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Source: Weed Technology, 26(4):818-825. 2012.
Published By: Weed Science Society of America
DOI: http://dx.doi.org/10.1614/WT-D-12-00084.1
URL: http://www.bioone.org/doi/full/10.1614/WT-D-12-00084.1

Weed Technology 2012 26:818–825

Winter Annual Weed Suppression in Rye–Vetch Cover Crop Mixtures

Zachary D. Hayden, Daniel C. Brainard, Ben Henshaw, and Mathieu Ngouajio*

Winter annual weeds can interfere directly with crops and serve as alternative hosts for important pests, particularly in reduced tillage systems. Field experiments were conducted on loamy sand soils at two sites in Holt, MI, between 2008 and 2011 to evaluate the relative effects of cereal rye, hairy vetch, and rye–vetch mixture cover crops on the biomass and density of winter annual weed communities. All cover crop treatments significantly reduced total weed biomass compared with a no-cover-crop control, with suppression ranging from 71 to 91% for vetch to 95 to 98% for rye. In all trials, the density of nonmustard family broadleaf weeds was either not suppressed or suppressed equally by all cover crop treatments. In contrast, the density of mustard family weed species was suppressed more by rye and rye–vetch mixtures than by vetch. Cover crops were more consistently suppressive of weed dry weight per plant than of weed density, with rye-containing cover crops generally more suppressive than vetch. Overall, rye was most effective at suppressing winter annual weeds; however, rye–vetch mixtures can match the level of control achieved by rye, in addition to providing a potential source of fixed nitrogen for subsequent cash crops.

Nomenclature: Cereal rye, *Secale cereale* L.; hairy vetch, *Vicia villosa* Roth; mustard family, *Brassicaceae*
Key words: Biculture, biomass, cereal, density, grass, legume.

Las malezas anuales de invierno pueden interferir directamente con los cultivos y pueden servir como hospederos alternativos para plagas importantes, particularmente en sistemas con labranza reducida. Se realizaron experimentos de campo en suelos areno limosos en dos sitios en Holt, Michigan entre 2008 y 2011 para evaluar los efectos relativos de los cultivos de cobertura *Secale cereale* , *Vicia villosa* y la mezcla *S. cereale-V. villosa* sobre la biomasa y la densidad de las comunidades de malezas anuales de invierno. Todos los tratamientos de cultivos de cobertura redujeron significativamente la biomasa total de malezas en comparación con el testigo sin cultivo de cobertura, con una supresión que varió de 71 a 91% en el caso de *V. villosa* y de 95 a 98% en el caso de *S. cereale*. En todos los experimentos, la densidad de malezas de hoja ancha que no pertenecen a la familia de la mostaza (*Brassicaceae*) no fue suprimida o fue suprimida de la misma forma por todos los tratamientos de cobertura. En contraste, la densidad de la familia de la mostaza fue suprimida más por los tratamientos con *S. cereale* que el tratamiento de *V. villosa*. Los cultivos de cobertura fueron más consistentemente supresores del peso seco por individuo de malezas que de la densidad de malezas, y las coberturas que contenían *S. cereale* fueron más supresoras que la cobertura de *V. villosa*.

Crop production losses in the United States due to agricultural weeds may be as high as $33 billion annually, and American farmers spend an estimated $6 billion each year on herbicides, tillage, and cultivation for weed control (Liebman et al. 2001; Pimentel et al. 2005). Summer annual weed species are undoubtedly the greatest contributors to these costs, because they have life cycles that facilitate direct interference with most agronomic and vegetable crops. As a result, comparatively little research in summer annual cropping systems has focused on winter annual weeds, which establish before warm-season production windows and are typically controlled by preplanting tillage or herbicide applications. However, in part because of increasing adoption of reduced tillage systems (CTIC 2008), reductions in residual herbicide usage (Young 2006), and trends toward milder winter temperatures in North America (Hayhoe et al. 2006), winter annuals may become a greater management priority in the future (Creech et al. 2008).

In the absence of an established forage or cover crop, winter annual weeds may provide valuable services in fields during the off-season, including erosion control and recycling of residual nutrients (Jordan and Vatovec 2004). However, the significant challenges posed by increasingly prevalent winter annual populations likely outweigh any potential benefits. In no-till and other reduced tillage systems, winter annual and perennial weeds not controlled in the fall or spring can interfere directly with early-season or summer cash crops, and their previous establishment can make them highly competitive (Brainard et al. 2012b; Liebman et al. 2001). This is particularly problematic in organic reduced tillage systems, where the prohibition of synthetic herbicides leaves few options for effective preplant control. Failure to effectively control winter annual weeds will also increase soil seedbanks over time, which can lead to costly infestations in winter annual cash crops (e.g., winter cereals) grown later in a rotation (Mirsky et al. 2010). Moreover, many "winter annual" weed species are actually facultative winter annuals, which can germinate in both the fall and spring (Cici and Van Acker 2009), and can reduce yields, interfere with harvest, and serve as costly contaminants in summer annual as well as winter annual crops. For example, mayweed chamomile (*Anthemis cotula* L.) is a weed in winter wheat and can also interfere with combining during pea (*Pisum sativum* L.) harvest in Washington and northern Idaho (Ogg et al. 1993). Furthermore, as alternative hosts for economically important pests and diseases, overwintering weeds can also serve as

DOI: 10.1614/WT-D-12-00084.1
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"biological bridges" from one growing season to the next (Norris and Kogan 2005; Wisler and Norris 2005), fostering plant parasitic nematodes and plant pathogenic viruses, as well as their insect vectors in some cases (Creech et al. 2007; Duffus 1971; Groves et al. 2001). Since many common winter annuals belong to the Brassicaceae (mustard family), vegetable crops in this family may be particularly vulnerable to pests and diseases where winter annuals are not controlled (Chen et al. 2009; Schaad and Dianese 1981).

Cover cropping is an important component of integrated approaches to weed management. Residues from winter cover crops are well studied for their potential to suppress summer weed populations, particularly when maintained as a surface mulch in reduced tillage systems (Carrerra et al. 2004; Teasdale 1996; Teasdale and Mohler 1993). However, in addition to the provision of agroecosystem services like erosion control, organic matter addition, nutrient recycling, and nitrogen fixation, winter cover crops also have significant potential for managing winter annual weeds. Displacing winter annual populations with cover crop species that are unsuitable or less-suitable alternative hosts may reduce overwintering reservoirs of important pests and diseases, as well as draw down weed seedbanks over time. Cover crops are more likely to be adopted, however, if they can combine effective weed suppression with other desirable services.

Winter cover crops composed of mixtures of cereal and legume species, such as cereal rye and hairy vetch, have been studied for their potential to provide significant fixed nitrogen with greater weed suppression and lower overall seed costs than monoculture legumes (Brainard et al. 2012a). Mixtures are often more efficient than monocultures in the capture of light, water, and nutrients (Liebman and Dyck 1993), which may contribute to greater biomass productivity in cover crop mixtures vs. monocultures, and suggests that mixtures may be more competitive with weeds. In practice, weed suppression in cereal–legume mixtures may be more closely related to the presence of the competitively dominant cereal species, rather than on the diversity of the mixture, per se (Liebman and Dyck 1993). Accordingly, many studies suggest that cereal–legume mixtures often suppress weeds better than a monoculture of the legume, but less than or equivalent to a monoculture of the cereal (Akemo et al. 2000; Brainard et al. 2011; Brennan and Smith 2005; Mohler and Liebman 1987; Poggio 2005).

Although cereal rye and hairy vetch are well researched both as winter cover crop monocultures and in mixture, few studies have documented the effects of rye–vetch mixtures on winter annual weeds. In monoculture, the notable ability of rye to suppress weeds, reduce nitrate leaching, and control erosion is often tempered by the high C : N ratio of its residues and the threat of subsequent yield losses due to nitrogen immobilization (McCracken et al. 1994; Shipley et al. 1992; Wagger et al. 1998). Vetch, on the other hand, can fix large amounts of nitrogen, but generally provides less effective weed suppression than rye (Clark 2007; Clark et al. 2007; Mennan et al. 2009). In mixture, rye–vetch stand characteristics vary among studies, but total N release from mixture residues can approach the amount released from vetch monocultures, and total dry-matter yields of rye–vetch cover crops can be greater than yields of either species in monoculture (Ranells and Wagger 1996; Sainju et al. 2005). These qualities suggest that rye–vetch mixtures could be effective cover crops for controlling winter annual weeds, in balance with providing other important services.

The objective of this research was to evaluate the relative effects of rye, hairy vetch, and rye–vetch mixture cover crops on the biomass and density of winter annual weed communities.

Materials and Methods

Two separate experiments were conducted at the Michigan State University (MSU) Horticulture Teaching and Research Center in Holt, MI (42°40′N, 84°28′W) at two sites within 2 km of each other (hereafter referred to as College Rd and Jolly Rd), both on Spinks loamy sand soil (sandy, mixed, mesic Lamellic Hapludalf). Initial soil chemical characteristics at College Rd included pH 6.6; CEC 7.7 cmol kg^{-1}; and P, K, and Mg levels of 117, 146, and 42 mg kg^{-1}, respectively. Initial soil chemical characteristics at Jolly Rd included pH 7.9; CEC 7.5 cmol kg^{-1}; and P, K, and Mg levels of 71, 83, and 266 mg kg^{-1}, respectively. Experiments at both sites were repeated for two seasons, alternating between adjacent fields, from 2008 to 2011. Summer cover crops of sorghum sudangrass (*Sorghum bicolor* × *S. bicolor* var. sudanense) were grown on each field before seeding winter cover crops in the fall.

Experiments at both sites investigated the effects of rye and hairy vetch cover crops on winter annual weed populations using a randomized complete block design with four replications. Cover crop treatments common to the College Rd and Jolly Rd experiments included: hairy vetch in monoculture (V), cereal rye in monoculture (R), a rye–vetch mixture (RV), and a control treatment with no winter cover crop (C). Vetch seeding rates were 42 and 45 kg ha^{-1} in monoculture and 21 and 22.5 kg ha^{-1} (50% of monoculture rate) in mixture at College Rd and Jolly Rd, respectively, whereas rye was sown at 94 and 125 kg ha^{-1} in monoculture and 47 and 62.5 kg ha^{-1} in mixture. "Variety not stated" (VNS) vetch seed from Oregon was used at both sites, whereas VNS rye from Minnesota and 'Wheeler' rye were used at the College Rd and Jolly Rd sites, respectively (Albert Lea Seed House, Albert Lea, MN). At College Rd, plot sizes were 6.7 by 8.5 m in 2009 to 2010 and 6.1 by 7.6 m in 2010 to 2011, whereas at Jolly Rd, plots were 3.8 by 18.3 m in 2008 to 2009 and 3.0 by 12.2 m in 2009 to 2010.

The dates of key field operations and data collection are summarized in Table 1. Previous sorghum sudangrass summer cover crops were flail mowed and incorporated at least 2 wk before winter cover crop seeding in all trials. Incorporation was accomplished with a rototiller at College Rd and with a moldboard plow and rotary spader at Jolly Rd in 2008 and 2009, respectively, followed by secondary tillage with a disk. The College Rd experiment was managed organically with no additional soil amendments applied. The Jolly Rd experiment was managed conventionally, and fall fertilizer applications included 224 kg ha^{-1} 19-19-19 (N–P–K) in 2008 and 45 kg ha^{-1} urea plus 67 kg ha^{-1} potash in

Table 1. Dates of key field operations and data collection at College Rd and Jolly Rd.

	College Rd		Jolly Rd	
Activity	2009–2010	2010–2011	2008–2009	2009–2010
Cover crops seeded	September 1	September 1	September 4	September 5
THLAR[a] transplanted	—	—	September 29	October 16
Ambient weeds sampled	May 10	May 14	—	April 2
THLAR biomass sampled	—	—	May 13	May 7
Cover crop biomass sampled	May 10	May 14	May 29	May 27

[a] Field pennycress, *Thlaspi arvense* L.

2009, in addition to 336 kg ha^{-1} elemental S applied in both years to lower soil pH. All amendments were broadcast and incorporated using a harrow. At College Rd, winter cover crop treatments were sown on September 1 in both 2010 and 2011. Rye and vetch seeds were broadcast by hand using a grid system to ensure uniformity, and then incorporated to a depth of roughly 5 cm using a field cultivator. Cover crops at Jolly Rd were drilled on September 2, 2008 using a Moore Unidrill no-till seeder (County Antrim, Northern Ireland). In 2009, rye was drilled using a John Deere 750 no-till grain drill (Deere and Company, Moline, IL) on September 4, whereas vetch was seeded using a Jang push seeder (JP-3, Chungbuk, South Korea). All vetch seed was inoculated with N-DURE *Rhizobium leguminosarum* inoculant before seeding (INTX Microbials LLC, Kentland, IN) at a rate of approximately 10 g inoculant kg^{-1} seed.

Cover crop densities and aboveground biomass were sampled in the spring from four 25- by 50-cm (0.125 m^2) quadrats in each plot at College Rd on May 10, 2010 and May 14, 2011, and from two 0.5-m^2 quadrats per plot at Jolly Rd on May 29, 2008 and May 27, 2009. At College Rd, biomass and densities of weed populations were sampled from those same quadrats at the time of cover crop sampling, and weeds sampled from C, V, RV, and R treatments were subsequently sorted by species in the laboratory. At Jolly Rd, weed populations were not sampled in 2009, and weed biomass was not collected in 2010. However, densities of weed populations were sampled on April 2, 2010 using two 0.5-m^2 quadrats in each plot. In addition, individuals of field pennycress were transplanted into Jolly Rd cover crop plots to evaluate the effects of cover crop treatments on the growth of this problematic mustard family weed while also controlling for variability in field population densities and possible confounding effects of cover crops on field pennycress emergence. A total of 12 (in 2008) and 5 (in 2009) field pennycress individuals that emerged after preplanting tillage (growing outside but adjacent to the experimental area) were transplanted into two locations in each plot on September 29, 2008 and October 16, 2009. Field pennycress rosettes were 2.5 to 5 cm in diameter at the time of transplanting, and were transplanted at a spacing of 30 cm within rows. After overwintering and spring growth periods, the number of surviving transplants was recorded and their biomass sampled on May 13, 2009 and May 7, 2010. Average survival of transplants was 82 and 99% in 2009 and 2010, respectively, and cover crop treatment did not significantly affect transplant survival in either year (data not shown). For both trials, all cover crop and weed biomass samples were dried to constant weight at 38 C.

Weeds were identified to species, and the data were then grouped into the following categories for analysis: mustard family weeds, other broadleaves, grasses, and total weeds. The fixed effect of rye–vetch cover crop treatment on all variables was evaluated using the Proc MIXED procedure in SAS (Version 9.2, SAS Institute, Cary, NC) with block (replicate) included as a random effect in the model. Data were natural-log or square-root transformed as necessary to meet ANOVA assumptions of normality and homogeneity of variances. Data were analyzed separately by trial location and year because of differences in management and the composition of weed communities among the experimental fields. Where the global F test was significant ($P < 0.05$), treatment means were separated using Fisher's Protected LSD test.

Results and Discussion

Figure 1 presents aboveground biomass produced by rye and vetch in cover crop monoculture and mixture treatments in the College Rd and Jolly Rd experiments. Average vetch biomass in monoculture varied between 356 and 563 g m^{-2} across sites and years, whereas rye biomass ranged from 330 to 587 g m^{-2}, both typical ranges for these cover crop species in the Great Lakes region (Clark 2007; Sarrantonio 1994). Seeding dates were similar across trials and years, with cover crops at Jolly Rd seeded 3 to 4 d later in September than at College Rd (Table 1). However, cover crops were sampled on average 2 wk later in May at Jolly Rd than at College Rd (Table 1), resulting in a longer period of cover crop growth for the Jolly Rd experiment. Total rye–vetch mixture biomass tended to be dominated by rye at Jolly Rd (60 and 69% rye by dry weight in 2009 and 2010, respectively), whereas the proportions of rye to vetch biomass in mixtures at College Rd were closer to 1 : 1 (46 and 55% rye in 2010 and 2011, respectively). Higher rye seeding rates, higher soil N fertility as a result of fall fertilization, and slightly later fall planting dates at Jolly Rd could all favor rye over vetch in mixture (Clark et al. 2007; Jannink et al. 1997; Jensen 1996; Shipley et al. 1992).

Total aboveground biomass production among the cover crop treatments did not differ significantly at College Rd in 2010 or 2011 (Figure 1A). In contrast, total biomass production in the rye–vetch mixture was significantly greater than either monoculture at Jolly Rd in 2009, and rye and rye–vetch mixture treatments produced similar biomass in 2010,

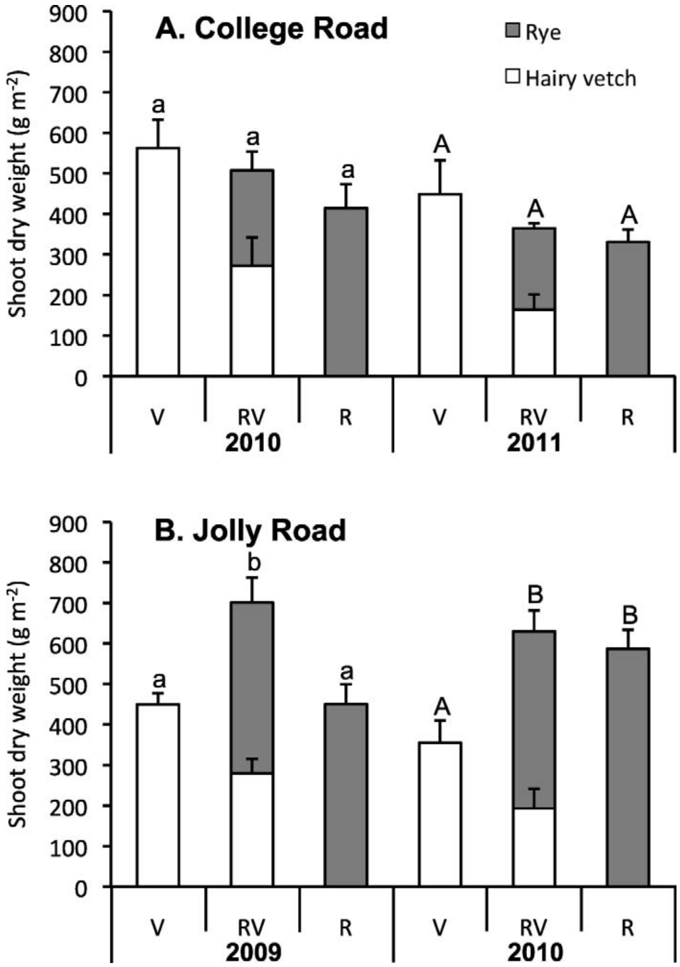

Figure 1. Mean (± SE) shoot dry weight of vetch (V), rye–vetch mixture (RV), and rye (R) winter cover crops in the spring at (A) College Rd in 2010 and 2011, and (B) Jolly Rd in 2009 and 2010. For RV treatments, the height of the stacked bar represents total cover crop biomass (rye + vetch), whereas depicted standard errors correspond to the mean biomass of each component species in the mixture. Within a given site and year, total cover crop biomass is not significantly different for treatments labeled with the same letter ($\alpha = 0.05$).

both significantly greater than the vetch monoculture (Figure 1B). The large amounts of total biomass produced by the rye–vetch mixtures relative to the monoculture treatments at Jolly Rd were driven largely by the rye component; although seeded at half the monoculture rate, rye biomass in mixture was 94 and 74% of that produced in monoculture in 2009 and 2010, respectively.

Weed community composition in experimental fields varied with location and year. Table 2 lists dominant weed species at College Rd and Jolly Rd in 2010 and 2011. Collectively, mustard family species made up 52 to 55% of the total weed density in control treatments at College Rd in 2010 and 2011, respectively, but accounted for only 22 to 29% of the total weed biomass, reflecting their relatively small size in the spring compared with other winter annual broadleaf and grass species present in the fields. Common chickweed [*Stellaria media* (L.) Vill.] was an abundant broadleaf weed in all years at both sites. Other broadleaf species present at College Rd included henbit (*Lamium amplexicaule* L.) in 2010 and corn chamomile (*Anthemis arvensis* L.) in 2011, whereas at Jolly Rd, broadleaf weeds other than chickweed were not identified to the species level. No grass weeds were abundant at College Rd in 2011, and annual bluegrass (*Poa annua* L.) was the only grass species abundant in 2010; however, annual bluegrass distribution across the field tended to be more variable than other weed species at College Rd, likely reducing the power of statistical inference regarding cover crop effects on annual bluegrass. At Jolly Rd, grasses comprised nearly 40% of the total weed community by density, but data were not collected to the species level. Total weed pressure in experimental fields, on the basis of control treatments, was lowest at Jolly Rd in 2010 (139 plants m^{-2}), followed by College Rd in 2010 (431 plants m^{-2}), and highest at College Rd in 2011 (1,120 plants m^{-2}).

In both years at College Rd, all winter cover crop treatments reduced weed biomass (dry weight, g m^{-2}) compared with the no-cover-crop control, although the reduction was not significant for annual bluegrass (Table 3A). In 2010, suppression of total weed biomass ranged from 91% in vetch monoculture to 95 and 98% in the rye–vetch mixture and rye monoculture, respectively. Rye provided significantly greater suppression of weed biomass than vetch monoculture for mustard species, but not for other broadleaf species (mostly common chickweed). In 2011, total weed biomass suppression was 71% in vetch monoculture, compared with 94 and 95% in the rye–vetch mixture and rye monoculture, respectively. Rye suppressed both mustard and other broadleaf species significantly more than vetch. In both years, the rye–vetch mixture provided suppression of weed biomass equivalent to that of the rye monoculture.

Our results are generally consistent with previous studies showing greater weed-suppressive ability of cereal species compared with legumes (Brainard et al. 2011; Ofori and Stern 1987), which may be a result of more effective resource competition or allelopathy (Barnes and Putnam 1986). Suppression by rye-containing cover crops was also less variable between 2010 and 2011 compared with suppression by vetch in monoculture, suggesting that the suppressive ability of rye may be more robust in the face of year-to-year variability in environmental conditions than vetch. We speculate that cooler spring temperatures in 2011 (data not shown) may have limited vetch growth relative to both weeds and rye that year, resulting in less effective weed suppression by vetch, and perhaps a greater proportion of rye in the rye–vetch mixture (Figure 1A). The relative proportion of the component species in cereal–legume mixtures is likely a key determinant of mixture performance. In a study of rye–pea cover crop mixtures, Akemo et al. (2000) observed that weed biomass decreased with increasing proportion of rye in the mixture, despite decreasing total cover crop biomass. Therefore, the weed suppressiveness of cereal–legume mixtures is likely closely related to the relative proportion of the cereal species.

Although total weed biomass in the field is a relevant measure of actual weed pressure, it is also a function of both the density of weeds present and their average individual biomass production. Separately evaluating effects on weed

Table 2. Dominant weed species present at College Rd and Jolly Rd in 2010 and 2011, including percent composition based on density and biomass calculated from control treatments.

	% Density			% Biomass	
	College Rd		Jolly Rd	College Rd	
Species	2010	2011	2010	2010	2011
	%				
Mustard family species	**52**	**55**	**30**	**22**	**29**
Field pepperweed—*Lepidium campestre* (L.) R. Br.	12	29	—	6	20
Mouse-ear cress—*Arabidopsis thaliana* (L.) Heynh.	8	21	—	5	5
Shepherd's-purse—*Capsella bursa-pastoris* (L.) Medik.	20	3	7	10	4
Spring whitlowgrass—*Draba verna* L.	11	2	—	2	< 1
Field pennycress—*Thlaspi arvense* L.	—	—	20	—	—
Hoary alyssum—*Berteroa incana* (L.) DC.	—	—	3	—	—
Other broadleaf species	**30**	**45**	**30**	**61**	**71**
Common chickweed—*Stellaria media* (L.) Vill.	22	20	12	51	18
Henbit—*Lamium amplexicaule* L.	7	—	—	9	—
Corn chamomile—*Anthemis arvensis* L.	—	25	—	—	53
Other[a]	—	—	18	—	—
Grass species	**19**	—	**39**[b]	**18**	—
Annual bluegrass—*Poa annua* L.	19	—	—	18	—

[a] With the exception of *Stellaria media*, "Other broadleaf species" data were not collected to the species level at Jolly Rd.

[b] Data for "Grass species" were not collected to the species level at Jolly Rd.

density and weed dry weight per plant can provide greater insight into the potential mechanisms behind suppression by cover crops. For example, Kumar et al. (2008) found that both the inhibitory effects of cover crops on weeds (including corn chamomile and shepherd's-purse) and the mechanisms responsible for these effects (nitrogen and fungal pathogens) differed for emergence and growth life stages.

At College Rd, all cover crops reduced the density of weeds (with the exception of annual bluegrass) compared with the control in 2010 (Table 3B). Rye was significantly more suppressive of mustard weed density than both the vetch monoculture and the rye–vetch mixture, but the density of other broadleaf species was reduced equally by all cover crop treatments. In 2011, mustard weed density was suppressed by all cover crop treatments, with the rye–vetch mixture and rye monoculture providing equivalent control, both greater than the vetch monoculture. The density of other broadleaf species, however, was not significantly affected by any of the cover crops.

Table 3. Effect of cover crop treatment on (A) total shoot dry weight, (B) density, and (C) shoot dry weight per plant of dominant winter annual weeds present in the College Rd experiment in 2010 and 2011.

	Mustards		Other broadleaves		Grasses[a]		Total	
Cover Crop	2010	2011	2010	2011	2010	2011	2010	2011
	$g\ m^{-2}$							
A. Dry weight								
None	25.9 a[b]	45.5 a	72.3 a	110.8 a	21.1 a	—	119.3 a	156.3 a
Vetch	1.5 b	19.2 b	3.3 b	27.0 b	5.5 a	—	10.3 b	46.2 b
Rye–vetch	0.6 bc	2.6 c	3.2 b	6.6 c	2.6 a	—	6.3 bc	9.2 c
Rye	0.1 c	1.9 c	1.4 b	6.7 c	0.9 a	—	2.4 c	8.6 c
	plants m^{-2}							
B. Density								
None	223 a	616 a	128 a	504 a	81 a	—	431 a	1,120 a
Vetch	38 b	275 b	14 b	226 a	56 a	—	108 b	500 b
Rye–vetch	37 b	138 c	15 b	185 a	72 a	—	123 b	323 b
Rye	6 c	105 c	17 b	259 a	25 a	—	48 b	364 b
	mg $plant^{-1}$							
C. Dry weight per plant								
None	118.1 a	75.8 a	589.5 a	235.1 a	195.8 a	—	279.3 a	137.5 a
Vetch	37.0 b	75.1 a	225.5 b	128.7 b	129.2 a	—	102.0 b	96.8 a
Rye–vetch	14.1 c	16.7 b	217.1 b	34.9 c	71.9 a	—	85.0 bc	26.8 b
Rye	18.1 c	15.4 b	67.9 c	24.7 c	34.0 a	—	46.5 c	22.2 b

[a] Annual bluegrass (*Poa annua* L.) was the only abundant grass species present in 2010.

[b] For a given measurement, means within a column followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 4. Effect of cover crop treatment on density of dominant winter annual weeds present in the Jolly Rd experiment in 2010.[a]

Cover crop	Mustards	Other broadleaves	Grasses	Total
	plants m^{-2}			
None	42 a[b]	42 a	55 a	139 ab
Vetch	42 a	47 a	70 a	159 a
Rye–Vetch	11 b	50 a	5 b	66 c
Rye	11 b	50 a	11 b	72 bc

[a] Density data do not include transplanted field pennycress (Figure 2).

[b] Means within a column followed by the same letter are not significantly different ($\alpha = 0.05$).

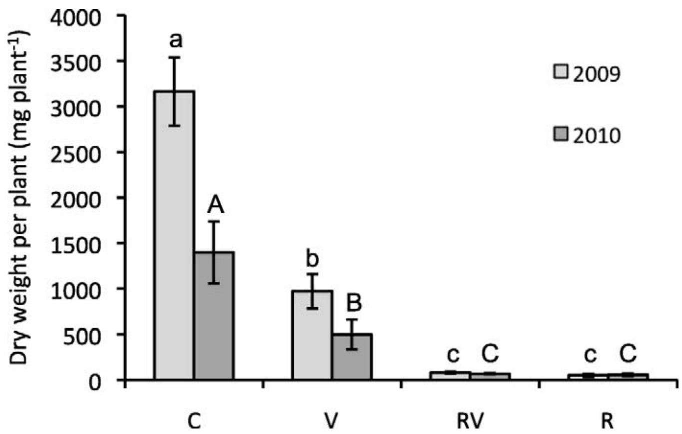

Figure 2. Mean (± SE) dry weight per plant of transplanted field pennycress (*Thlaspi arvense* L.) in control (C), vetch (V), rye–vetch mixture (RV), and rye (R) treatments at Jolly Rd in 2009 and 2010. Within a given year, means labeled with the same letter are not significantly different ($\alpha = 0.05$).

Comparable results were obtained at Jolly Rd in 2010, where the rye–vetch mixture and rye monoculture both significantly reduced mustard and grass species density compared with the control and vetch monoculture, but did not have an effect on other broadleaf density (Table 4). In contrast to the results from College Rd, however, the vetch monoculture did not reduce weed densities compared with the control at Jolly Rd. This difference may in part be attributable to the early timing of weed sampling at Jolly Rd (April 2, compared with mid-May at College Rd). Vetch often doesn't achieve more than 30% ground cover in the fall, and produces the majority of its biomass during the warmest months of the spring (Shipley et al. 1992; Teasdale et al. 2004). Cover crops that can close their canopy earlier in the season are often better at suppressing weeds (Brennan et al. 2011), and vetch biomass at the time weeds were sampled was likely close to only half the amount observed in May. Rye, on the other hand, generally provides more extensive soil cover in the fall (Boyd et al. 2009), in addition to its capacity to deplete soil moisture and nutrients (particularly N) early in the season (Brainard et al. 2012c; Shipley et al. 1992). The potential for rye to effectively interfere with weeds earlier than vetch may explain why the rye monoculture and rye–vetch mixture (69% rye biomass) at Jolly Rd still exhibited suppression of mustard and grass weed density at the earlier sampling date. Furthermore, the suppression of grass species by rye-containing cover crops at Jolly Rd suggests that the lack of significant cover crop effects for annual bluegrass at College Rd is not reflective of grasses in general.

Interestingly, in all trials, the density of nonmustard broadleaf species (common chickweed, corn chamomile, and henbit) was suppressed equally by all cover crop treatments, whereas that of mustards was suppressed more by rye than by vetch (Tables 3B and 4). In a broad sense, cover crops reduce weed density through a combination of inhibiting seed germination or emergence, and promoting post-emergence mortality through interference or environmental effects. Although we can only speculate, the greater suppression of mustards by rye compared with vetch may have been due in part to mustard sensitivity to nitrogen depletion or shade. Many members of the mustard family are highly sensitive to soil N levels in both their germination (Kumar et al. 2008) and growth (Blackshaw et al. 2003) responses, so reductions in soil N due to rye may have weakened these species and contributed to their mortality. Conversely, several of the nonmustard species present in our trials, including common chickweed and corn chamomile, are known to be relatively shade tolerant (Turkington et al. 1980) and less sensitive to nitrogen depletion (Blackshaw et al. 2003; Kumar et al. 2008), and thus perhaps better able to withstand competition from rye and vetch cover crops than mustards. In a study comparing the effects of 12 weed species on kale and sugar beets under different levels of nitrogen, Welbank (1963) found that the competitive effect of chickweed—one of the primary nonmustard broadleaf species in our trials—was relatively unaffected by nitrogen level. The greater inhibitory effects of rye relative to vetch are likely to be most pronounced for weed species that germinate and grow primarily in the fall when rye growth typically exceeds that of hairy vetch. Conversely, for facultative winter annuals that have significant flushes of emergence in the spring—potentially including common chickweed, henbit, and corn chamomile, but also shepherd's-purse and field pennycress (Cici and Van Acker 2009; Kay 1971)—fewer differences in density suppression due to cover crops might be expected since growth of rye and vetch is more similar at that time.

Cover crop treatments, particularly those containing rye, were more consistently suppressive of weed biomass production (as measured by dry weight per plant) than of weed density. All cover crop treatments significantly reduced the dry weight per plant of other broadleaf species compared with the control in trials at College Rd, with rye monoculture consistently providing the highest level of suppression (Table 3C). The rye–vetch mixture equaled rye in 2011, but not in 2010. Mustard dry weight per plant was not significantly lower in vetch monoculture than in the control in 2011, but otherwise, all cover crop treatments suppressed the growth of mustard species as well. Rye monoculture and the rye–vetch mixture provided equivalent suppression of mustards in both years at College Rd, a trend that was also present for annual bluegrass in 2010, though not significant. Transplanted field pennycress responded similarly to cover crop treatments at Jolly Rd in 2009 and 2010 (Figure 2). Both the rye monoculture and the rye–vetch mixture provided over 95% suppression of field pennycress dry weight per plant in each year, compared with less than 70% suppression by vetch monoculture. Cereals are generally better competitors than legumes (Ofori and Stern 1987), and as our results support, this quality tends to be manifest more in the suppression of weed growth than weed density (Boyd et al. 2009).

This research supports that winter cover crops composed of rye or vetch (or both) can significantly suppress winter annual weeds. Reductions in the biomass of winter annuals present in fields may decrease the size of overwintering populations of important pests and diseases, which could in turn lower disease pressure during the following season. However, hairy vetch is also known to be a reproductive host for several species of plant parasitic nematodes, so growing vetch before susceptible crops should be avoided (Aarssen et al. 1986; Rich et al. 2009; Timper et al. 2006). Despite suppressing weed biomass production across taxonomic groups, the cover crops failed to consistently reduce the density of nonmustard broadleaf weeds, including common chickweed, henbit, and corn chamomile. Particularly in organic reduced tillage systems, dense populations of these low-growing species could become a problem in subsequent crops if they are able to survive mechanical kill of the cover crops. The persistence of these weeds highlights the importance of integrating winter cover crops with other weed-management strategies to provide more complete control and avoid increases in problematic weeds over time (Liebman and Gallandt 1997).

Overall, cereal rye was the most effective weed suppressor. Therefore, where winter annual weed control is a primary objective, rye would likely be the most effective and inexpensive cover crop option. However, our results demonstrate that rye–vetch mixtures can match the level of suppression achieved by rye monoculture, in addition to providing a potential source of fixed nitrogen—a benefit particularly relevant for organic production. The weed suppressiveness of the mixtures is likely tied to relative species composition, and mixtures containing less than 50% rye biomass may sacrifice winter annual weed control. Additional research is needed to relate rye–vetch seeding rates to resulting stand characteristics, and to investigate how species proportions in rye–vetch mixtures influence the provision of other agroecosystem services.

Acknowledgments

This research received financial support from the U.S. Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA) Sustainable Agriculture Research and Education (SARE) program (project no. GNC09-108), from USDA Cooperative State Research, Education, and
?1 Extension Service (CSREES) Special Research Grant no. 03162 (Sustainable Agriculture 2008: Developing Sustainable Agriculture and Food Systems), from MSU AgBioResearch Project GREEEN (project no. GR09-068), and from The Ceres Trust Organic Research Initiative. Additional support came from the C. S. Mott Group for Sustainable Food Systems and the Ecological Food and Farming Systems Program at Michigan State University. Special thanks to Ajay Nair, Drey Clark, Corey Noyes, Damen Kurzer, and Daryl Lederle for their assistance with field management and data collection.

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Received May 22, 2012, and approved July 22, 2012.