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Comparison of Mixtures vs. Monocultures of Cover Crops for Fresh-market Tomato Production With and Without Herbicide

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Abstract. **Hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.), and rye (*Secale cereale* L.) and mixtures of rye with hairy vetch and/or crimson clover were compared for no-tillage production of staked, fresh-market tomatoes (*Lycopersicon esculentum* Mill.) on raised beds. All cover crops were evaluated both with or without a postemergence application of metribuzin for weed control. Biomass of cover crop mixtures were higher than that of the hairy vetch monocrop. Cover crop nitrogen content varied little among legume monocrops and all mixtures but was lower in the rye monocrop. The C:N ratio of legume monocrops and all mixtures was <30 but that of the rye monocrop was >50, suggesting that nitrogen immobilization probably occurred only in the rye monocrop. Marketable fruit yield was similar in the legume monocrops and all mixtures but was lower in the rye monocrop when weeds were controlled by metribuzin. When no herbicide was applied, cover crop mixtures reduced weed emergence and biomass compared to the legume monocrops. Despite weed suppression by cover crop mixtures, tomatoes grown in the mixtures without herbicide yielded lower than the corresponding treatments with herbicide in 2 of 3 years. Chemical name used: [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one](metribuzin).**

Fresh-market tomato production with a hairy vetch cover crop is a viable alternative to production with black polyethylene mulch (Kelly et al., 1996). This production system involves growing tomatoes without tillage in residue of mow-killed hairy vetch (Abdul-Baki and Teasdale, 1997). Maintenance of tomato leaf area for a longer duration accounts for greater production in a hairy vetch than in black polyethylene mulch (Teasdale and Abdul-Baki, 1997). Hairy vetch has a high N content and can reduce N requirements for tomato production by at least one-half (Abdul-Baki et al., 1997).

Although hairy vetch has proven to be a reliable cover crop for tomato production, it has several limitations. Hairy vetch grows primarily in spring and, therefore, does not capture excess soil N during the fall and winter months when leaching often occurs (Shipley et al., 1992). Also, hairy vetch residue decomposes rapidly; Wagger (1989) showed that over half of vetch biomass was degraded during the first month after desiccation. Rapid decomposition can be beneficial when N is released in synchrony with crop growth, but can be detrimental when the surface mulch degrades too fast to effectively suppress weeds. Mohler and Teasdale (1993) showed that hairy vetch residue was less effective at suppressing weeds late in the season because of vetch decomposition.

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A rye cover crop has properties that can complement the limitations of hairy vetch. Rye grows at cooler temperatures, develops faster in spring, and captures more residual N than does hairy vetch (Shipley et al. 1992). In addition, rye residue decomposes more slowly than hairy vetch (Wagger, 1989) and maintains weed suppression over a longer period of time (Mohler and Teasdale, 1993). However, because of a high C:N ratio, rye residue immobilizes N and can decrease yield of crops with a high N requirement such as corn (Clark et al., 1994, 1997b).

A mixture of hairy vetch and rye may offset the disadvantages of each species alone. Mixtures of legume and rye cover crops produced equivalent or higher dry matter and N than monocultures of each species (Clark et al., 1994, 1997a; Rannells and Wagger, 1996). The C:N ratio of these mixtures was usually low enough to prevent immobilization of N. Legume and rye mixtures tended to be intermediate between corresponding monocultures in decomposition and N release rate (Rannels and Wagger, 1996) and in optimum fertilizer N requirements for corn (Clark et al., 1997b). A crimson clover-rye mixture was intermediate between monocultures in fall and winter capture of residual N (Rannells and Wagger, 1997).

Mixtures of species can improve resource capture in both space and time relative to respective monocultures (Fukai and Trenbath, 1993). Jannink et al. (1996) demonstrated that optimum biomass production by a pea-oat-vetch mixture was due to early radiation interception by the pea component and high radiation use efficiency by the mixture during midseason. Mixtures of legume and rye winter annual cover crops should have similar advantages in biomass production because of early growth of rye (Clark et al., 1994; Shipley et al., 1992) and the ability of hairy vetch to climb into the rye canopy and continue rapid growth after canopy closure (Jannink et al., 1996). Creamer et al. (1997) found that cover crop mixtures including a small grain produced the highest biomass and that hairy vetch and crimson clover were the only legumes capable of contributing significantly to the biomass of these mixtures.

Higher production of cover crop biomass can increase weed suppression by the cover crop residue (Mohler and Teasdale, 1993; Wicks et al., 1994). Creamer et al. (1996) found that a cover crop mixture of hairy vetch, crimson clover, rye, and barley (*Hordeum vulgare* L.) produced high biomass levels and suppressed weeds as well as a standard herbicide treatment. Cover crop mixtures dominated by rye were most suppressive of weeds (Creamer et al., 1997). However, when tomatoes were grown with a monoculture rye cover crop, weed suppression was not always sufficient to eliminate the need for additional control measures (Masiunas et al., 1995; Smeda and Weller, 1996). Generally, biomass levels achieved by cover crops suppress weed emergence early in the season but do not provide full-season weed control (Teasdale, 1996).

In summary, a system for producing fresh-market tomatoes based on a hairy vetch cover crop has proven more productive and economical than a system based on black polyethylene mulch or bare soil (Kelly et al., 1996). However, a system based on mixtures of hairy vetch, crimson clover, and rye potentially could improve performance of this cover crop system compared to a hairy vetch monoculture. This research was conducted to determine whether cover crop mixtures could 1) increase weed suppression and eliminate the need for herbicides and 2) maintain fresh-market tomato yield at levels similar to a hairy vetch monoculture.

Materials and Methods

Experiments were conducted at the Beltsville Agricultural Research Center, Beltsville, Md., on an Elsinboro sandy loam (fine-loamy, mixed, mesic Typic Hapludult) in 1995 and 1997 and on a Woodstown sandy loam (fine-loamy, mixed, mesic Aquic Hapludult) in 1996. Beds 15 cm high, 0.9 m wide, and 1.5 m center-to-center were prepared in mid-September of the year preceding tomato planting. Common hairy vetch, 'Dixie' crimson clover, and 'Abruzzi' rye were planted individually or in mixtures by running a Brillion seeder (Brillion Iron Works, Brillion, Wis.) over the tops of the beds. Each species in the cover crop mixtures was planted in a separate operation. Hairy vetch and rye were seeded at 45 kg•ha^{-1} and crimson clover at 22 kg•ha^{-1} both in individual and mixture plantings. In late winter, 200 seed per m^2 each of redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), and giant foxtail (*Setaria faberi* Herrm.) were broadcast over the top of beds to ensure uniform weed populations.

Cover crops were flail-mowed in late May when hairy vetch was beginning to flower, crimson clover was in late bloom, and rye was pollinating. There was very little cover crop regrowth when mowed at this time. Five-week old 'Sunbeam' tomato plants were transplanted at a 50-cm spacing along the center of the beds with a no-tillage transplanter (Holland Co., Holland, Mich.) that inserted plants with minimum disruption to the mulches. Many plants that were transplanted through the thicker mulches in the mixture treatments had to be hand-set to ensure good soil contact. Drip irrigation tubing was installed on the surface of the mulches 8 cm from the tomato row. Plants were supported by three tiers of string woven between stakes. Calcium nitrate was applied at 112 kg•ha^{-1} of N through the drip irrigation system over four biweekly applications beginning 4 weeks after transplanting. This rate was optimum for tomatoes grown in a hairy vetch mulch according to Abdul-Baki and Teasdale (1997). Soil tests indicated that no P application was required any year but 70 kg•ha^{-1} of K was required in 1996. Pesticides were applied for insect and disease control according to a Univ. of Maryland scouting program.

There were three cover crop treatments in 1995 (hairy vetch, hairy vetch plus rye, and hairy vetch plus crimson clover plus rye) and six treatments in 1996 and 1997 (hairy vetch, crimson clover, rye, hairy vetch plus rye, crimson clover plus rye, and hairy vetch plus crimson clover plus rye). Each cover crop treatment was planted in four adjacent beds per block in 1995 and two adjacent beds per block in 1996 and 1997. After transplanting, two experimental units consisting of 20-plant sections of row were established along each bed in each block. One unit received no herbicide treatment and the other received an application of 0.56 kg•ha^{-1} of metribuzin directed to the base of tomato plants when weeds emerged approximately 3 weeks after transplanting. Treatments were arranged in a strip block design with cover crop and herbicide treatments traversing each block in perpendicular directions. There were two blocks resulting in eight experimental units per treatment in 1995 and three blocks resulting in six experimental units per treatment in 1996 and 1997.

Cover crop biomass was sampled just before flail mowing by cutting at the soil surface and separating by species. Four 1-m^2 samples per cover crop treatment were taken in 1995 and three 0.25-m^2 samples were taken in 1996 and 1997. Samples were dried for determination of mass and N and C contents were determined with a LECO CHN-600 analyzer (Leco Corp., St. Joseph, Mich.). Total N content and C:N ratio for mixtures were determined by calculation from component values.

Weed populations were counted just before herbicide application from five 1.0-m^2 quadrats (1995), eight 0.1-m^2 quadrats (1996), or four 0.1-m^2 quadrats (1997) placed on the bed top of each plot. The size of quadrats was decreased in 1996 and 1997 because of higher weed populations in those years. Weed density data were log transformed before analysis to homogenize variance and back-transformed for presentation. Analysis of variance (ANOVA) was performed only for cover crop effects, since data was collected before herbicide application.

Weed biomass was sampled at the beginning of fruit harvest from a 4.0-m^2 area of each plot (a 1.0-m^2 area was used for plots without herbicide in 1996 because of the high weed biomass present in those plots). Ripe fruit (pink to firm red) were picked weekly from the middle 16 plants of each plot until mid-September. ANOVA was performed on weed and tomato data using PROC MIXED (SAS Version 6.11, SAS Institute, Cary, N.C.). Means were separated according to the protected LSD test ($P \leq 0.05$).

Results and Discussion

The biomass of the cover crop mixtures was higher than that of their component monocultures in at least one year but tended to be higher in all years (Table 1). Averaged over 3 years the biomass of hairy vetch, hairy vetch plus rye, and hairy vetch plus crimson clover plus rye was 5260, 7610, and 8420 kg•ha^{-1}, respectively. Analysis of variance of the main effect of these cover crops over years showed a significant difference between hairy vetch monoculture and each mixture but no difference between the two- and three-species mixtures.

Nitrogen content of legume monocultures and their mixtures did not differ in any year (Table 1). With one exception, rye had a lower N content than all other treatments. The C:N ratio of all cover crops other than the rye monoculture was less than 30 (Table 1). Only rye had a C:N ratio that would result in net N immobilization (Vigil and Kissel, 1991). The proportion of species in most mixtures was relatively balanced (Table 1), thereby leading to C:N ratios intermediate between components. Creamer et al. (1997) also showed that mixtures of small grains and legumes had acceptable C:N ratios as long as the proportion of grain to legume was relatively balanced.

Fewer total weeds emerged through residue of cover crop mixtures than through monoculture hairy vetch residue, with one exception (Table 2). The overseeded annual weed species, redroot pigweed, common lambsquarters, and giant foxtail, were suppressed similarly by cover crop mixtures in 1995 and 1997. However, native biennial species, primarily horseweed [*Conyza canadensis* (L.) Cronq.] and marsh yellowcress [*Rorippa islandica* (Oeder) Borbas], were less affected by residue than the annual species, and dominated weed populations in the 1996 field. These results confirm previous research demonstrating that small-seeded annual weeds are most sensitive to cover crop residue (Mohler and Teasdale, 1993). Also, the associated increase in cover crop biomass and weed suppression with cover crop mixtures is consistent with previous research showing that weed emergence declined exponentially with increasing residue biomass (Mohler and Teasdale, 1993).

The interaction between cover crop and herbicide treatments for weed biomass was significant in every year. This interaction was the result of significant differences in weed biomass among cover crop treatments in the absence of herbicide but no difference among cover crop treatments when herbicide was applied (Table 3). In the absence of herbicides, cover crop mixtures reduced weed biomass compared with the legume monocultures, but not to a level equivalent to that achieved with herbicide. Cover crops were flail mowed in our experiments, leading to more rapid decomposition and perhaps poorer weed control than if residues had been left intact. Creamer et al. (1995) found that undercutting and rolling

Table 1. Cover crop biomass, N content and C:N ratio just before mowing in late May.[z]

Year	Cover crop[y]	Biomass (kg•ha^{-1})	Fraction of biomass (%) HV	CC	R	N content (kg•ha^{-1})	C:N ratio
1995	HV	5180 c	100	---	---	160 a	13 b
	HV + R	8180 b	40(3)	---	60(3)	166 a	21 a
	HV + CC + R	9910 a	21(13)	2(1)	77(12)	149 a	26 a
1996	HV	3840 c	100	---	---	118 a	15 c
	CC	4250 c	---	100	---	92 ab	21 bc
	R	4180 c	---	---	100	41 b	56 a
	HV + R	5360 bc	59(11)	---	41(11)	124 a	20 bc
	CC + R	7720 a	---	60(3)	40(3)	131 a	27 b
	HV + CC + R	6620 ab	37(9)	33(10)	30(10)	157 a	20 bc
1997	HV	6770 a	100	---	---	236 a	13 d
	CC	8790 a	---	100	---	206 ab	19 c
	R	7300 a	---	---	100	69 c	51 a
	HV + R	9280 a	68(5)	---	32(5)	237 a	18 c
	CC + R	9830 a	---	49(8)	51(8)	169 b	27 b
	HV + CC + R	8740 a	30(3)	34(9)	36(6)	192 ab	21 c

[z]Mean separation within columns and years by LSD ($P \leq 0.05$). The standard error is presented in parentheses following each biomass fraction value.

[y]Cover crops: hairy vetch (HV), crimson clover (CC), and rye (R).

Table 2. Cover crop influence on weed density at the time of herbicide application ≈3 weeks after transplanting.

Year	Cover crop[y]	Early weed density[z] (plants/m^2)			
		AMARE[x]	CHEAL	SETFA	Total
1995	HV	1.9 a	2.5 a	2.7 a	9.7 a
	HV + R	0.7 b	0.6 b	0.7 b	2.1 b
	HV + CC + R	0.8 b	0.9 b	0.6 b	2.8 b
1996	HV	5.2 ab	4.9 a	11.6 b	100 b
	CC	2.5 bc	2.1 bc	6.5 cd	71 cd
	R	6.4 a	0.6 c	25.6 a	131 a
	HV + R	4.0 ab	4.2 ab	10.0 bc	78 bc
	CC + R	0.9 c	0.8 c	4.3 d	37 e
	HV + CC + R	3.4 abc	3.8 ab	3.9 d	54 d
1997	HV	8.7 a	15.1 a	3.0 a	31.2 a
	CC	4.0 b	10.9 a	2.2 ab	20.2 a
	R	0.3 c	0.3 c	2.9 a	20.9 a
	HV + R	1.1 c	2.1 bc	0.3 b	3.9 b
	CC + R	0.6 c	1.3 bc	0.3 b	2.3 b
	HV + CC + R	0.3 c	4.6 b	0.3 b	5.5 b

[z]Mean separation within columns and years by LSD ($P \leq 0.05$).
[y]Cover crops: hairy vetch (HV), crimson clover (CC), and rye (R).
[x]AMARE = redroot pigweed, CHEAL = common lambsquarters, and SETFA = giant foxtail. Horseweed and marsh yellowcress also contributed to total weed density in 1996.

Table 3. Cover crop and herbicide influence on weed biomass at the beginning of fruit harvest.

Year	Cover crop[y]	Weed biomass[z] (g·m^{-2})	
		Minus herbicide	Plus herbicide
1995	HV	204 a	1 a
	HV + R	63 b	3 a
	HV + CC + R	76 b	1 a
1996	HV	468 a	78 a
	CC	427 a	59 a
	R	388 ab	112 a
	HV + R	308 bc	23 a
	CC + R	236 c	42 a
	HV + CC + R	299 bc	25 a
1997	HV	644 a	7 a
	CC	415 b	5 a
	R	264 c	4 a
	HV + R	268 c	0 a
	CC + R	136 c	1 a
	HV + CC + R	161 c	2 a

[z]Mean separation within columns and years by LSD ($P \leq 0.05$). All comparisons between herbicide treatments within cover crop were significant except those within HV + R and HV + CC + R in 1995. Weed biomass consisted primarily of common lambsquarters and redroot pigweed in 1995 and 1997 and giant foxtail in 1996.
[y]Cover crops: hairy vetch (HV), crimson clover (CC), and rye (R).

Table 4. Influence of cover crop and herbicide on marketable tomato fruit yield.

Year	Cover crop[y]	Marketable yield[z] (Mg·ha^{-1})	
		Minus herbicide	Plus herbicide
1995	HV	94 a	108 a
	HV + R	97 a	99 a
	HV + CC + R	106 a	111 a
1996	HV	20 ab	53 a
	CC	12 bc	47 ab
	R	6 c	39 b
	HV + R	18 ab	53 a
	CC + R	24 a	50 a
	HV + CC + R	28 a	53 a
1997	HV	59 c	113 a
	CC	67 bc	113 a
	R	60 c	93 b
	HV + R	73 abc	104 ab
	CC + R	83 ab	102 ab
	HV + CC + R	87 a	113 a

[z]Mean separation within columns and years by LSD ($P \leq 0.05$). All comparisons between herbicide treatments within cover crop were significant except those within HV + R and HV + CC + R in 1995.
[y]Cover crops: hairy vetch (HV), crimson clover (CC), and rye (R).

cover crop mixtures left the residue intact and provided superior weed control than flail mowing.

The postemergence application of metribuzin eliminated almost all emerged weed seedlings, resulting in low weed biomass levels in all cover crop treatments receiving herbicide (Table 3). Very few weeds emerged after herbicide application in 1995 and 1997 but high rainfall stimulated emergence and growth of giant foxtail in midseason of 1996. Since weeds were absent from herbicide-treated plots during the critical period of 28 to 35 d after transplanting (Weaver and Tan, 1983), tomato yield should not have been affected by later-developing weeds in these plots.

There were no differences in marketable yield between cover crop mixtures and legume monocultures in herbicide-treated plots (Table 4). The rye monoculture reduced yield compared to the legume monoculture or mixture treatments. Because weeds were controlled by the herbicide treatment in these experiments, differences in yield between cover crop treatments were probably related to mulch effects on N availability. Yield followed a similar pattern to the C:N ratio of these mulches (Table 1).

Marketable yield was lower in all cover crop treatments without than with herbicide in 1996 and 1997 (Table 4). Although cover crop mixtures improved weed suppression in these years, they did not provide sufficient control to eliminate the need for herbicide treatment. However, in 1995, yields of tomatoes grown with cover crop mixtures were similar with and without herbicide treatment. Cover crop mixtures were probably more effective at suppressing weeds in 1995 because of lower weed populations and growth in that year (Tables 2 and 3). This suggests that attaining high cover crop biomass with mixtures may be an effective strategy for eliminating herbicides on fields with low weed pressure.

Cover crop mixtures had little effect on crop maturity in 1995 and 1997, but delayed harvest by ≈3 to 7 d in comparison with the hairy vetch monoculture in 1996 (data not shown). Probably cool, wet soils under the heavier mulch cover in the mixture treatments accounted for delayed fruit maturity in this relatively cloudy, rainy season. Since fruit maturity tends to be delayed by a hairy vetch compared to a black polyethylene mulch (Teasdale and Abdul-Baki, 1997), further delays by cover crop mixtures could limit their utility in areas with a premium for early produce.

This research demonstrates that rye/legume cover crop mixtures can increase residue biomass and improve weed suppression compared with a hairy vetch monocrop. However, new equipment and management approaches will be needed to fully realize the potential of these mixtures. Despite improved weed suppression by cover crop mixtures, intervention with an herbicide or other weed control tactic usually will be required to achieve optimum weed control and yield. Killing cover crop mixtures by undercutting and/or rolling may increase weed suppression and eliminate the need for herbicides. Improved transplanters also will be needed to effectively plant through dense layers of mulch with minimal disturbance. With proper management, cover crop mixtures offer new opportunities for customizing cover crops to local cropping practices and nutrient management requirements.

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