weed

DOI: 10.1614/WT-D-15-00023.1

* First, second, and third authors: Graduate Student, Professor, and Professor, Department of Agronomy and Plant Genetics, University of Minnesota, 1991 Upper Buford Circle, St. Paul, MN 55108. Current address of first author: Department of Ecology, Evolution and Behavior, University of Minnesota, 1987 Upper Buford Circle, St. Paul, MN 55108. Corresponding author's E-mail: gies0107@umn.edu

populations and competitiveness, ecological weed management can mitigate this risk. One of the ecological weed management strategies available to organic farmers is cover cropping. Liebman and Davis (2000) suggest two ways cover crops can improve weed management in organic systems: by reducing off-season weed seed production through competition, and by reducing weed recruitment during the cropping season through allelopathy or stimulation of plant pathogens that attack weed seeds and seedlings.

Radish is a relatively new cover crop with potential usefulness as part of an ecological weed management system. Fall-seeded radish cover crops grow quickly but winterkill in northern climates, leaving a low-residue seedbed in the spring (Lawley et al. 2011). Fall-seeded radish consistently suppresses weed growth in the fall and early spring (Charles et al. 2006; Kruidhof et al. 2008; Lawley et al. 2011; O'Reilly et al. 2011; Stivers-Young 1998). In addition, Wang et al. (2008) reported that fall-seeded radish reduced weed seedbank size in a vegetable rotation where the major weed species were yellow nutsedge (*Cyperus esculentus* L.), common purslane (*Portulaca oleracea* L.), redroot pigweed (*Amaranthus retroflexus* L.), and wild mustard (*Sinapis arvensis* L.). The low-residue, nearly weed-free seedbed produced by radish may allow organic farmers to reduce the number or intensity of tillage passes used for seedbed preparation (Lawley et al. 2011). However, weed suppression by fall-seeded radish generally does not persist into the following summer (Charles et al. 2006; Lawley et al. 2011, O'Reilly et al. 2011). Indeed, fall-seeded radish sometimes increases weed emergence during the following summer, perhaps because of its effect on soil nitrate levels (Charles et al. 2006; Lawley et al. 2011, 2012). Thus, fall-seeded radish cover crops must be combined with other measures to maintain season-long weed control.

The potential of spring-seeded radish for weed control has not been studied. Spring-seeded radish evidently has allelopathic or pathogen-promoting effects; emergence of direct-seeded muskmelon (*Cucumis melo* L.) was reduced to zero where a radish cover crop was incorporated 7 to 8 days before muskmelon seeding (Ackroyd and Ngouajio 2011). However, effects on weed emergence were not reported in that study. Other brassicaceous cover crops seeded in spring have been reported to reduce weed emergence. A spring-seeded mustard mixture (*Brassica juncea* L. and *Sinapis alba* L.) incorporated into the soil reduced densities of annual grasses by 58 to 73% relative to a weedy check, but generally did not affect densities of broadleaf weeds (Norsworthy et al. 2005). In a field bioassay, incorporation of spring-seeded brassicaceous cover crops (*Brassica napus* L. and *S. alba*) reduced average emergence of 16 bioassay species by 23 to 34% and delayed emergence by about 2 days, compared to a fallow control (Haramoto and Gallandt 2005).

The mechanism of weed suppression may differ between fall- and spring-seeded radish cover crops. Like other members of the family Brassicaceae, radish contains glucosinolates in both above- and belowground tissues (Brown and Morra 1997; Sang et al. 1984). The main degradation products of glucosinolates are isothiocyanates, several of which inhibit weed seed germination and seedling growth (Brown and Morra 1997; Haramoto and Gallandt 2004). In laboratory bioassays, extracts of fresh radish tissue reduced germination and radicle length of muskmelon, honeydew (*C. melo*), and cucumber (*Cucumis sativus* L.; Ackroyd and Ngouajio 2011), while extracts of dried tissue inhibited germination and root growth of lettuce (*Lactuca sativa* L.; Lawley et al. 2012). However, field trials of a fall-seeded radish cover crop and laboratory bioassays with extracts of decomposing radish residue and soil provided little or no evidence for allelopathy (Lawley et al. 2012). Thus, Lawley et al. (2012) attributed weed suppression by fall-seeded radish cover crops to competition during the fall growing season rather than allelopathic effects. The lack of allelopathic effect seen in trials with fall-seeded radish may be due to rapid loss of isothiocyanates from the soil (Brown and Morra 1997; Petersen et al. 2001); by the time weed seeds begin germinating in the spring, any allelochemicals from the radish biomass may have degraded. Incorporation of spring-seeded radish immediately before crop planting may be more effective for allelopathic suppression of weeds, though the risk of allelopathy toward the crop must be studied.

The compatibility of radish cover crops with weed management methods used by organic farmers requires study before radish cover crops can be recommended for organic systems. Organic farmers typically use an integrated system of mechanical and cultural tactics to control weeds, including delayed planting and pre- and postplanting cultivation. Delayed planting permits early flushes of weeds to be removed by preplanting tillage. It may be coupled with the false-seedbed technique, in which the soil is tilled one or more times at least 1 wk before planting to stimulate emergence of weed seedlings that will be killed by the next tillage pass (Bond and Grundy 2001). Delayed planting also allows the soil to warm, mitigating the risk of seedling losses in the absence of chemical seed protectants. Compared to the conventional system, the organic system might limit the usefulness of fall-seeded radish for weed control, but make it more feasible to use spring-seeded radish. In Maryland, fall-seeded radish suppressed weeds through the early spring, but stimulated weed emergence later in the spring (Lawley et al. 2011, 2012). In the organic system, the need to delay crop planting until the soil warms would limit the benefit of the fall radish cover crop's early spring weed suppression. Stimulation of weed emergence before crop planting could increase the effectiveness of the false-seedbed technique. However, stimulation of weed emergence after planting would likely reduce weed management success in organic systems, because the effectiveness of postplanting mechanical cultivation depends in part on weed density (Mohler 2001). Finally, delayed crop planting may make it possible to add a spring-seeded radish cover crop to an organic system, but if a false seedbed is used, the spring-seeded radish may be killed by tillage along with the weeds. Therefore, it is necessary to examine the impacts of fall and spring-seeded radish cover crops on weed management in combination with a range of possible tillage strategies.

The objectives of this study were (1) to quantify the biomass production of fall- and spring-seeded radish cover crops in an organically managed corn rotation; (2) to evaluate the effect of radish cover crops on weed density, cover, and biomass in the subsequent corn crop; and (3) to examine the compatibility of radish cover crops with spring tillage practices typically used by organic farmers.

Materials and Methods

Site Characteristics and Experimental Design. Two-year field experiments were established in August 2010 and 2011 at the University of Minnesota Rosemount Research and Outreach Center (Rosemount, MN, 44.72°N, 93.11°W) and Southwest Research and Outreach Center (Lamberton, MN, 44.25°N, 95.31°W), for a total of 4 site years. At Rosemount, the soil was a well-drained Waukegan silt loam (fine–silty over sandy or sandy–skeletal, mixed, superactive, mesic Typic Hapludolls). At Lamberton, the soil was a mixture of poorly drained Webster clay loam (fine–loamy, mixed, superactive mesic Typic Endoaquolls) and somewhat poorly drained Normania loam (fine–loamy, mixed, superactive, mesic Aquic Hapludolls). Study sites at Lamberton were certified organic, whereas sites at Rosemount were not certified organic but were managed with organic practices during the corn growing season.

The experiment had a split-plot design with four replicate blocks. Tillage treatment was the main plot, and cover-crop treatment was the subplot. Subplots were 4.6 m (six corn rows) wide by 7.6 m long at Rosemount in 2010 to 2011, 3.0 m (4 corn rows) wide by 9.1 m long at Lamberton in 2010 to 2011, and 4.6 m wide by 9.1 m long at both sites in 2011 and 2012. Cover-crop treatments were fall-seeded radish (fall only), spring-seeded radish (spring only), both fall- and spring-seeded radish (fall + spring), and a no–cover-crop control (no-cover control). The radish used was GroundHog®, a large-rooted daikon or forage radish selection marketed as a cover crop (Ampac Seed Company, Tangent, OR). To establish a range of weed pressures and test the compatibility of cover-crop treatments with tillage practices commonly used for weed control by organic farmers, three tillage treatments were imposed. In all tillage treatments, the seedbed was prepared immediately before corn planting with a disk (Lamberton) or field cultivator (Rosemount). In the false-seedbed treatment, plots were tilled with a disk (Lamberton) or field cultivator (Rosemount) 20 to 50 d before corn planting, retilled immediately before planting, and cultivated once or twice with a rotary hoe and once or twice with a row cultivator between planting and the V8 growth stage of the corn crop. In the standard-tillage treatment, plots were tilled before planting and cultivated once or twice with a rotary hoe and twice with a row cultivator. In the reduced-tillage treatment, plots were tilled before planting and cultivated once with a rotary hoe and once with a row cultivator. Dates of all tillage operations are presented in Table 1. In 2011, due to weather and management constraints, the standard and reduced

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 1. Dates of data collection and field operations at Lamberton and Rosemount, MN in 2010–2012.

	Lamberton		Rosemount	
	2010–2011	2011–2012	2010–2011	2011–2012
Fall radish seeding	August 18, 2010	August 23, 2011	August 19, 2010	August 19, 2011
Weed percent cover rating	–	October 26, 2011	–	October 11, 2011
Radish biomass sampling	October 19, 2010	October 25, 2011	October 28, 2010	October 22, 2011
Spring radish seeding	March 25, 2011	March 20, 2012	April 8, 2011	March 19, 2012
Early preplanting tillage[a]	May 5, 2011	May 1, 2012	May 6, 2011	March 22, 2012
Preplanting weed and radish counts, radish biomass sampling	May 17, 2011	May 17, 2012	May 18, 2011	May 15 & 16, 2012
Preplanting tillage[b]	June 6, 2011	May 18 and 22, 2012	May 26, 2011	May 16, 2012
Corn planting	June 7, 2011	May 22, 2012	May 26, 2011	May 16, 2012
First rotary hoeing[b]	June 16, 2011	June 4, 2012	June 1, 2011	May 22, 2012
Second rotary hoeing[c]	–	June 8, 2012	–	June 1, 2012
Post-planting weed counts	June 30, 2011	June 11, 2012	June 20, 2011	June 8, 2012
First row cultivation[b]	June 30, 2011	June 18, 2012	June 27, 2011	June 14, 2012
Second row cultivation[c]	July 18, 2011	June 27, 2012	–	June 25, 2012
Weed percent cover rating	August 30, 2011	August 24, 2012	August 25, 2011	August 22, 2012
Weed biomass sampling	August 30, 2011	August 24, 2012	August 26, 2011	August 22, 2012
Corn grain harvest	October 25, 2011	October 12, 2012	October 21, 2011	October 10, 2012

[a] False seedbed treatment only.

[b] All treatments.

[c] False seedbed and standard tillage treatments.

tillage treatments were treated identically through June at Lamberton and through the end of the season at Rosemount. Where this occurred, the standard tillage plots were treated as an additional replication of the reduced tillage treatment in statistical analyses.

Field Management and Data Collection. Dates of data collection and field operations are presented in Table 1. At Rosemount in 2010, the radish cover crop was established following an oat crop that was harvested for grain, with the straw baled and removed. At all other locations and years, the preceding crop was a soybean green manure. Aboveground soybean biomass was sampled shortly before mowing to determine its nitrogen content. Preplanting soil nitrate levels were determined by analysis of two to four bulk 0 to 60–cm soil samples per field. Each sample was a composite of at least four cores. At Rosemount, cores were collected with a standard 1.9-cm-diam hand probe and dried in a forced-air dryer at 35 C. At Lamberton, cores were collected with a tractor-mounted hydraulic probe and dried in a forced-air dryer at ambient temperature. Nitrate content of soil samples was analyzed by CaCl extraction (Lamberton) or $CaSO_4$ extraction (Rosemount) followed by cadmium reduction and colorimetry. Prior to establishing

Table 2. Soil nitrate–nitrogen, nitrogen content of soybean green manure, and nutrient content of manure applied prior to radish cover-crop planting at Lamberton and Rosemount, MN in 2010 and 2011.

Site	Year	Soil (0–60 cm) Nitrate–nitrogen	Soybean biomass Total nitrogen	Manure Total nitrogen	Manure P_2O_5	Manure K_2O
		kg ha^{-1}				
Lamberton	2010	34	117	126	133	78
	2011	41	–[a]	215	202	202
Rosemount	2010	18	–[b]	151	139	61
	2011	50	61	110	33	72

[a] Data not available.

[b] Soybean not present.

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

the radish cover crop, liquid swine manure (Rosemount) or solid beef manure (Lamberton) was broadcast and incorporated. Soil nitrate levels, soybean biomass nitrogen, and manure nitrogen, phosphorus, and potassium are presented in Table 2. The field was prepared for planting with the use of a disk, field cultivator, harrow, and/or packer as necessary to create a smooth seedbed.

In the fall-only and fall + spring cover-crop treatments, radish was seeded with a cone-drill seeder at 19 kg ha^{-1} between August 18 and August 23 of each year. Seeding depth was about 2.5 cm, and row spacing was 15 cm at Rosemount and 19 cm at Lamberton. At Lamberton in the fall of 2010, radish was seeded in all treatments, but removed from the spring-only and no-cover control treatments with a field cultivator 12 d after planting. At Rosemount in 2010, volunteer oats were controlled in all treatments with clethodim (SelectMax®, 0.12 kg ai ha^{-1}, Valent USA Corporation, Walnut Creek, CA) 20 d after planting. In the spring-only and fall + spring cover-crop treatments, radish seed was broadcast by hand at 19 kg ha^{-1} as soon as it was possible to enter the field in the spring, between March 19 and April 8.

Between 16 May and 7 June, following preplanting tillage operations, corn was planted across the entire plot area in 76-cm rows at a seeding rate of 79,000 seeds ha^{-1} at Rosemount and 84,000 seeds ha^{-1} at Lamberton. The corn hybrid used was certified organic '42A32' (Blue River Hybrids, Kelley, IA). Postplanting tillage treatments were imposed as described above and in Table 1.

Root and shoot biomass of fall-seeded radish were collected in mid to late October of the establishment year, before severe frost damage occurred, by digging or pulling plants in a single 0.25-m^2 quadrat in each subplot in the fall-only and fall + spring treatments. This method allowed collection of the swollen, fleshy portion of the taproot, though fine roots were not collected. Roots were separated from shoots at or shortly after harvest. Root biomass was washed to remove clinging soil. Shoot biomass was also washed at Rosemount in 2010. Because of the amount of biomass collected, shoot biomass was stored in plastic bags at 6 C for up to 2 d before washing, whereas root biomass was stored for up to 3 wk. Both root and shoot biomass were dried in paper bags in a forced-air dryer at 60 C before weighing. In 2011, weed cover was visually rated (0 to 100%, to the nearest 1%) in all plots in mid to late October, around the time of radish biomass sampling.

Stand density and shoot biomass of spring-seeded radish were determined by counting and harvesting radish plants in two 0.25-m^2 quadrats in each plot in mid-May of each year, prior to corn planting. Root biomass of spring-seeded radish was not measured because of the small size of the plants.

Weed density data were collected at two dates early in the corn growing season to determine the effect of radish cover crops on weed populations. Weed density was measured before corn planting by counting plants in two 0.25-m^2 quadrats per plot. In treatments with spring-seeded radish, weed density counts occurred in the same quadrats used for radish sampling. Weed density was also determined when the corn was at the V3 to V4 stage, between rotary hoeing and row cultivation. At this sampling date, weeds were counted in one (Lamberton 2011) to two (all other locations and years) quadrats per plot. Quadrats were 0.44 by 0.76 m (0.33 m^2) and were centered on a row of corn, making it possible to obtain a representative sample of the in-row and interrow space. Some weed seedlings were pulled to aid in identification. Radish was present in some treatments. Weed cover and biomass data were collected in late August, when weeds were expected to be near peak cover and biomass, as measures of the impact of radish cover crops on weed growth integrated over the growing season. Weed and radish cover were visually rated. Biomass of weeds plus radish (henceforth "noncrop biomass") was determined by clipping aboveground biomass in three 0.33-m^2 quadrats centered on one of the middle two rows of corn. Because of time constraints, weed and radish biomass were collected and weighed together. Corn grain yield was measured in October by harvesting 9.2 to 16.0 m of row from each subplot with a combine. All yields were adjusted to 15.5% moisture.

Temperature and precipitation data were obtained from weather stations located at the experiment sites. Growing degree days (GDD) were calculated with the use of the standard equation $GDD = (T_{max} + T_{min})/2 - T_{base}$, where T_{max} is the daily maximum temperature, T_{min} is the daily minimum temperature, and T_{base} is the base

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

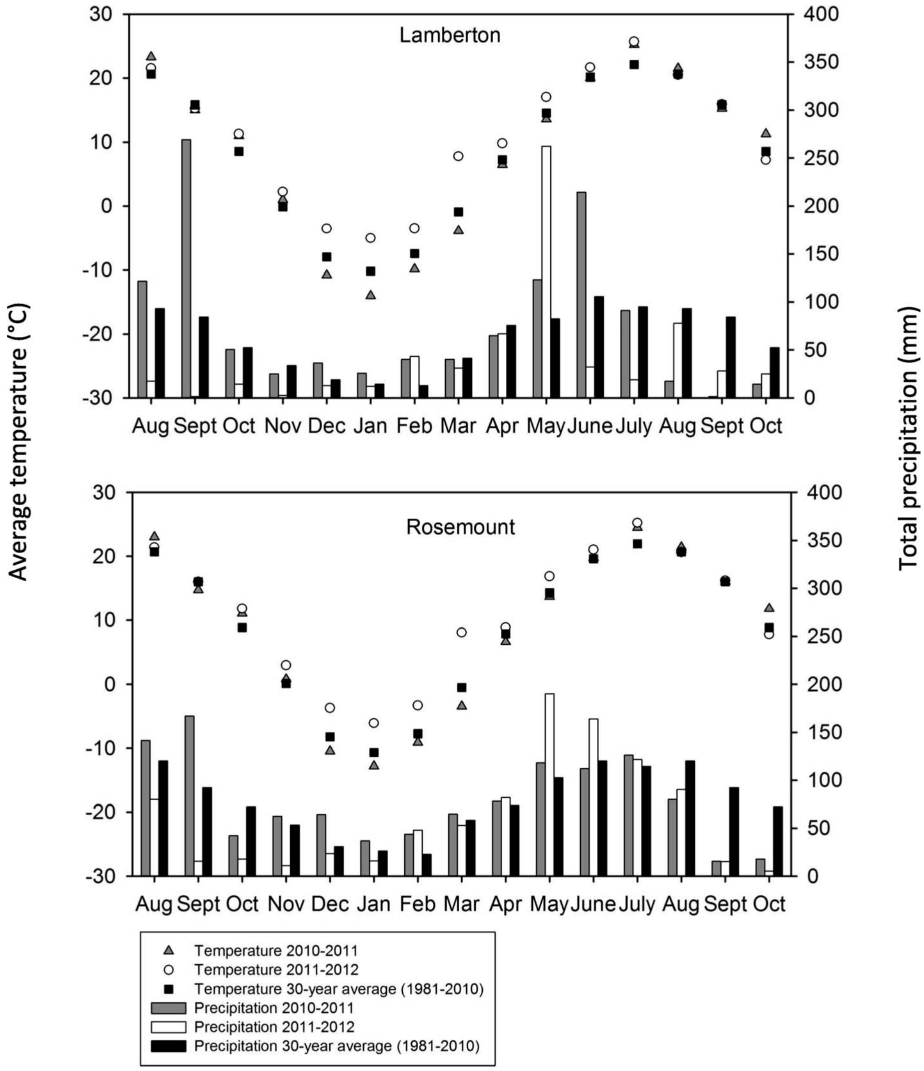

Figure 1. Monthly average temperature and total precipitation at Lamberton and Rosemount, MN.

temperature (McMaster and Wilhelm 1997). The base temperature for radish was set at 5 C, on the basis of estimates for other brassicaceous species (Adams et al. 2005; Huang et al. 2001). T_{max} and T_{min} values less than 5 C were set equal to 5 C before calculating GDD.

Table 3. Growing degree day (GDD) accumulation from March 15 to May 15 at Lamberton and Rosemount, MN in 2011 and 2012.

Site	Year	GDD	Deviation from 1981–2010 mean
Lamberton	2011	169	−77
	2012	453	207
Rosemount	2011	175	−92
	2012	431	164

Statistical Analysis. All data were analyzed with SAS software (Version 9.3, SAS Institute, Cary, NC). Because of treatment by site year interactions for several variables, each site year was analyzed separately. Data were analyzed with the use of PROC GLIMMIX to perform an ANOVA appropriate for a split-plot design, with tillage and cover-crop treatments as fixed effects and block as a random effect. Early in the growing season (and throughout the growing season at Rosemount in 2011), the standard and reduced tillage treatments were treated identically. In these cases, an unbalanced ANOVA was used, with the standard and reduced tillage treatments recoded as a no–false-seedbed treatment. Means separations were performed with the use of LSMeans statements

Table 4. Biomass accumulation of a fall-seeded radish cover crop at Lamberton and Rosemount, MN in 2010 and 2011.

	Lamberton		Rosemount	
Biomass[a]	2010	2011	2010	2011
	kg ha^{-1}			
Root	1,308 ± 75	1,360 ± 89	1,302 ± 121	1,390 ± 69
Shoot	3,831 ± 188	3,019 ± 141	2,612 ± 151	2,767 ± 116
Total	5,139 ± 231	4,379 ± 218	3,913 ± 250	4,157 ± 169

[a] Mean ± standard error of the mean.

(Tukey-Kramer, α = 0.05). Residual plots were visually examined for deviations from the assumptions of ANOVA. Square-root transformations were used to correct skew in the June weed density data from Lamberton. Means presented are based on backtransformed data.

Results and Discussion

Weather Conditions. Temperature and precipitation data for the study sites are presented in Figure 1. The spring cover-crop growing season (March 15 to May 15) was cooler than normal in 2011, but warmer than normal in 2012 (Figure 1; Table 3). Spring growing-degree-day accumulation was greater in 2012 than in any of the previous 30 yr. At Lamberton in 2011, precipitation ≥ 5 mm occurred on 14 d out of 46 from May 16 to June 30. These frequent precipitation events interfered with field work and promoted weed growth. Average air temperature was normal to slightly cooler than normal in May and June 2011, but warmer than normal in July 2011 and May to July 2012.

Radish Cover-Crop Establishment and Growth. Fall-seeded radish cover crops established and grew well in all 4 site years (Table 4). However, shoot biomass of spring-seeded radish cover crops was much lower than shoot biomass of fall-seeded radish (Table 5). Even in the unusually warm spring of 2012, radish shoot biomass in treatments with no false seedbed was only 399 kg ha^{-1} at Lamberton and 1,098 kg ha^{-1} at Rosemount, compared to fall shoot biomass of more than 2,600 kg ha^{-1} in all site years (Table 4). Use of the false-seedbed technique further reduced radish biomass

Table 5. Effect of tillage treatment on stand count and shoot biomass production of a spring-seeded radish cover crop in mid-May at Lamberton and Rosemount, MN in 2011 and 2012.

	Stand count				Shoot biomass			
	Lamberton		Rosemount		Lamberton		Rosemount	
Factor[a,b]	2011	2012	2011	2012	2011	2012	2011	2012
	No. m^{-2}				kg ha^{-1}			
Tillage[c]								
False seedbed	32	79	53 a	39 b	0	83 b	23	18 b
No false seedbed	29	88	30 b	110 a	24	399 a	19	1,098 a
	NS	NS			NS		NS	
	P > F							
ANOVA								
Fall cover crop (C)[d]	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	NS	0.011	0.044	NS	0.014	NS	0.011
C by T	NS	NS	NS	NS	NS	NS	NS	NS

[a] Within a column, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).
[b] NS, not significant at the $\alpha = 0.05$ level.
[c] Data combined across spring-only and fall + spring cover crop treatments.
[d] Only the spring-only and fall + spring cover crop treatments were included in the analysis.

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 6. Weed community composition during the corn growing season at Lamberton and Rosemount, MN in 2011 and 2012.[a]

Month	Weed species or group	Lamberton 2011	Lamberton 2012	Rosemount 2011	Rosemount 2012
		Proportion of total[b]			
May (weed density)	Grasses[c]	0.62	0.82	0.41	0.25
	Common lambsquarters	0.20	0.08	0.36	0.38
	Amaranthus spp.	0.00	0.04	0.00	0.19
	Eastern black nightshade	0.00	0.00	0.00	0.08
	Other	0.18	0.07	0.23	0.10
June (weed density)	Grasses	0.52	0.84	0.41	0.27
	Common lambsquarters	0.10	0.04	0.35	0.34
	Amaranthus spp.	0.31	0.05	0.06	0.18
	Eastern black nightshade	0.00	0.00	0.04	0.05
	Dandelion[d]	0.00	0.01	0.01	0.07
	Common purslane[e]	0.00	0.01	0.05	0.03
	Other	0.08	0.04	0.08	0.06
August (weed cover)	Grasses	0.46	0.53	0.25	0.56
	Common lambsquarters	0.06	0.14	0.39	0.23
	Amaranthus spp.	0.37	0.25	0.09	0.14
	Other	0.11	0.09	0.28	0.06

[a] Weed density: only those species or groups which made up at least 5% of the total at one or more site year are listed. Weed cover: only grasses, common lambsquarters, and *Amaranthus* spp. were estimated separately, as these were the most common weeds in all site years.

[b] Due to rounding, proportions may not sum to 1.00.

[c] Due to time constraints, grasses were not identified by species at most sampling dates. In June 2011, the dominant grasses were *Setaria* spp. (green, yellow, and/or giant foxtail), which made up 83% of the total grasses at Lamberton and 20% at Rosemount, and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], which made up 12% of the grasses at Lamberton and 55% at Rosemount. In May 2012, the dominant grass species at both sites was giant foxtail (*Setaria faberi* Herrm.; data not shown).

[d] *Taraxacum officinale* G. H. Weber in Wiggers.

[e] *Portulaca oleracea* L.

in 2012. In the cool spring of 2011, spring radish shoot biomass was less than 25 kg ha^{-1} in all treatments and was not affected by tillage treatment. Fall-seeded radish did not affect stand count or biomass of spring-seeded radish (Table 5). The effect of tillage treatment on stand count varied by site-year, probably because of weather-related differences in timing of radish emergence relative to tillage events. Stand count of spring-seeded radish was always at least 29 plants m^{-2} (Table 5). In a separate field experiment testing the effect of seeding rate on biomass of fall-seeded radish, a stand count of 19 plants m^{-2} was sufficient to achieve shoot biomass production of 2,400 kg ha^{-1} (MF Gieske, unpublished data). Thus, low spring biomass production is due to the short growing season available between snowmelt and corn planting, rather than poor stand establishment.

Fall Weed Cover. At Rosemount in 2011, fall-seeded radish reduced October weed cover from 4 to 0% (data not shown). The dominant weeds in this site year were *Amaranthus* species, common lambsquarters (*Chenopodium album* L.), and eastern black nightshade (*Solanum ptychanthum* Dunal), all of which are summer annuals (data not shown). Both *Amaranthus* and common lambsquarters flowered during the fall season, although plants were small. At Lamberton in 2011, October weed cover was 0% both with and without fall-seeded radish. The effect of fall-seeded radish on fall weed cover was not measured in 2010. In small grain crops, postharvest seed production accounts for a large portion of yearly seed rain (Kegode et al. 2003). Liebman and Davis (2000) proposed the use of cover crops as a way to reduce weed seed production between cash crops. The results of this experiment suggest that fall-seeded radish cover crops may be useful for this purpose. However, further research is needed to determine

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 7. Effect of tillage and cover crop treatments on total weed density in mid-May at Lamberton and Rosemount, MN in 2011 and 2012.

	Weed density			
	Lamberton		Rosemount	
Factor[a,b]	2011	2012	2011	2012
	No. m^{-2}			
Cover crop[c]				
Fall only	66	66	73	171
Spring only	71	73	97	206
Fall + spring	73	59	98	149
No-cover control	73	78	90	217
	NS	NS	NS	NS
Tillage[d]				
False seedbed	13 b	22 b	43 b	60 b
No false seedbed	128 a	116 a	136 a	312 a
	$P > F$			
ANOVA				
Cover crop (C)	NS	NS	NS	NS
Tillage (T)	0.0132	0.0044	0.0256	0.0019
C by T	NS	NS	NS	NS

[a] Within a column and factor, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).

[b] NS, not significant at the $\alpha = 0.05$ level.

[c] Data combined across tillage treatments.

[d] Data combined across cover crop treatments.

whether fall seed rain is affected by radish cover crops.

Winter Annual Weeds. Fall-seeded radish also showed promise for control of winter annual weeds. Although densities of winter annual species were low, field pennycress accounted for the majority of May weed cover at Lamberton in 2011 because of the large size of the plants (data not shown). In this site year, in treatments with no false seedbed, pennycress density was 9 plants m^{-2}, where fall-seeded radish was not present and less than 1 plant m^{-2} where fall-seeded radish was present ($P = 0.0006$). Fall-seeded radish also reduced the density of horseweed at Rosemount in 2011 from 6 to 2 plants m^{-2} ($P = 0.0038$) in treatments with no false seedbed. In other site years, densities of winter annual weeds were too low to permit measurement of the effect of radish cover crops (data not shown). In agreement with the observations of Lawley et al. (2011), these results suggest that fall-seeded radish cover crops may be useful for management of winter annuals. The effect of fall-seeded radish on horseweed density may be of particular interest to conventional farmers, because herbicide-resistant horseweed is a problem in conventional no-till systems (Davis and Johnson 2008). It should be noted that horseweed does not always behave as a winter annual (Davis and Johnson 2008). Buhler and Owen (1997) found that 28 to 32% of total horseweed emergence at Rosemount occurred in the spring, beginning in mid-May. Although it is likely that the majority of the horseweed plants observed in this study emerged in the fall, further research is needed to clarify the effect of fall-seeded radish on fall- and spring-emerging horseweed.

Summer Annual Weeds. Weed community composition data are presented in Table 6. In mid-May, when organic corn is typically planted in Minnesota, the most common weeds included summer annual grasses (25 to 82% of total weed count) and common lambsquarters (8 to 38%) in all site years, as well as *Amaranthus* spp. (19%) and eastern black nightshade (8%) at Rosemount in 2012. The most common weeds in June and August in all site years were summer annual grasses (25 to 84% of total

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 8. Effect of cover crop and tillage treatments on total weed density in June at Lamberton and Rosemount, MN in 2011 and 2012.

Factor[a,b]	Weed density			
	Lamberton		Rosemount	
	2011	2012	2011	2012
	No. m^{-2}			
Cover crop[c]				
Fall only	121	7	14 ab	38 a
Spring only	91	4	10 ab	17 b
Fall + spring	120	7	14 a	27 ab
No-cover control	120	5	7 b	34 ab
	NS	NS		
Tillage[d]				
False seedbed	130	4 a	12	5 b
Standard tillage	–	4 a	–	8 b
Reduced tillage	96	11 a	10	75 a
	NS		NS	
Tillage by cover crop				
False seedbed by fall only	147	4	14	10 bc
False seedbed by spring only	94	1	11	4 c
False seedbed by fall + spring	142	5	15	4 c
False seedbed by no-cover control	138	5	9	2 c
Standard tillage by fall only	–	5	–	5 bc
Standard tillage by spring only	–	4	–	11 bc
Standard tillage by fall + spring	–	4	–	9 bc
Standard tillage by no-cover control	–	3	–	6 bc
Reduced tillage by fall only	97	14	13	99 a
Reduced tillage by spring only	87	8	9	36 bc
Reduced tillage by fall + spring	99	13	14	69 ab
Reduced tillage by no-cover control	103	9	5	95 a
	NS	NS	NS	
ANOVA	P > *F*			
Cover crop (C)	NS	NS	0.0344	0.0379
Tillage (T)	NS	0.0472	NS	0.0044
C by T	NS	NS	NS	0.0063

[a] Within a column and factor, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).
[b] NS, not significant at the $\alpha = 0.05$ level.
[c] Data combined across tillage treatments.
[d] Data combined across cover crop treatments. At Lamberton in 2012, means separation showed no difference between treatments despite the significant tillage effect in the ANOVA.

weeds), *Amaranthus* spp. (5 to 37%), and common lambsquarters (4 to 39%).

Radish cover crops did not affect May weed density (Table 7), August weed cover, or August noncrop (weed plus radish) biomass (Tables 7 and 9). June weed density was affected by radish cover crops only at Rosemount (Table 8). The fall + spring cover-crop treatment had greater June weed density than the no-cover control at Rosemount in 2011, although weed density was fairly low ($\leq$ 14 plants m^{-2}) in all treatments. At Rosemount in 2012, there was no cover-crop effect in the false seedbed and standard tillage treatments, but in the reduced-tillage treatment, spring-seeded radish reduced June weed density. August weed cover and noncrop (weed plus radish) biomass were not affected by radish cover crops (Table 9). Across treatments, June weed

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 9. Effect of cover crop and tillage treatments on August weed cover and noncrop biomass at Lamberton and Rosemount, MN in 2011 and 2012.

Factor[a,b]	Weed cover				Noncrop biomass[c]			
	Lamberton		Rosemount		Lamberton		Rosemount	
	2011	2012	2011	2012	2011	2012	2011	2012
	%				$kg\ ha^{-1}$			
Cover crop[d]								
Fall-only	19 a	3	5	4	1,864	162	103	114
Spring-only	16 a	4	7	3	1,211	331	200	70
Fall + spring	16 a	3	5	3	1,446	289	165	64
No-cover control	16 a	4	6	4	1,298	246	126	96
		NS	NS	NS	NS	NS	NS	NS
Tillage[e]								
False seedbed	18	3	5 b	1 b	1,608	203 b	85	9 b
Standard tillage	16	3	–	1 b	1,343	199 b	–	7 b
Reduced tillage	18	5	7 a	10 a	1,413	369 a	211	241 a
	NS	NS			NS		NS	
	$P > F$							
ANOVA								
Cover crop (C)	0.0399	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	NS	0.0450	0.0003	NS	0.0242	NS	0.0062
C by T	NS	NS	NS	NS	NS	NS	NS	NS

[a] Within a column and factor, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).
[b] NS, not significant at the $\alpha = 0.05$ level.
[c] Noncrop biomass refers to weed plus radish biomass.
[d] Data combined across tillage treatments. At Lamberton in 2011, means separation showed no difference between treatments despite the significant cover crop effect in the ANOVA.
[e] Data combined across cover crop treatments.

density (Table 8) and August weed cover and noncrop biomass (Table 9) were much higher at Lamberton in 2011 than in the other site years, a difference that can be attributed to differences in weather conditions and weed seedbank size between site years. These results suggest that radish cover crops tend not to be effective for managing summer annual weeds.

Tillage treatments affected weed growth during the corn growing season more frequently than cover-crop treatments. Use of a false seedbed consistently reduced May weed density (Table 7), but did not affect weed responses later in the growing season, relative to the standard tillage treatment (Tables 8 and 9). As expected, weed densities in June (Table 8), weed cover in August, and noncrop biomass in August (Table 9) were greater in the reduced tillage treatment compared to the other tillage treatments.

Potential of Radish to Escape Control. The potential of a cover crop to escape control and compete with the crop must be considered when evaluating cover-crop species and management techniques (Snapp et al. 2005). A cover crop can become weedy if it has hard seed, if it produces seed before being killed, or if plants escape seedbed preparation. Fall-seeded radish uniformly was winter killed. Neither fall- nor spring-seeded radish flowered. Radish plants were not present in the fall-only treatment in June and were present at very low densities in August (Table 10). Thus, neither hard seed nor seed set was a problem in this experiment. However, spring-seeded radish sometimes escaped control at crop planting. In treatments with spring-seeded radish and no false seedbed, June radish density could be as high as 12 plants m^{-2} and August radish cover could be as high as 4.6%. Use of a false seedbed controlled

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 10. Effect of cover crop and tillage treatments on density and percent cover of escaped radish at Lamberton and Rosemount, MN in 2011 and 2012.[a]

	June radish density				August radish cover			
	Lamberton		Rosemount		Lamberton		Rosemount	
Factor[a,b]	2011	2012	2011	2012	2011	2012	2011	2012
	no. m^{-2}				%			
Cover crop[c]								
Fall only	0 a	0 b	0 b	0 b	0.0 b	0.2	0.1 c	0.0
Spring only	1 a	1 b	8 a	0 b	0.2 a	0.5	2.8 a	0.0
Fall + spring	1 a	3 a	4 a	1 a	0.1 ab	0.8	1.9 b	0.1
No-cover control	0 a	0 b	0 b	0 b	0.0 b	0.2	0.0 c	0.0
						NS		NS
Tillage[d]								
False seedbed	0	0 b	1	0	0.0	0.4	0.5 b	0.0
Standard tillage	–	1 a	–	0	0.1	0.4	–	0.0
Reduced tillage	1	1 a	5	1	0.1	0.4	1.9 a	0.1
	NS		NS	NS	NS	NS		NS
Tillage by Cover crop								
False seedbed by fall only	0	0 b	0 c	0 b	0.0	0.5	0.1 c	0.0
False seedbed by spring only	0	0 b	3 bc	0 b	0.0	0.3	1.1 c	0.0
False seedbed by fall + spring	1	0 b	1 bc	0 b	0.2	0.5	0.8 c	0.0
False seedbed by no-cover control	0	0 b	0 c	0 b	0.0	0.5	0.1 c	0.0
Standard tillage by fall only	–	0 b	–	0 b	0.0	0.0	–	0.0
Standard tillage by spring only	–	1 b	–	0 b	0.4	0.5	–	0.0
Standard tillage by fall + spring	–	3 a	–	0 b	0.1	1.0	–	0.0
Standard tillage by no-cover control	–	0 b	–	0 b	0.0	0.0	–	0.0
Reduced tillage by fall only	0	0 b	0 c	0 b	0.0	0.0	0.1 c	0.0
Reduced tillage by spring only	1	1 b	12 a	0 b	0.3	0.8	4.6 a	0.0
Reduced tillage by fall + spring	1	4 a	7 ab	2 a	0.1	0.8	3.1 b	0.3
Reduced tillage by no-cover control	0	0 b	0 c	0 b	0.0	0.0	0.0 c	0.0
	NS				NS	NS		NS
	P > *F*							
ANOVA								
Cover crop (C)	0.0416	<0.0001	<0.0001	0.0044	0.0066	NS	<0.0001	NS
Tillage (T)	NS	0.0077	NS	NS	NS	NS	0.0095	NS
C by T	NS	< 0.0001	0.0073	0.0117	NS	NS	< 0.0001	NS

[a] Within a column and factor, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).

[b] NS, not significant at the $\alpha = 0.05$ level.

[c] Data combined across tillage treatments. At Lamberton in 2011, means separation showed no difference in radish density between treatments despite the significant cover crop effect in the ANOVA.

[d] Data combined across cover crop treatments.

escaped radish. Within the false-seedbed treatment, radish density and cover were not significantly greater in plots with spring-seeded radish than in the no-cover control.

Corn Yield. Corn grain yield was not affected by radish cover crop or tillage treatments (Table 11). Grain yield at Lamberton in 2011 was unusually low due to a combination of late planting, unsuccessful weed control, and a frost in September that killed the corn before it reached physiological maturity.

Radish can be established successfully as a cover crop in Minnesota when seeded in mid-August. Although fall-seeded radish did not generally improve management of weeds in this study, it may have benefits in particular situations. For example, the effect of fall-seeded radish on weed seed rain during the fall deserves further study. If

https://doi.org/10.1614/WT-D-15-00023.1 Published online by Cambridge University Press

Table 11. Effect of cover crop and tillage treatments on corn grain yield at Lamberton and Rosemount, MN in 2011 and 2012.[a]

	Corn grain yield			
	Lamberton		Rosemount	
Factor[b,c]	2011	2012	2011	2012
	Mg ha^{-1}			
Cover crop[d]				
Fall-only	4.6	11.1	9.6	10.5
Spring-only	4.9	11.3	8.6	10.8
Fall + spring	4.6	10.9	8.7	10.8
No-cover control	4.7	11.2	8.8	10.7
	NS	NS	NS	NS
Tillage[e]				
False seedbed	5.0	11.3	9.3	10.9
Standard tillage	4.3	11.1	–	10.5
Reduced tillage	4.7	10.9	8.5	10.7
	NS	NS	NS	NS
	$P > F$			
ANOVA				
Cover crop (C)	NS	NS	NS	NS
Tillage (T)	NS	NS	NS	NS
C by T	NS	0.0447	NS	NS

[a] Despite the C by T interaction at Lamberton in 2012, means separation showed no difference between treatments.

[b] Within a column and factor, means followed by the same letter are not significantly different (Tukey-Kramer, $\alpha = 0.05$).

[c] NS, not significant at the $\alpha = 0.05$ level.

[d] Data combined across tillage treatments.

[e] Data combined across cover crop treatments.

fall-seeded radish can reduce weed seed rain, it could play an important role in integrated weed management systems. Likewise, the effect of fall-seeded radish on horseweed establishment should be studied further, with attention to the phenology of the local horseweed population.

Spring-seeded radish had low biomass production because of the short growing window before corn planting. Extending this growing window by further delaying corn planting is unlikely to be acceptable to organic producers in this region because of the risk of crop damage from fall frosts. Although spring-seeded radish sometimes reduced weed emergence during the corn growing season, it did not reduce weed cover and tended to escape control later in the season. Based on the results of this research, the use of a spring-seeded radish cover crop for weed management in organic field crop systems in Minnesota is not advisable.

Acknowledgments

Many thanks to Kevin Betts, Jerry Holz, Brad Kinkaid, Joshua Larson, Zach Marston, Doug Miller, and Steve Quiring for invaluable assistance with this research, and to Carroll Johnson and two anonymous reviewers for comments that greatly improved the manuscript.

Literature Cited

Ackroyd VJ, Ngouajio M (2011) Brassicaceae cover crops affect seed germination and seedling establishment in cucurbit crops. HortTechnology 21:525–532

Adams C, Scott WR, Wilson DR, Purves L (2005) Dry matter accumulation and phenological development of four brassica cultivars sown in Canterbury. Pages 1–18 *in* Proceedings of the Thirty-fifth Annual Conference, Agronomy Society of New Zealand. Hastings, NZ: Agronomy Society of New Zealand

Bastiaans L, Paolini R, Baumann DT (2008) Focus on ecological weed management: what is hindering adoption? Weed Res 48:481–491

Bond W, Grundy AC (2001) Non-chemical weed management in organic farming systems. Weed Res 41:383–405

Brown PD, Morra MJ (1997) Control of soil-borne plant pests using glucosinolate-containing plants. Adv Agron 61:167–231

Buhler DD, Owen MDK (1997) Emergence and survival of horseweed (*Conyza canadensis*). Weed Sci 45:98–101

Cavigelli MA, Teasdale JR, Conklin AE (2008) Long-term agronomic performance of organic and conventional field crops in the mid-Atlantic region. Agron J 100:785–794

Charles KS, Ngouajio M, Warncke DD, Poff KL, Hausbeck MK (2006) Integration of cover crops and fertilizer rates for weed management in celery. Weed Sci 54:326–334

Davis VM, Johnson WG (2008) Glyphosate-resistant horseweed (*Conyza canadensis*) emergence, survival, and fecundity in no-till soybean. Weed Sci 56:231–236

Haramoto ER, Gallandt ER (2005) Brassica cover cropping: I. Effects on weed and crop establishment. Weed Sci 53:695–701

Haramoto ER, Gallandt ER (2004) Brassica cover cropping for weed management: a review. Renewable Agric Food Syst 19:187–198

Huang JZ, Shrestha A, Tollenaar M, Deen W, Rajcan I, Rahimian H, Swanton CJ (2001) Effect of temperature and photoperiod on the phenological development of wild mustard (*Sinapis arvensis* L.). Field Crops Res 70:75–86

Kegode GO, Forcella F, Durgan BR (2003) Effects of common wheat (*Triticum aestivum*) management alternatives on weed seed production. Weed Technol 17:764–769

Kruidhof H, Bastiaans L, Kropff M (2008) Ecological weed management by cover cropping: effects on weed growth in

autumn and weed establishment in spring. Weed Res 48:492–502
Lawley YE, Teasdale JR, Weil RR (2012) The mechanism for weed suppression by a forage radish cover crop. Agron J 104:205–214
Lawley YE, Weil RR, Teasdale JR (2011) Forage radish cover crop suppresses winter annual weeds in fall and before corn planting. Agron J 103:137–144
Liebman M, Davis AS (2000) Integration of soil, crop and weed management in low-external-input farming systems. Weed Res 40:27–47
McMaster GS, Wilhelm WW (1997) Growing degree-days: one equation, two interpretations. Agric Forest Meteorol 87:291–300
Minnesota Department of Agriculture (2007) Overview: Experiences and Outlook of Minnesota Organic Farmers. St. Paul, MN: Minnesota Department of Agriculture. 9 p
Mohler CL (2001) Mechanical management of weeds. Pages 139–209 *in* Liebman M, Mohler CL, Staver CP, eds. Ecological Management of Agricultural Weeds. Cambridge, United Kingdom: Cambridge University Press
Moynihan M (2010) Status of organic agriculture in Minnesota: A report to the Minnesota Legislature: 2010. St. Paul, MN: Minnesota Department of Agriculture. 55 p
Norsworthy JK, Brandenberger L, Burgos NR, Riley M (2005) Weed suppression in *Vigna unguiculata* with a spring-seeded brassicaceae green manure. Crop Prot 24:441–447
O'Reilly KA, Robinson DE, Vyn RJ, Van Eerd LL (2011) Weed populations, sweet corn yield, and economics following fall cover crops. Weed Technol 25:374–384
Petersen J, Belz R, Walker F, Hurle K (2001) Weed suppression by release of isothiocyanates from turnip-rape mulch. Agron J 93:37
Porter PM, Huggins DR, Perillo CA, Quiring SR, Crookston RK (2003) Organic and other management strategies with two- and four-year crop rotations in Minnesota. Agron J 95:233–244
Posner JL, Baldock JO, Hedtcke JL (2008) Organic and conventional production systems in the Wisconsin integrated cropping systems trials: I. Productivity 1990–2002. Agron J 100:253–260
Sang JP, Minchinton IR, Johnstone PK, Truscott RJW (1984) Glucosinolate profiles in the seed, root and leaf tissue of cabbage, mustard, rapeseed, radish and swede. Can J Plant Sci 64:77–93
Snapp SS, Swinton SM, Labarta R, Mutch D, Black JR, Leep R, Nyiraneza J, O'Neil K (2005) Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron J 97:322–332
Stivers-Young L (1998) Growth, nitrogen accumulation, and weed suppression by fall cover crops following early harvest of vegetables. HortScience 33:60–63
Walz, E (1999) Final Results of the Third Biennial National Organic Farmers' Survey. Santa Cruz, CA: Organic Farming Research Foundation. 126 p
Wang G, Ngouajio M, Warncke DD (2008) Nutrient cycling, weed suppression, and onion yield following brassica and sorghum sudangrass cover crops. HortTechnology 18:68–74

Received February 20, 2015, and approved December 7, 2015.

Associate Editor for this paper: W. Carroll Johnson III, USDA-ARS.