EFFECTS OF OVERSEEDED LEGUME LIVING MULCHES AND TILLAGE ON WEED SUPPRESSION AND BROCCOLI YIELD

by

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(ABSTRACT)

Experiments were conducted at two sites in Blacksburg, Virginia to study the effects of tillage (conventional plow-disk and no-tillage) and overseeding (underseeding) of legume cover crops (red clover, *Trifolium pratense* L.; white clover, *Trifolium repens* L.; and hairy vetch, *Vicia villosa* Roth.) at transplanting on weed suppression and yield of 'Big Sur' broccoli (*Brassica oleracea* var. *italica* Plenck). In both sites, weed suppression from overseeded red clover, white clover, and hairy vetch equalled or surpassed that of the preemergent herbicide (oxyfluorfen) control. The legumes did not affect broccoli yield components in site 1 nor head number in site 2. However, hairy vetch reduced broccoli yield and head size in site 2. These reductions were attributed to competition with the broccoli. Overseeding tended to delay broccoli yield and head number in the two sites, but this trend was not significant. Tillage system did not affect weed suppression or broccoli yield components, and there were no tillage x overseeding effects. Based on this data, overseeded legumes can provide residual weed control in no-till broccoli, thus allowing a more sustainable production method.

DEDICATION

This thesis is dedicated to peace, the true spirit of farming, and sustainable agriculture.

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INTRODUCTION

Sustainable agriculture is defined as one that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species (Harwood, 1990). The most important environmental concerns that have lead to sustainable agriculture development are soil erosion; loss of soil productivity and quality; depletion of water and energy resources; and agrichemical contamination of ground water, drinking water, and wildlife habitats (Poincelot, 1986).

Conservation tillage addresses some of the concerns mentioned above--its benefits are familiar: improved soil structure; increased water infiltration and retention; reduced topsoil, fertilizer, and pesticide runoff; and energy conservation (Poincelot, 1986; Lal et al., 1991). The effect of no-tillage (NT) on vegetable yield is inconclusive (Knavel et al., 1977; Knavel and Herron, 1986). Broccoli yield in NT systems has been variable. Morse and Seward (1986) found that broccoli yield and head size with NT were equal to or greater than conventional tillage (CT). On the other hand, Knavel (1988) reported lower broccoli yields from NT compared to CT.

Despite its benefits, conservation tillage depends on herbicides to desiccate the cover crop prior to planting and to provide residual weed control (Wallace and Bellinder, 1992). Furthermore, registered pesticides for vegetable production are limited and declining every year. Also, consumers are concerned about pesticide residues in produce and the environment (Phatak, 1992). Therefore, alternative weed control methods for conservation tillage vegetable systems within the context of sustainable agriculture are needed. The use of living mulches provides one such option.

The advantages of living mulches are similar to those of conservation tillage but include reduced use of chemical and organic fertilizers and weed suppression. Even so, a major disadvantage of living mulches can be light, water, and nutrient competition with the cash crop (Lal et al., 1991). Overseeding (underseeding) living mulches into established vegetables might overcome this drawback. Foulds et al. (1991) found that broccoli yields were not affected by overseeded legumes, but weed biomass was reduced.

The objective of this study was to examine the effects of overseeded legume live mulches and tillage on weed suppression and broccoli yield.

LITERATURE REVIEW

Vegetable Yield in No-Till Systems

Multiple-vegetable studies. The variability of vegetable yields under no-tillage (NT) compared to conventional tillage (CT) was found in a study by Knavel et al. (1977)--the results are summarized below:

	Year 1	Year 2	Year 3
Cucumis sativus L.	NT=CT	NT<CT	NT=CT
Zea mays var. *rugosa* L.	NT>CT	NT=CT	NT=CT
Lycopersicon esculentum Mill.	NT<CT	NT<CT	NT=CT
Capsicum annuum L.	NT<CT	NT<CT	NT<CT

In a similar experiment, the yields of several vegetables were measured (Knavel and Herron, 1986):

	Yield	
	Year 1	Year 2
Phaseolus vulgaris L.	NT<CT	NT<CT
Zea mays var. *rugosa* L.	NT<CT	NT<CT
Cucurbita pepo L.	NT=CT	-----
Lycopersicon esculentum Mill.	NT≥CT	NT≤CT
Brassica oleracea var. *capitata* L.	NT<CT	NT≤CT

***Lycopersicon esculentum* Mill.** No NT effect on yields relative to CT was found by Doss et al. (1981), Price and Baughn (1987), and Drost and Price (1991). However, in another investigation NT yields were twice as high as those of CT (Shelby et al., 1988).

***Phaseolus vulgaris* L.** Skarphol and Corey (1987) reported NT yields equal to or higher than those of CT. No yield differences between NT and CT systems were found by Mullins et al. (1980) and DeGregorio and Ashley (1986). In a subsequent study, NT yields were lower than CT (Mullins et al., 1988).

***Brassica*.** Cabbage yields were equal to, lower, or higher in NT than in CT (Knavel, 1989). Love (1986) obtained NT cabbage yields similar to or lower than CT yields. Also, broccoli and cabbage yields under NT were equivalent to or greater than those under CT (Morse and Seward, 1986). No NT effect on cabbage and cauliflower (*Brassica oleracea* var. *botrytis* L.) yields relative to CT was evident in a Norwegian experiment (Ekeberg, 1987) nor on cabbage yields in an investigation by Wilhoit et al. (1990). On the other hand, cabbage, broccoli, and cauliflower yields were reduced by NT compared to CT (Knavel and Herron, 1981; Knavel, 1988).

***Miscellaneous vegetables*.** No yield differences between NT and CT carrots (*Daucus carota* L.) and cowpeas (*Vigna unguiculata* L.) were reported (Orzolek and Carroll, 1978; Simpson and Gumbs, 1985). Furthermore, NT reduced lima bean (*Phaseolus lunatus* L.), sweet corn, okra (*Abelmoschus esculentus* L.), and egusi-melon (*Colocynthus citrullus* L.) yields relative to CT (Mullins et al., 1980; Petersen et al., 1986; Asoegwu, 1987).

Agronomic Yield and Weed Control in Legume Living Mulch Systems

Interseeded/undersown systems (crop and mulch seeded simultaneously). Broad red clover (*Trifolium pratense* L.) interseeded with barley (*Hordeum vulgare* L.) and field beans (*Vicia faba* L.) decreased couch grass (*Agropyron repens* L.) growth by 50% in the barley and 75% in the field beans (Dyke and Barnard, 1976). However, the clover reduced field bean height by 5-10 cm--an estimated 20% yield decrease. Stewart et al. (1980) found that undersown red or white clover did not depress barley yields. Interseeded arrowleaf clover (*Trifolium vesiculosum* Savi.) or a combination of arrowleaf and crimson clovers (*Trifolium incarnatum* L.) increased rye yields 109% and 141%, respectfully (Lynd et al., 1984). Hartl (1989) reported that winter wheat (*Triticum aestivum* L.) undersown with persian clover (*Trifolium resupinatum* L.) or black medic (*Medicago lupulina* L.) had lower yields than the controls. Moreover, the two legumes decreased weed dry matter by 50%. Also, in the same study interseeded white clover did not affect winter wheat yields but reduced weed dry matter by 70%. An experiment by Brandt et al. (1989) showed that undersown subclover (*Trifolium subterraneum* L.) lowered, increased, or had no effect on yield of winter wheat.
Interplanted/intercropped systems (crop planted into established mulch). Yields from maize (*Zea mays* L.) grown with tropical legumes were lower than NT yields (Akobundu and Okigbo, 1984). Haynes et al. (1985) indicated that interplanted crownvetch (*Coronilla varia* L.) depressed corn yields but not weed yields. The corn

and weed yields from a corn-hairy vetch interplant (CV) were compared to NT and CT controls (Echtenkamp and Moomaw, 1989):

Corn Yield		Weed Yield	
Year 1	Year 2	Year 1	Year 2
CV=NT; CV<CT	CV<NT,CT	CV>NT,CT	CV<NT; CV=CT

Enache and Ilnicki (1990) found that yields from NT corn-subclover interplants were equal to or lower than those of CT interplants, and no differences in weed biomass were obtained between these two systems. White and Scott (1991) reported the effects of six interplanted legumes--crownvetch; birdsfoot trefoil (*Lotus corniculatus* L.); white, red, ladino (*Trifolium repens* var. *giganteum* L.) clovers; and alfalfa (*Medicago sativa* L.)--on yields and weed biomass of winter wheat and rye:

Year 1

- Only red clover decreased wheat yield.
- Rye yield was unaffected by interplanted legumes.
- There were no legume effects on weed biomass.

Year 2

- All legumes except red clover reduced wheat yield.
- All legumes except clovers depressed rye yield.
- All legumes except crownvetch lowered weed biomass.

Overseeded Systems (mulch seeded into established crop). Evers (1983) reported that weed production in bahiagrass (*Paspalum notatum* Flugge) and bermudagrass (*Cynodon dactylon* L.) sods overseeded with arrowleaf or subclover was no different than simazine controls. Also, weeds were virtually eliminated by the second year of the experiment.

Vegetable Yield and Weed Control in Legume Living Mulch Systems

***Zea mays* var. *rugosa* L.** Vrabel et al. (1980) indicated reduced yields when sweet corn was planted into established full or strip covers of red, white, ladino clovers and alfalfa. No yield reductions were found when the corn was seeded simultaneously with strip or full-cover legumes. Furthermore, the ladino and white clovers provided the best weed suppression while red clover provided the worst. White clovers intercropped with sweet corn did not affect yields (Nicholson and Wien, 1983). Sweet corn interplanted with subclover living mulch produced yields equivalent to, lower, or higher and weed cover equal to or higher than herbicide controls (Lanini et al., 1989).

Brassica. Intercropped white clovers lowered the yields of cabbage (Nicholson and Wien, 1983). Broccoli yields were not influenced, but weed biomass was reduced by overseeded white, red, sweet, crimson clovers, and hairy vetch (Foulds et al., 1991).

Miscellaneous vegetables. Lanini et al. (1989) reported that lettuce (*Lactuca sativa* L.)-subclover interplants produced yields equivalent to and weed cover greater than the herbicide controls. Snap bean yields were depressed, and weed biomass increased when two cultivars of red clover were used as intercropped living mulches (DeGregorio and Ashley, 1986). Abdul-Baki and Teasdale (1993) found that tomatoes grown with hairy vetch or subclover living mulches outyielded nonmulched (control) plants.

Additional research is needed to examine the combined effects of tillage and overseeded legume living mulches on vegetable yield and weed control with the goal of reducing or eliminating herbicide use.

MATERIALS AND METHODS

Field experiments were conducted in 1992 at two sites at the Virginia Polytechnic Institute and State University Whitethorne-Kentland Agriculture Research Farm. The soil used was a Hayter loam (fine-loamy, mixed, mesic, Ultic Hapludalf) at pH 6.9 in site 1 and pH 7.2 in site 2. The experimental design was a split plot with four replications. Whole plots were tillage systems: no-tillage (NT) or conventional tillage (CT). Subplots were red clover (RC--*Trifolium pratense* L.), white clover (*WC--Trifolium repens* L.), and hairy vetch (HV--*Vicia villosa* Roth.), and control (HB--no legume cover, one application of preemergent herbicide). Whole and subplot dimensions were 12 m x 9 m and 9 m x 3 m, respectfully.

NT residue preparation. Cereal rye (*Secale cereale* L.) at 45 kg ha^{-1} and inoculated hairy vetch at 15 kg ha^{-1} were drilled into site 2 on 16 October 1991; site 1 was left fallow. The cover crops in site 2 were mowed at the rye immature heading stage, and 450 kg ha^{-1} 10N-4.3P-8.3K fertilizer was applied to both sites on 21 May 1992. On 3 June 1992, 43 kg ha^{-1} of foxtail millet (*Setaria italica* L.) was drilled into sites 1 and 2. The millet and all other vegetation was desiccated with 1.5 liter ha^{-1} of glyphosate [N-(phosphonomethyl) glycine] on 21 July 1992 and 3.5 liter ha^{-1} of paraquat [1,1'-dimethyl-4,4'-bipyridinium salt] on 11 August 1992. The desiccated stubble was then mowed with a rotary mower. Total cover crop residue in dry weight was estimated to be 2.7 Mg ha^{-1} in site 1 and 3.3 Mg ha^{-1} in site 2 by taking 1 m^2 samples from each site.

Broccoli culture. CT plots were cultivated by using a chisel plow and rotovator. Oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-trifluoromethyl) benzene] at 2.9 liter ha^{-1} was applied to control subplots prior to broccoli planting. On 18 August 1992, twin rows of 'Big Sur' broccoli (*Brassica oleracea* var. *italica Plenck*) were planted into the center of each plot using a Subsurface Tiller-Transplanter (SST-T) (Morse et al., 1993). Each row contained 14 plants (28 plants/subplot), and spacing within rows was 35.6 cm; between-row spacing was 61 cm. Captan [N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide] at 0.62 g $liter^{-1}$; metalaxyl [N-(2,6-dimethylphenyl)-N-(methoxyacetyl) alanine methyl ester] at 0.36 ml $liter^{-1}$; diazinon [0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate] at 1.0 ml $liter^{-1}$; and 9N-19P-12K starter solution at 6 g $liter^{-1}$ were applied by the SST-T at transplanting at the rate of 200 ml/plant.

Overhead sprinkler irrigation was provided throughout the growing season as needed. Pesticides were applied according to standard commercial broccoli recommendations (Anon., 1993). The broccoli was sidedressed once three weeks prior to the first harvest with 56 kg N/ha. Broccoli tissue samples were taken in each subplot by removing two young mature leaves from all plants with head diameters less than 3 cm. The samples were dried at 70°C, ground with a cyclone mill, and a complete nutritional analysis was conducted.

Legume overseeding. Two days after transplanting, 16.8 kg ha^{-1} RC, 11.2 kg ha^{-1} WC, and 50.4 kg ha^{-1} HV were surface broadcast without incorporation. Just prior to overseeding, legume seeds (46.9 g RC, 31.3 g WC, and 140.7 g HV) were inoculated with the proper *Rhizobium* species, thoroughly mixed with 1500 g of finely ground and sieved soybean meal, and uniformly sown by hand over each treatment plot.

Broccoli harvest. Broccoli was first harvested on 30 September 1992 and weekly thereafter for six weeks. Except for the end border plants of each subplot, all visually marketable heads (green, tight bud stage) were counted and weighed.

Legume and weed biomass. Legume cover and weed samples from outside (OR) and inside (IR) the broccoli twin-row were taken during the second week in November, 1992. For the OR samples, all surface vegetation was removed within a 50 cm x 50 cm (0.25 m^2 quadrant placed 50 cm in front of the twin-row. IR samples were collected in the same manner except the 0.25 m^2 quadrant was placed in the center of the twin-row equidistant from each end. All samples were dried at 70°C for two weeks and weighed.

Statistical analysis. Analysis of variance was executed on all main effects and interactions. Tukey's Studentized Range Test was used for mean separation.

RESULTS

Weed biomass. No significant effect of treatment on OR weed biomass was found in site 1 (Table 1). In site 2, hairy vetch and white clover lowered OR weed biomass compared to the herbicide control (Table 1).

In-row weed biomass was not affected by treatment in site 1 or site 2 (Table 1). However, mean IR weed biomass tended to be lowest in hairy vetch plots in both sites. Foulds et al. (1991) reported no effect of overseeded red clover, white clover, or hairy vetch on weed biomass in broccoli.

Legume biomass. In-row legume biomass in site 2 was over 200% higher than that in site 1. Out-row and in-row hairy vetch biomass in site 1 and site 2 was higher than that of red clover and white clover (Table 1). Foulds et al. (1991) also observed greater biomass of overseeded hairy vetch than that of overseeded red clover or white clover.

Total biomass. Out-row total biomass in hairy vetch was higher than in the herbicide control, red clover, and white clover plots in sites 1 and 2 (Table 1).

In-row total biomass in hairy vetch plots of site 1 was greater than in the herbicide control (Table 1). In site 2, in-row total biomass in the herbicide control, red clover, and white clover was lower than that in hairy vetch plots.

Added over all treatments, IR total biomass was 87% lower than OR total biomass in site 1, and 78% lower in site 2 (Table 1).

Broccoli yield. No treatment effects on yield, head size, or head number were found in site 1 (Table 2). However, in site 2, hairy vetch reduced yield and head size relative to the herbicide control (Table 2). These reductions were most likely caused by excessive hairy vetch competition. The treatments did not affect broccoli head number in site 2 (Table 2), indicating that the yield reduction in the hairy vetch plots resulted from smaller head size rather than reduced number of marketable heads. Corn yields were severely depressed by hairy vetch living mulch (Echtenkamp and Moomaw, 1989).

The legume living mulches tended to delay broccoli yield and head number in both sites compared to the herbicide control (Figures 1 and 2). At early harvest, yield and head number under the legume covers were lower than the herbicide control, but by later harvest, they were higher than the control. Even so, this trend was not significant, yet under drought conditions significance might have been observed. Nicholson and Wien (1983) found that white clover live mulch delayed cabbage maturity. Furthermore, hairy vetch and subterranean clover living mulches delayed tomato fruit maturity by about 10 days (Abdul-Baki and Teasdale, 1993).

Broccoli nutrition. In site 1, leaf nitrogen content of broccoli in hairy vetch and herbicide plots was higher than those of white clover, but phosphorous and potassium contents were unaffected by treatment (Table 3). There was no effect of treatment on leaf nitrogen, phosphorous, and potassium in site 2 (Table 3).

No significant tillage or interactive effects were found for any of the variables measured. Yields of NT broccoli grown in Virginia were also shown to be equal to those of CT (Morse and Seward, 1986).

Table 1. Effects of tillage and overseeded legume covers on legume, weed, and total biomass.[z]

Legume cover (LC)	Site 1[Y]			Site 2		
	CT	NT	LC mean	CT	NT	LC mean
			Out-row legume cover (kg ha⁻¹)			
Red clover	1498	1955	1726 b[x]	1561	1466	1514 b
White clover	1979	1917	1948 b	1489	1821	1655 b
Hairy vetch	3595	3144	3370 a	3073	2935	3004 a
Tillage mean	2357	2339			2041	2074
Treatment effects						
Tillage (T)	NS			NS		
LC	*			*		
T x LC	NS			NS		
			In-row legume cover (kg ha⁻¹)			
Red clover	173	137	155 b	251	424	338 b
White clover	59	139	99 b	198	242	220 b
Hairy vetch	388	652	520 a	931	1262	1096 a
Tillage mean	207	309		460	643	
Treatment effects						
Tillage (T)	NS			NS		
LC	*			*		
T x LC	NS			NS		
			Out-row weed biomass (kg ha⁻¹)			
Herbicide	317	544	431 a	1553	457	1005 a
Red clover	997	345	671 a	707	148	428 ab
White clover	164	187	176 a	342	78	210 b
Hairy vetch	135	275	205 a	151	12	82 b
Tillage mean	403	338		688	174	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			*		
T x LC	NS			NS		

Table 1. (cont'd).

Legume cover (LC)	Site 1[Y] CT	NT	LC mean	Site 2 CT	NT	LC mean
			In-row weed biomass (kg ha^{-1})			
Herbicide	138	28	8 a	0	17	8 a
Red clover	278	8	143 a	102	15	58 a
White clover	321	27	84 a	31	30	31 a
Hairy vetch	24	20	22 a	0	0	0 a
Tillage mean	191	21		33	16	
Treatment effects						
Tillage (TC)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		
			Out-row total biomass (kg ha^{-1})			
Herbicide	317	544	431 c	1553	457	1005 c
Red clover	2495	2300	2398 b	2268	1614	1941 b
White clover	2143	2104	2124 b	1831	1899	1865 bc
Hairy vetch	3730	3419	3574 a	3224	2947	3086 a
Tillage mean	2171	2092		2219	1729	
Treatment effects						
Tillage (TC)	NS			NS		
LC	*			*		
T x LC	NS			NS		

Table 1. (cont'd).

Legume cover (LC)	Site 1[Y] CT	NT	LC mean	Site 2 CT	NT	LC mean
	In-row total biomass (kg ha^{-1})					
Herbicide	139	28	84 b	0	17	8 c
Red clover	451	145	298 ab	353	439	396 b
White clover	200	166	183 b	229	272	251 bc
Hairy vetch	412	672	542 a	931	1262	1096 a
Tillage mean	301	253		378	498	
Treatment effects						
Tillage (TC)		NS			NS	
LC		*			*	
T x LC		NS			NS	

[z] Weed species in order of decreasing visual frequency: site 1--*Mollugo verticillata* L., *Malva neglecta* Wallr., *Stellaria media* L., *Lamium amplexicaule* L., *Galinsoga ciliata* Raf.; site 2--*Vicia villosa* Roth., *Festuca arundinacea* Schreb., *Lamium amplexicaule* L., *Malva neglecta* Wallr., *Setaria italica* L.

[Y] CT = conventional tillage; NT = no-till

[x] Mean separation within mean effects within columns by Tukey ($P \leq 0.05$)
NS, * = not significant or significant, 5% level

Table 2. Effects of tillage and overseeded legume covers on marketable broccoli yield and yield components.

Legume cover (LC)	Site 1[z] CT	Site 1[z] NT	Site 1[z] LC mean	Site 2 CT	Site 2 NT	Site 2 LC mean
			Yield (Mg ha^{-1})			
Herbicide	15.1	14.3	14.7 a	13.9	14.6	14.3 a[Y]
Red clover	14.9	15.9	15.4 a	13.7	12.4	13.1 ab
White clover	15.6	15.0	15.3 a	14.6	13.8	14.2 ab
Hairy vetch	14.2	14.7	14.5 a	12.6	11.9	12.2 b
Tillage mean	15.0	15.0		13.7	13.2	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			*		
T x LC	NS			NS		
			Head size (g/head)			
Herbicide	385	351	368 a	325	372	348 a
Red clover	374	365	370 a	337	297	317 ab
White clover	376	373	374 a	343	335	339 a
Hairy vetch	364	362	363 a	296	284	290 b
Tillage mean	375	363		325	322	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			*		
T x LC	NS			NS		
			Head number (1000s/ha)			
Herbicide	39.4	40.7	40.1 a	42.6	39.4	41.1 a
Red clover	40.0	43.8	41.9 a	40.7	41.9	41.3 a
White clover	41.9	40.3	41.1 a	42.6	41.3	42.1 a
Hairy vetch	39.4	40.7	40.1 a	42.6	41.9	42.3 a
Tillage mean	40.1	41.5		42.3	41.1	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		

[z] CT= conventional tillage; NT = no-till

[Y] Mean separation within mean effects within columns by Tukey ($P \leq 0.05$)

NS, * = not significant or significant, 5% level

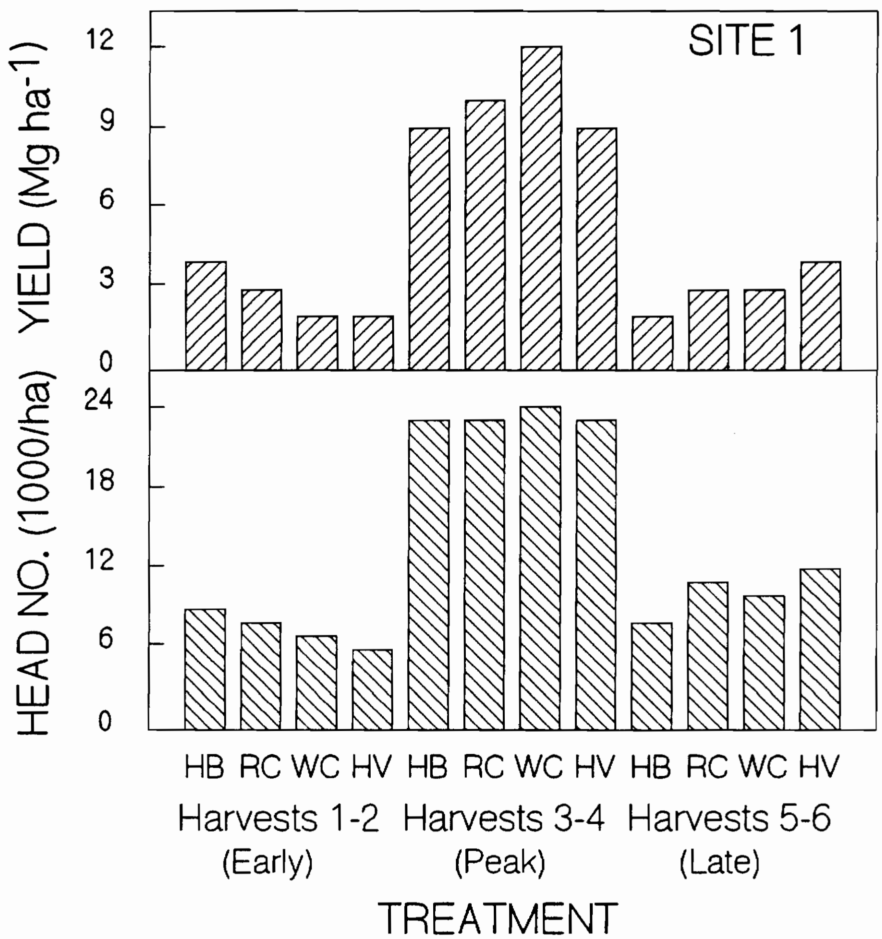

Figure 1. Effect of overseeded legume covers on marketable yield and head number for three harvest periods (early, peak, and late) in site 1. Data are average of CT and NT main plots. For all harvest periods for both yield and head number, there were no significant (5% level) differences among legume cover treatments.

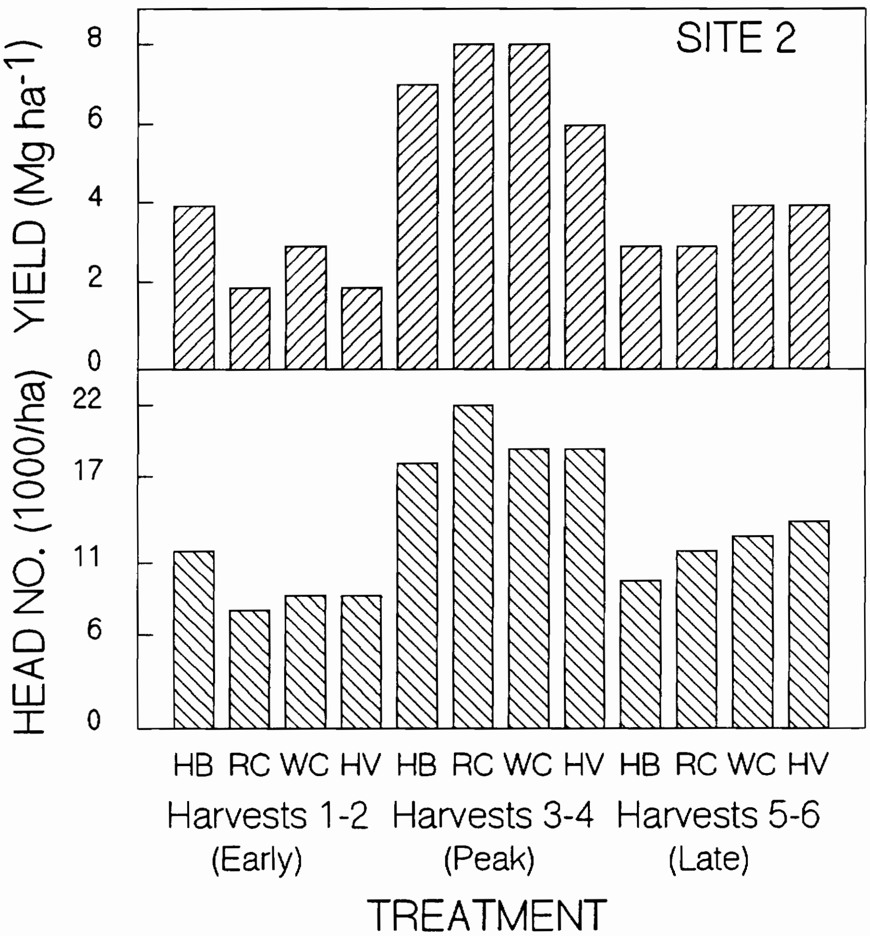

Figure 2. Effect of overseeded legume covers on marketable yield and head number for three harvest periods (early, peak, and late) in site 2. Data are average of CT and NT main plots. For all harvest periods for both yield and head number, there were no significant (5% level) differences among legume cover treatments.

Table 3. Effects of tillage and overseeded legume covers on N, P, and K concentrations of broccoli leaves.

Legume cover (LC)	Site 1[z] CT	Site 1[z] NT	Site 1[z] LC mean	Site 2 CT	Site 2 NT	Site 2 LC mean
	Nitrogen (%) [sufficiency range: 3.2-5.5 %][Y]					
Herbicide	6.2	6.2	6.2 a[x]	6.1	5.7	5.9 a
Red clover	6.0	6.3	6.1 ab	6.4	6.0	6.2 a
White clover	5.7	5.8	5.8 b	6.0	5.7	5.8 a
Hairy vetch	6.5	6.1	6.3 a	6.2	6.0	6.1 a
Tillage mean	6.1	6.1		6.2	5.8	
Treatment effects						
Tillage (T)	NS			NS		
LC	*			NS		
T x LC	NS			NS		
	Phosphorous (%) [sufficiency range: 0.30-0.75 %]					
Herbicide	0.84	0.87	0.85 a	0.85	0.85	0.85 a
Red clover	0.88	0.90	0.89 a	0.91	0.85	0.88 a
White clover	0.86	0.86	0.86 a	0.86	0.78	0.82 a
Hairy vetch	0.92	0.90	0.91 a	0.90	0.81	0.85 a
Tillage mean	0.87	0.88		0.88	0.82	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		
	Potassium (%) [sufficiency range: 2.0-4.0 %]					
Herbicide	3.1	3.3	3.2 a	3.9	3.7	3.8 a
Red clover	3.3	3.4	3.4 a	3.8	3.8	3.8 a
White clover	3.2	3.4	3.3 a	3.9	3.8	3.8 a
Hairy vetch	3.4	3.4	3.4 a	4.0	3.8	3.9 a
Tillage mean	3.3	3.4		3.9	3.8	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		

[z] CT = conventional tillage; NT = no-till

[Y] (Jones et al., 1991).

[x] Mean separation within mean effects within columns by Tukey ($P \leq 0.05$)

NS, * = not significant or significant, 5% level

DISCUSSION

Broccoli canopy effects on weed suppression. The large reduction in IR compared to OR biomass was attributed to shading by the broccoli canopy, illustrating the potential of rapid canopy closure as a weed-control strategy (Stoller and Myers, 1989; Ramirez and Sweet, 1986; Sweet et al., 1974).

Transplants, as opposed to direct seeding, and particularly in this experiment using the 'Big Sur' cultivar with its wide spreading leaves, accelerated canopy closure and weed suppression. Furthermore, vigorous growth with virtually no transplant shock was encouraged by the application of starter fertilizer and irrigation. The rapid occlusion of the broccoli canopy effectively eliminated the competitive pressure from weeds and overseeded legumes in all plots except with hairy vetch in site 2.

Proper synchronization of planting and growth of the overseeded legume crops is essential to avoid weed problems or yield reductions in the main crop (Regnier and Janke, 1990). Premature establishment of the overseeded legumes can result in excessive early competition and subsequent reduction in plant size and yield potential of the main crop (Vrabel et al., 1980). Conversely, delayed overseeding into an established stand of undesirable fast-growing weeds would possibly result in ineffective weed suppression and consequent yield reductions of the main crop. In this study, overseeding two days after transplanting resulted in good weed suppression without reduction of broccoli yield except in the hairy vetch plots in site 2. Both sites were essentially weed-free at overseeding, and growth of the broccoli transplants probably was not checked by the uniform dense stand of legumes that developed outside the twin rows. Except in the hairy vetch plots in site 2, IR growth of legumes and weeds was suppressed enough by the rapid canopy closure of the broccoli to not affect broccoli yield. In site 2, a mixture of overwintering hairy vetch and cereal rye was grown in 1991-1992 prior to drilling millet in June, 1992. Volunteer hairy vetch was the major "weed" species in site 2 (Table 1) and possibly, when combined with the overseeded hairy vetch biomass, increased the total to a competitive level sufficient to reduce broccoli yield.

Effect of tillage on weed suppression, legume biomass, and broccoli yield. In this experiment, tillage had no significant effect on weed suppression and production of legume biomass. Thus, for the irrigation regime used in this study, surface broadcasting was an effective seeding method in both CT and NT plots. However, under nonirrigated conditions, legume seed germination and subsequent biomass production conceivably could have been reduced in the CT plots because of their greater susceptibility to soil-moisture deficits and soil-crusting problems than NT plots (Morse et al., 1982). Since legume growth was similar between tillage treatments, there was apparently no allelopathic inhibition of legume seed germination in the NT plots (Putnam, 1990).

Broccoli yield was unaffected by tillage system, indicating that soil compaction was not a problem in the NT plots or that it was overcome by the soil-loosening action of the Subsurface Tiller Transplanter (SST-T) (Morse et al., 1993; South, 1993). When soil moisture is not a limiting factor, vegetable yields are frequently lower in NT than in the loosened soil of CT and ST (strip tillage) plots (Knavel and Herron, 1981; Morse, 1989). In compacted NT soils, poor root-soil contact occurs when in-row loosening is inadequate, resulting in reduced survival and early growth of vegetable (Knavel and Herron, 1981) and tobacco (Zartman et al., 1976) transplants.

Legume overseeding and vegetables--requisites for success. In both sites, weed suppression by overseeded legumes equalled or surpassed that of the herbicide control. Weed control through legume overseeding attempts to replace an undesirable and sporadic weed population with one that is innocuous, dense, and uniform. In addition, legume cover crops improve soil aggregation, structural properties, infiltration capacity, and subsequent season fertility. Moreover, they decrease the risks of runoff and erosion and increase biodiversity (Lal et al., 1991). Nonetheless, excessive encroachment of legume living mulches can reduce vegetable yield--an effect more severe under limited growth inputs (water, nutrients, light, and carbon dioxide) (Lake and Harvey, 1985; Vrabel, 1983). In this study, the plots where hairy-vetch encroachment reduced broccoli yield showed no water and nutrient limitations. Possibly, shading of the broccoli reduced photosynthesis enough to decrease yields. Nicholson and Wien (1983) suggested that light competition between white clovers and cabbage may have been a factor in reducing cabbage yields because rampant clover growth shaded lower cabbage leaves. Hairy vetch encroachment into broccoli twin-rows could have lowered broccoli yield in the same manner. Repeated rototilling or mowing of the living mulch has been employed successfully to reduce living-mulch encroachment and minimize yield depression (Grubinger and Minotti, 1990; Vrabel, 1983).

Overseeded legumes employed for weed control should have quick and uniform germination and growth; strong weed suppression through competition, allelopathy, and/or physical effects (Lal et al., 1991); minimal competition with vegetable transplants; and rapid subsidence under shading from the vegetable crop (Palada et al., 1983). Therefore, the ideal overseeded legume provides early, critical weed control after transplanting (Lanini and Strange, 1991; Thakral et al., 1989); thereafter, it is checked sufficiently by the vegetable canopy to avoid yield reduction and delay. A grower can promote this ideal by overseeding after the main crop is properly established (Regnier and Janke, 1990) and by the utilization of vegetable cultivars that enclose rapidly and maintain a tight canopy (Regnier and Janke, 1990; Nicholson and Wien, 1983; Sweet et al., 1974), relatively large and vigorous vegetable transplants, narrow row spacing (Teasdale and Frank, 1983; Williams et al., 1973), starter fertilizers (Grubinger et al., 1993), uniform and dense overseeding into relatively weed-free fields, and proper placement and timing of fertilizer and irrigation applications.

With the exception of hairy vetch in site 2, all three legumes tested in this experiment effectively suppressed weeds without reducing broccoli yield. When considering only yield on a single-season basis, exposing a vegetable crop to the potentially harmful competitive effects of a living mulch appears to be a tenuous practice. Furthermore, the use of this practice where water, nutrients, and other growth inputs are not maintained might be considered highly questionable. Nevertheless, as the world moves toward more sustainable agriculture systems, the long-term maintenance and even improvement in soil productivity by the utilization of leguminous crops and the elimination of herbicides far outweigh any possible short-term yield disadvantages.

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APPENDIX

Table 4. Effects of tillage and overseeded legume covers on Ca, Mg, Cu, Fe, Zn, B, and Mn concentrations of broccoli leaves.

Legume cover (LC)	Site 1[z]			Site 2		
	CT	NT	LC mean	CT	NT	LC mean
	Calcium (%) [sufficiency range: 1.0-2.5 %][Y]					
Herbicide	1.6	1.7	1.7 a	1.8	1.7	1.7 a
Red clover	1.9	1.7	1.8 a	1.8	1.7	1.8 a
White clover	1.7	1.9	1.8 a	2.0	1.8	1.9 a
Hairy vetch	1.8	1.7	1.8 a	1.8	1.8	1.8 a
Tillage mean	1.8	1.8		1.8	1.7	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	*			NS		
	Magnesium (%) [sufficiency range: 0.25-0.75 %]					
Herbicide	0.38	0.39	0.38 a	0.41	0.39	0.40 a
Red clover	0.44	0.40	0.42 a	0.42	0.40	0.41 a
White clover	0.42	0.40	0.41 a	0.44	0.41	0.42 a
Hairy vetch	0.42	0.40	0.41 a	0.42	0.42	0.42 a
Tillage mean	0.41	0.39		0.42	0.40	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		
	Copper (ppm) [sufficiency range: 5-15 ppm]					
Herbicide	6.2	6.8	6.5 b[x]	6.1	6.3	6.2 a
Red clover	12.7	6.5	9.6 ab	6.6	8.0	7.3 a
White clover	12.8	6.0	9.4 a	5.9	7.7	6.8 a
Hairy vetch	8.0	5.8	6.8 b	6.5	5.2	5.9 a
Tillage mean	9.9	6.2		6.3	6.8	
Treatment effects						
Tillage (T)	*			NS		
LC	*			NS		
T x LC	*			NS		

Table 4. (cont'd).

Legume cover (LC)	Site 1[z]			Site 2		
	CT	NT	LC mean	CT	NT	LC mean
	Iron (ppm) [sufficiency range: 70-300 ppm]					
Herbicide	63	64	64 a	61	60	61 a
Red clover	79	61	70 ab	61	66	64 a
White clover	72	66	69 b	63	58	60 a
Hairy vetch	74	62	68 a	74	56	65 a
Tillage mean	72	63		65	60	
Treatment effects						
Tillage (T)		*			NS	
LC		NS			NS	
T x LC		NS			*	
	Zinc (ppm) [sufficiency range: 35-200 ppm]					
Herbicide	60	71	66 a	41	40	40 a
Red clover	113	49	81 a	43	40	42 a
White clover	55	59	57 a	38	35	37 a
Hairy vetch	109	58	83 a	41	36	38 a
Tillage mean	84	59		41	38	
Treatment effects						
Tillage (T)		NS			NS	
LC		NS			NS	
T x LC		NS			NS	
	Boron (ppm) [sufficiency range: 30-100 ppm]					
Herbicide	38	37	37 a	36	37	36 a
Red clover	38	38	38 a	40	37	38 a
White clover	38	34	36 a	35	33	34 a
Hairy vetch	40	36	38 a	37	31	34 a
Tillage mean	38	37		37	35	
Treatment effects						
Tillage (T)		NS			NS	
LC		NS			*	
T x LC		NS			NS	

Table 4. (cont'd).

Legume cover (LC)	Site 1[z] CT	NT	LC mean	Site 2 CT	NT	LC mean
	Manganese (ppm) [sufficiency range: 25-200 ppm]					
Herbicide	84	91	88 a	102	68	85 a
Red clover	99	96	98 a	96	98	97 a
White clover	61	92	77 a	115	118	117 a
Hairy vetch	130	107	119 a	141	86	113 a
Tillage mean	94	97		113	92	
Treatment effects						
Tillage (T)	NS			NS		
LC	NS			NS		
T x LC	NS			NS		

[z] CT = conventional tillage; NT = no-till

[Y] (Jones et al., 1991)

[x] Mean separation within mean effects within columns by Tukey ($P \leq 0.05$)
NS, * = not significant or significant, 5% level

VITA

Tammam Serage was born on November 28, 1966 in London, United Kingdom. He received a Bachelor and Master of Science degree from Virginia Polytechnic Institute and State University in December 1990 and June 1993, respectively.

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