Evaluation of Cover Crop Mixtures for Use in Vegetable Production Systems

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Abstract. Planting polyculture mixtures of cover crops can optimize the benefits of their use. Thirteen polyculture mixtures of cover crops were evaluated in Columbus and Fremont, Ohio, to find a species mix that would establish quickly for erosion control, overwinter in Ohio, contribute sufficient N and have a C : N ratio between 20:1 and 30:1 to optimize N availability for subsequent crops, be killable by mechanical methods, and have high weed control potential. All of the mixtures in Columbus had achieved 30% ground cover 1 month after planting, but only four of the mixtures achieved this in Fremont due to poor conditions at planting. Above-ground biomass (AGB) accumulation in the mixtures ranged from 3631 to 13,642 kg·ha⁻¹ in Columbus, and 449 to 12,478 kg·ha⁻¹ in Fremont. Nitrogen in the AGB ranged from 74 to 269 kg·ha⁻¹ in Columbus, and 10 to 170 kg·ha⁻¹ in Fremont. Weed cover in the cover crop plots ranged from 1% to 91% eight weeks after cover crop kill in Columbus, and 12% to 90% seven weeks after cover crop kill in Fremont. Because one or more species in each screened mixture was determined not to be suitable, none of the mixtures was optimum. However, information gained about performance of individual species within the mixtures is also useful. 'Nitro' alfalfa (*Medicago sativa* L.), ladino clover (*Trifolium repense* L.), subterranean clover (*Trifolium subterraneum* L.), Austrian winter peas [*Pisum sativum* ssp. *Arvense* (L.) Poir], and annual ryegrass (*Lolium multiflorum* Lam.) did not overwinter dependably in Ohio. Tall fescue (*Festuca arundinacea* L.), perennial ryegrass (*Lolium perenne* L.), and orchardgrass (*Dactylis glomerata* L.) did not compete well with taller, more vigorous species, and were not persistent in the mixtures. Medium and mammoth red clover (*Trifolium pratense* L.), annual and perennial ryegrass, and white and yellow blossom sweetclover [*Melilotus alba* Desr., and *Melilotus officianalis* (L.) Desr.], were not killable by mechanical methods. Individual species that established quickly, were competitive in the mixtures, overwintered dependably, and were killed by mechanical methods were rye (*Secale cereale* L.), barley (*Hordeum vulgare* L.), crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* Roth.)

Vegetable production in the United States normally requires generous chemical inputs to maintain fertility and to control diseases, insects, and weeds. Increased consumer concern

about pesticides in food, the loss and threatened loss of many currently used pesticides, and poor economic return for growers with high chemical input costs (Francis and King, 1988) is prompting the investigation of vegetable production methods that reduce the reliance on synthetic chemical inputs. The use of cover crops in vegetable production systems is one way to achieve this goal (Abdul-Baki and Teasdale, 1993; Creamer et al., 1996).

Farmers spend >\$3.6 billion per year on herbicides (Pimentel and Levitan, 1986), yet weeds still reduce yields by ≈10% (or \$7 to \$12 billion) (Shaw, 1982). Weed management can be especially difficult in vegetable crops because of the limited number of herbicides registered for use, and the degree of control necessary to maintain adequate yields. Difficulty of weed control is often the production factor most mentioned by growers who are trying to reduce chemical inputs. Cover crops can be managed to enhance weed control by killing them and leaving the dead residue on the surface as a mulch (Teasdale, 1993).

Mixtures of cover crop species can be

planted to optimize the benefits associated with cover crop use. Above-ground biomass (AGB) (and, subsequently, N content of the AGB) can be increased by taking advantage of more below-ground and above-ground niches for nutrients, water, and light (Haynes, 1980; Ofori and Stern, 1987). Nitrogen accumulated by legumes through symbiotic relationship with *Rhizobia* bacteria can also benefit nonlegumes growing in mixtures through transfer of N by the roots (Giller et al., 1991). Also, by growing a legume with a nonlegume, the legume may accumulate more N than it would if it were growing by itself. Because nonlegumes are generally better at obtaining N from the soil, the nonlegume depletes soil N so that associated legumes must increase biological N fixation (Ofori and Stern, 1987). Another benefit of polyculture mixes is that species that may not always overwinter when grown by themselves can benefit by being planted with a nurse crop (Exner and Cruse, 1993). A more desirable carbon : nitrogen (C : N) ratio can also be achieved by planting mixtures. Breakdown of the cover crop mixture, and subsequent N release, is in part regulated by the C : N ratio (Power and Doran, 1988). By combining plants whose C : N ratio is high (mature cereals) with those that are low (legumes), immobilization can be reduced, and the release of N can theoretically be timed with crop uptake.

Another reason for planting mixtures of cover crops is to take advantage of the allelopathic potential of the cover crops to suppress weeds. Allelopathic suppression of weeds has been shown to be a species-specific phenomenon (Hazebroek et al., 1989; Lehle et al., 1983; Overland, 1966; Purvis et al., 1985). Therefore, a broader spectrum of weed control may be obtained by growing a mixture of cover crops with allelopathic activity toward various weed species.

Although some studies have been conducted on biculture mixes (Clark et al., 1994; Sullivan et al., 1991), few, if any, studies have been conducted on polycultures. Therefore, an evaluation of various mixtures is the logical first step in identifying those that have potential for use. We recognized that, because the number of potential species combinations is quite large, it was possible that none of the screened mixtures would prove optimum, though information about the performance of individual species in the mixtures would still be of value.

The objective of this study was to evaluate several cover crop mixtures for use in vegetable production systems. Specifically, we sought a species mix that established quickly, gave adequate erosion control, was winter hardy, accumulated considerable biomass and N, had a C : N ratio of between 20:1 and 30:1, could be killed by mechanical methods, and had high weed control potential.

Materials and Methods

Cover crop mixtures were evaluated in 1991–92 in Columbus, Ohio (Ohio State Univ. Horticulture Farm), on a Miami silt loam

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Table 1. 1991 seeding rate for each species evaluated in Columbus and Fremont, Ohio.

Species	Scientific name	Seeding rate (kg·ha ⁻¹)
Legumes		
Alfalfa, 'Nitro'	<i>Medicago sativa</i> L.	5.0
Austrian Winter Peas	<i>Pisum sativum</i> ssp. Arvense (L.) Poir	36.0
Clover, Crimson	<i>Trifolium incarnatum</i> L.	9.0
Clover, Ladino	<i>Trifolium repense</i> L.	1.4
Clover, Mammoth Red	<i>Trifolium pratense</i> L.	6.8
Clover, Medium Red	<i>Trifolium pratense</i> L.	6.8
Clover, Subterranean	<i>Trifolium subterraneum</i> L.	18.0
Sweetclover, Yellow blossom	<i>Melilotus officinalis</i> (L.) Desr.	4.5
Sweetclover, White blossom	<i>Melilotus alba</i> Desr.	4.5
Vetch, Bigflower	<i>Vicia grandiflora</i> Scop.	18.0
Vetch, Hairly	<i>Vicia villosa</i> Roth.	18.0
Winter-hardy small grains		
Barley, 'Pennco'	<i>Hordeum vulgare</i> L.	30.4
Rye, 'Wheeler'	<i>Secale cereale</i> L.	27.0
Wheat, 'Caldwell'	<i>Triticum aestivum</i> L.	27.0
Forage grasses		
Fescue, Tall	<i>Festuca arundinacea</i> L.	2.7
Orchardgrass	<i>Dactylis glomerata</i> L.	3.4
Ryegrass, Annual	<i>Lolium multiflorum</i> Lam.	2.0
Ryegrass, Perennial	<i>Lolium perenne</i> L.	2.0
Summer annuals		
Buckwheat	<i>Fagopyrum esculentum</i> Moench	16.9
Sorghum, Forage	<i>Sorghum bicolor</i> L.	10.1
Sorghum, Grain	<i>Sorghum bicolor</i> L.	10.1
Sorghum-Sudangrass Hybrid	<i>Sorghum bicolor</i> (L.) Moench × <i>S. bicolor</i> var. <i>sudanense</i>	10.1
Soybeans, 'Quailhaven'	<i>Glycine max</i> L.	18.0

(Mesic Typic Hapludaf), and at the Ohio Agriculture Research and Development Center's Vegetable Crops Branch, Fremont, on a Colwood fine sandy loam (fine, mixed Mesic Aeric Ochraqualfs).

Several species characteristics were used in determining which mixtures to evaluate. Species were chosen to complement each other and provide benefits as described above. Legumes and nonlegumes were combined in the mixtures with the goal of achieving C:N ratios between 20:1 and 30:1 at cover crop kill (with one exception that was entirely legumes). Each mixture comprised species that were known to either establish early, have allelopathic potential, produce high amounts of biomass, or have differing rooting depths and growth habits. The mixtures screened all comprised four species. Because we were trying to optimize weed suppression, we wanted to include as many species as possible in each mixture. We believed that having more than four species would limit grower adoption of planting polyculture mixtures. Summer annuals were included in some of the mixtures to accumulate biomass in the late summer and early fall, and potentially to play a role in weed suppression. In determining which mixtures to evaluate, information from monoculture cover crop screening studies was also used (Holderbaum et al., 1990; Nelson et al., 1991; Nicholson and Wien, 1983).

Cover crop and control plots were 3.05-m-long raised beds on 1.5-m centers. Soil was disked before forming beds with a rototiller/bedshaper. Soil tests indicated high P and K levels at both sites, so no preplant fertilizer was added to the plots. Each cover crop species was seeded at an appropriate rate (Table 1) in each of the mixtures in which it appeared. Seeding rates were either 30% or 40% of that

recommended for monoculture, depending on the species. Thirteen mixtures of cover crops were evaluated (Table 2). All of the mixtures were planted the second week of August and five of the mixtures were planted again the first week of September to observe trend differences due to planting date. Plots were retilled just before planting the cover crops at the second planting date. Cover crop mixtures were hand planted with the larger-seeded species raked to a depth of ≈2.5 cm, and the smaller-seeded species were lightly covered. All legumes were inoculated with the appropriate *Rhizobia* spp. Due to drought conditions, plots at Columbus were irrigated once to assure establishment.

The experiment design at both locations was a randomized complete block with four replications. Statistical analyses were performed with analysis of variance and simple regression procedures. Least significant difference tests were used to separate means, and single degree-of-freedom contrasts were con-

ducted to determine differences between early and late planted mixtures (Wilkinson, 1990).

To determine the level of fall cover, percent ground cover of each species was measured ≈1 and 2 months after planting by the beaded-string method (Sloneker and Moldenhauer, 1977). One string was stretched across each diagonal of the plots, with marks every 10 cm. AGB was determined on 19 May (Columbus), and 23 May (Fremont), by harvesting two randomly located 0.1-m² quadrats per plot. Samples were dried at 65 °C for at least 48 h and weighed. The small sample size was chosen to facilitate separating the biomass into individual species. However, it was very difficult to correctly identify similar species once cut. Other studies have also used small sample sizes to determine cover crop biomass (Dabney et al., 1989; Dyck and Liebman, 1994; Hesterman et al., 1992; Sarrantonio and Scott, 1988). Because of the difficulty in identifying similar species once cut, a biomass index was generated to deter-

Table 2. Cover crop mixtures screened in 1991–92. Mixtures 1–13 were planted on 12 Aug. (Columbus) and 15 Aug. (Fremont). Mixtures 1L–5L were planted on 3 Sept. (Columbus) and 9 Sept. (Fremont).

Treatment	Mixture
1 (1L) ^a	Bigflower vetch, barley, tall fescue, Austrian winter peas
2 (2L)	Bigflower vetch, ladino clover, annual ryegrass, rye
3 (3L)	Hairy vetch, tall fescue, barley, wheat
4 (4L)	Sorghum-sudangrass hybrid, rye, mammoth red clover, subterranean clover
5 (5L)	Annual alfalfa, hairy vetch, annual ryegrass, rye
6	Annual alfalfa, crimson clover, wheat, annual ryegrass
7	Bigflower vetch, medium red clover, forage sorghum, orchardgrass
8	Quailhaven soybeans, rye, crimson clover, perennial ryegrass
9	Yellow blossom sweetclover, bigflower vetch, subterranean clover, annual alfalfa
10	Ladino clover, white blossom sweetclover, wheat, buckwheat
11	Medium red clover, annual ryegrass, buckwheat, barley
12	Yellow blossom sweetclover, crimson clover, grain sorghum, tall fescue
13	Quailhaven soybeans, orchardgrass, hairy vetch, rye

^aParentheses denote treatments of the same mixture planted at later dates.

Table 3. Monthly average precipitation and daily average minimum and maximum temperatures at Columbus and Fremont, Ohio, in 1991–92.

Month	Meteorological data					
	Columbus			Fremont		
	Precipitation (mm)	Min. (°C)	Max. (°C)	Precipitation (mm)	Min. (°C)	Max. (°C)
August	42	15.0	30.6	46	14.4	28.3
September	60	12.2	26.1	49	8.9	24.4
October	33	6.1	21.1	120	8.9	18.9
November	14	-1.1	9.4	49	-1.7	7.8
December	97	-3.3	6.7	32	-4.4	4.4
January	35	-3.3	3.9	30	-7.2	1.7
February	21	-0.6	7.2	43	-5.0	3.9
March	87	-0.6	10.6	60	-4.4	7.8
April	68	5.5	16.7	60	1.7	13.9
May	86	8.3	22.2	79	7.2	20.6
June	64	13.3	25.6	109	11.1	23.9
July	270	17.2	27.8	147	15.0	26.7

mine species composition (Sarrantonio, 1991). Average plant heights for each species in a plot (three measurements/species/plot) were multiplied by a visually estimated percent ground cover for each species. The biomass index is reported to the nearest 10%.

After weighing, the biomass samples were coarsely ground with a Wiley mill. Representative subsamples were reground to a fine powder with a Brinkmann 2-MI centrifugal grinding mill (200-mm mesh screen; Brinkmann Instruments, Westbury, N.Y.). Carbon and N were determined, based on the Dumas method (Nelson and Summers, 1982), with an NA 1500 Series 2 analyzer (Carlo Erba Instruments, Milan, Italy).

On 22 May in Columbus, and 29 May in Fremont, the cover crops were mechanically killed with an undercutter and left on the surface as a mulch. The undercutter was designed and built by the Ohio State Univ. Agricultural Engineering Dept. Two blades at 45° degree angles from the direction of travel with a 15° pitch cut ≈ 5 cm deep. A mounted rolling harrow was attached to the undercutter to lay the cover crop flat on the surface after being cut (Creamer et al., 1995). Percent kill for the individual species was estimated 2 weeks after undercutting. Percent ground cover by the dead residue was visually estimated 6 weeks after kill (WAK) in Columbus, and 5 WAK in Fremont. Percent ground cover by weeds was visually estimated 6 and 8 WAK in Columbus, and 5 and 7 WAK in Fremont. Rainfall and temperature data for the two locations were collected (Table 3).

Results and Discussion

All of the mixtures at Columbus achieved 30% ground cover by 1 month after planting (Table 4). The U.S. Dept. of Agriculture Soil Conservation Service (SCS) recommends a 30% ground cover to adequately control soil erosion (SCS, 1985). At Fremont, only four of the mixtures (5, 9, 10, and 11) had attained a 30% ground cover 1 month after planting. Low soil moisture at the time of planting and high weed pressures (many weeds germinated with the cover crop) most likely played a role in the limited ground cover at Fremont. At 2 months after planting, mixtures 7 and 10 at Fremont still had <30% ground cover. Because of improved conditions at planting, the

later-planted mixtures in Fremont had a higher percent ground cover 1 month after planting when contrasted to their earlier-planted counterparts.

Rye was very competitive with the other species, and in five of the eight mixtures that included rye, it comprised at least 80% of the AGB just before kill (Table 5). The forage grasses (tall fescue, annual ryegrass, orchardgrass, perennial ryegrass) were not competitive with the more aggressive species, and often contributed little or no biomass to the mixtures. Hairy vetch was in two of the mixtures planted early and late, and comprised a larger percentage of the mixtures when planted early. In most cases, mixture compositions were fairly similar at the two locations. In mixtures 6 and 11, annual ryegrass survived in Columbus, but not Fremont, which caused differences in mixture composition between the two sites.

Mixtures 5, 1L, 2L, 4L, 5L, and 13 had >10 Mg·ha⁻¹ of AGB in Columbus (Table 6), and were not statistically different from each other. In Fremont, mixture 2L accumulated 12.48 Mg·ha⁻¹ AGB, and was not statistically different from any of the later-planted mixtures and

mixtures 2, 4, 5, 8, and 13. The later-planted mixtures (1L through 5L) at Columbus and Fremont had more AGB when contrasted with their earlier-planted counterparts, likely because of more favorable soil moisture conditions and less weed pressure at the time of establishment.

To promote the timely decomposition of organic matter and subsequent release of N, a C : N ratio of between 20:1 to 30:1 is desired (Allison, 1966; Kommedahl, 1984). All of the mixtures except 2, 2L, 4L, 8, 9, and 12 fell statistically within this range at both sites (Table 6).

In Columbus, N in the AGB ranged from 74 to 269 kg·ha⁻¹. In Fremont, it ranged from 10 to 170 kg·ha⁻¹ (Table 6), reflecting the lower biomass accumulation at Fremont. As a general rule, about half of the N in the AGB is mineralized in a growing season (Broadbent, 1984); however, this depends in part on the C : N ratio of the cover crop.

'Nitro' alfalfa, ladino clover, subterranean clover, Austrian winter peas, and annual ryegrass did not overwinter dependably at either location (data not shown). Annual ryegrass overwintered in Columbus but not

Table 4. Percent ground cover of cover crops 1 and 2 months after planting in Columbus and Fremont, Ohio, 1991. Refer to Table 2 for description of species in each treatment.

Crop mixture	Ground cover (%)			
	Columbus		Fremont	
	11 Sept.	9 Oct.	9 Sept.	2 Nov.
1	62	88	17	47
2	62	77	10	48
3	70	85	22	55
4	84	92	27	65
5	71	89	36	69
1L	---	81	---	75
2L	---	79	---	68
3L	---	70	---	73
4L	---	75	---	74
5L	---	68	---	77
6	72	82	23	48
7	60	67	26	17
8	61	88	20	55
9	61	80	33	60
10	73	71	38	26
11	81	89	42	51
12	48	49	25	33
13	63	90	26	63
LSD _{0.05}	12	14	12	16
Contrast ^a		NS		*

^aContrast significant (0.05) between early and late planted mixtures.

NS, *Nonsignificant or significant at $P = 0.05$, respectively.

Table 5. Mixture composition just prior to cover crop kill in Columbus and Fremont, Ohio, on 16 May and 21 May 1992, respectively.

Crop mixture	Percent of each species in the mixture in Columbus and Fremont (in parentheses)
1	30% (tr.) ^a bigflower vetch, 70% (100%) barley, tr. (tr.) tall fescue, tr. (0%) Austrian winter peas
2	tr. (tr.) bigflower vetch, tr. (0%) ladino clover, 10% (0%) annual ryegrass, 90% (100%) rye
3	60% (50%) hairy vetch, tr. (tr.) tall fescue, 30% (50%) barley, 10% (tr.) wheat
4	0% (0%) sorghum-sudangrass hybrid, 90% (100%) rye, 10% (tr.) mammoth red clover, 0% (tr.) sub. clover
5	0% (0%) annual alfalfa, 40% (30%) hairy vetch, 10% (0%) annual ryegrass, 50% (70%) rye
1L	10% (tr.) bigflower vetch, 70% (80%) barley, tr. (tr.) tall fescue, 20% (20%) Austrian winter peas
2L	10% (tr.) bigflower vetch, 0% (0%) ladino clover, tr. (0%) annual ryegrass, 90% (100%) rye
3L	40% (40%) hairy vetch, 0% (tr.) tall fescue, 50% (60%) barley, 10% (tr.) wheat
4L	0% (0%) sorghum-sudangrass hybrid, 100% (100%) rye, tr. (tr.) mammoth red clover, tr. (tr.) sub. clover
5L	0% (0%) annual alfalfa, 30% (20%) hairy vetch, tr. (0%) annual ryegrass, 70% (80%) rye
6	tr. (tr.) annual alfalfa, 20% (40%) crimson clover, 40% (60%) wheat, 40% (0%) annual ryegrass
7	40% (10%) bigflower vetch, 30% (50%) med. red clover, 0% (0%) forage sorghum, 30% (40%) orchardgrass
8	0% (0%) quailhaven soybeans, 90% (90%) rye, 10% (10%) crimson clover, tr (tr) perennial ryegrass
9	80% (80%) yellow blossom sweetclover, 20% (10%) bigflower vetch, tr. (10%) sub. clover, 0% (tr.) annual alfalfa
10	tr. (0%) ladino clover, 50% (40%) white blossom sweetclover, 50% (60%) wheat, 0% (0%) buckwheat
11	20% (10%) medium red clover, 30% (0%) annual ryegrass, 0% (0%) buckwheat, 50% (90%) barley
12	40% (90%) yellow blossom sweetclover, 40% (10%) crimson clover, 0% (0%) grain sorghum, 10% (tr.) tall fescue
13	0% (0%) quailhaven soybeans, tr. (tr.) orchardgrass, 50% (30%) hairy vetch, 50% (70%) rye

^atr. = trace (<5%).

Fremont, most likely due to a colder winter in Fremont.

Whether a species was easily killed by the undercutter depended primarily on growth stage. Species that were in mid-to-late bloom or beyond (rye, hairy vetch, bigflower vetch, crimson clover, barley, wheat, and subterranean clover) were easily killed (Creamer et al., 1995). Wheat and Austrian winter peas were killed by the undercutter in Columbus but not in Fremont. Both were further advanced in their growth stages in Columbus, which may have accounted for the difference in response (Creamer et al., 1995).

At 6 WAK, cover crops on most Columbus plots were inhibiting weed emergence and growth compared with the weedy control (Table 7). The exception was mixture 9, which consisted entirely of legumes. This mixture had a low C : N ratio (thus, quicker decomposition and higher N availability), limited above-ground biomass (Table 6) and only 50% of the

soil covered with dead residue. By 8 WAK, mixtures differed greatly in their effect on weed cover in Columbus. Plots with mixture 4L had the least weed cover, and did not differ from plots with mixtures 1, 2, 4, 2L, 5, 5L, or 8. Plots with mixture 9 did not differ from the weedy control. Weeds in Columbus were almost entirely broadleaves, primarily lambsquarters (*Chenopodium album* L.) and small flower galinsoga (*Galinsoga parviflora* Cav.). Plots with mixtures 6, 7, 10, and 11 consisted of >50% of cover crop species that were not killed mechanically, so weed cover was not estimated in those plots. In Columbus, >25 mm rain fell 2 d after undercutting, but at Fremont a significant rain did not occur for 1 week. This difference may have accounted for the reduced kill in Columbus.

The most weed-suppressive mixtures in Fremont 5 WAK were 4, 5, 1L, 2L, 3L, 4L, 5L, 8, 11, and 13 (Table 7). Mixtures 6, 7, and 10 did not differ from the weedy control. By 7

WAK, weed cover was high in most plots (>25%), and weed cover in plots planted to mixtures 3, 6, 7, 9, and 12 did not differ from the weedy control. In Fremont, 73% of the weeds were broadleaves, primarily annual sowthistle (*Sonchus oleraceus* L.), redroot pigweed (*Amaranthus retroflexus* L.), and lambsquarters. The main grass present was yellow foxtail [*Setaria lutescens* (Weigel) Hubb.]. Plots with earlier-planted mixtures had more weed biomass when contrasted with their later-planted counterparts at both sampling dates in Fremont. Some of the weeds that emerged with the earlier-planted mixtures were able to set seed before the killing frost, yielding more viable seed in the soil.

Rye was in all but two of the mixtures that were most effective at controlling weeds at Columbus and Fremont. In 10 of the 16 cases, rye made up over 85% of the mixture (Table 5).

Analyses were conducted to determine if

Table 6. Cover crop mixture above-ground biomass (AGB), carbon : nitrogen ratios (C : N), and N accumulation in the AGB at Columbus and Fremont, Ohio (1991–92).

Crop mixture	Columbus			Fremont		
	Mixture characteristics					
	AGB (Mg·ha ⁻¹)	C : N	N in AGB (kg·ha ⁻¹)	AGB (Mg·ha ⁻¹)	C : N	N in AGB (kg·ha ⁻¹)
1	8.06	28.7	117	8.07	32.1	110
2	7.18	42.1	74	10.04	31.5	142
3	5.90	17.0	147	9.27	24.4	166
4	9.48	34.2	120	9.81	32.9	130
5	11.49	21.3	250	11.06	29.8	160
1L	11.08	28.1	169	10.89	31.4	149
2L	10.62	39.3	122	12.48	33.0	163
3L	9.25	30.4	128	10.55	30.8	149
4L	11.36	41.4	120	10.20	28.9	155
5L	11.10	31.8	149	10.61	32.1	142
6	6.40	31.6	85	4.67	23.5	85
7	3.63	15.9	94	0.45	18.1	10
8	8.97	38.9	98	9.81	34.9	123
9	5.13	14.6	154	3.18	13.9	94
10	6.64	22.5	123	3.74	21.1	76
11	8.20	29.8	112	9.64	30.9	138
12	4.74	14.8	127	2.71	14.6	79
13	13.64	21.8	269	9.79	25.1	170
LSD (0.05)	3.49	5.0	85	2.78	4.9	48
Contrast	*	NS	NS	*	NS	NS

NS, *Nonsignificant or significant at $P \leq 0.05$ between early and late planted mixtures.

Table 7. Percent weed cover 6 and 8 weeks after kill (WAK) in Columbus, and 5 and 7 WAK in Fremont, Ohio, 1992.

Crop mixture	Weed cover (%)			
	Columbus		Fremont	
	Weeks after kill			
	6	8	5	7
Weedy control	60	85	61	92
1	11	16	23	54
2	1	3	18	33
3	6	34	18	64
4	1	4	5	39
5	3	19	5	21
1L	15	48	13	12
2L	3	6	4	26
3L	3	23	7	27
4L	0	1	3	15
5L	1	7	5	19
6	N/A ^z	N/A	46	89
7	N/A	N/A	55	90
8	1	4	4	19
9	66	91	36	68
10	N/A	N/A	53	54
11	N/A	N/A	6	38
12	31	60	31	65
13	6	30	11	27
LSD (0.05)	10	21	15	34
Contrast ^y	NS	NS	*	*

^zN/A = not applicable, as >50% of these mixtures did not kill.

^{ns}, *Significant at $P \leq 0.05$ between early and late planted mixtures.

there was a correlation between AGB or C : N, and weed cover. The r^2 values were low, and were <0.50 for both weed sampling dates at both locations.

Conclusions

Although many of the mixtures did well in 1991–92 based on the criteria used for evaluation, at least one or more species in each mixture was not particularly suited to this type of production system. 'Nitro' alfalfa, ladino clover, subterranean clover, Austrian winter peas, and annual ryegrass did not overwinter dependably at both locations and would not be good choices for this region. Some of the species, including tall fescue, perennial ryegrass, and orchardgrass, did not compete well with taller, more vigorous species. Several of the species tested were not killed by the mechanical undercutter, including medium and mammoth red clover, both ryegrasses, and both sweetclovers. The seed of bigflower vetch is expensive and not readily available and, as it did not produce as much biomass as hairy vetch, it would not be the best choice for use. The species remaining (hairy vetch, barley, rye, and crimson clover) were all fairly competitive, produced adequate biomass when grown in a mixture, overwintered well, established quickly, and were easily killed. In addition, in other studies, all of these species have been shown to be allelopathic to some weeds (Barnes et al., 1987; Bradow and Connick, 1990; Overland, 1966; White et al., 1989).

A mixture of these four species was used in a subsequent study and managed as a mulch for transplanted processing tomatoes (*Lycopersicon esculentum* Mill). The mixture covered the soil surface quickly, produced large amounts of biomass (9567 and 14,287 kg·ha⁻¹

AGB in Columbus and Fremont, respectively), contained ample N in the AGB (218 kg·ha⁻¹ in Columbus, and 363 kg·ha⁻¹ in Fremont), had a C : N ratio of 22:1, killed easily by mechanical means, and suppressed weeds as well as herbicides did (Creamer et al., 1996).

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