LNE88-05

Final Report

COVER CROPS FOR NEW ENGLAND VEGETABLE GROWERS:

ON-FARM RESEARCH, ECONOMIC ANALYSIS AND OUTREACH

A PROGRESS REPORT
March 31, 1991

for the NE Region
Low-Input Sustainable Agriculture Program

Submitted by

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INTRODUCTION

This report summarizes work that has been implemented as of March 31, 1991 by the University of Massachusetts in cooperation with New Alchemy Institute, Maine Organic Farmers and Growers Association and the University of Connecticut as part of a Low Input Sustainable Agriculture (LISA) grant from the U.S. Department of Agriculture. The report also outlines work that is continuing in 1991. The report is divided into the following areas:

1. Field experiments implemented by the University of Massachusetts as part of the 1989-90 funded proposal.
2. Economic analysis of hairy vetch/rye vs. rye cover crops.
3. Field days held and talks given on cover crop research.
4. Preliminary report on the progress of experiments that were initiated in the summer and fall of 1990 for the 1990-91 LISA grant.
5. Update on the research in progress at New Alchemy Institute and Maine Organic Farmers and gardeners Association.
6. Copies of two scientific papers and examples of educational factsheets based on LISA-funded work. The first manuscript has been accepted for publication by Biological Agricultural and Horticultural. The second is a "first draft" of a manuscript for a paper that will be submitted for publication.

1. FIELD STUDIERS: 1989-1990

Six field experiments were initiated and completed at the research farm of the University of Massachusetts in South Deerfield as part of the grant awarded in 1989.

i. Optimal Seeding and Mowing Dates for Hairy Vetch and Rye.

An important question concerning these two cover crop species is the optimum time of planting in the fall and mowing in the spring. Early seeding in the fall is essential to achieve sufficient biomass growth prior to winter freezing in order to provide an effective cover for control of soil erosion. When cover crops are to be left as a surface mulch for weed suppression it is also important to estimate the optimum cutting time the following spring. This is to ensure that the cover crops will not regrow and compete with planted cultivated crops.

Five different times of planting of the hairy vetch (*Vicia villosa*) and winter rye (*Secale cereale*) mixture were established and compared to an unplanted check in a replicated experiment in the summer and fall of 1989. Biomass samples were collected in late fall to determine plant growth. Figure 1 reports above-ground biomass yield of hairy vetch and rye. For the July 1 planting, rye growth was suppressed by competition from the hairy vetch.

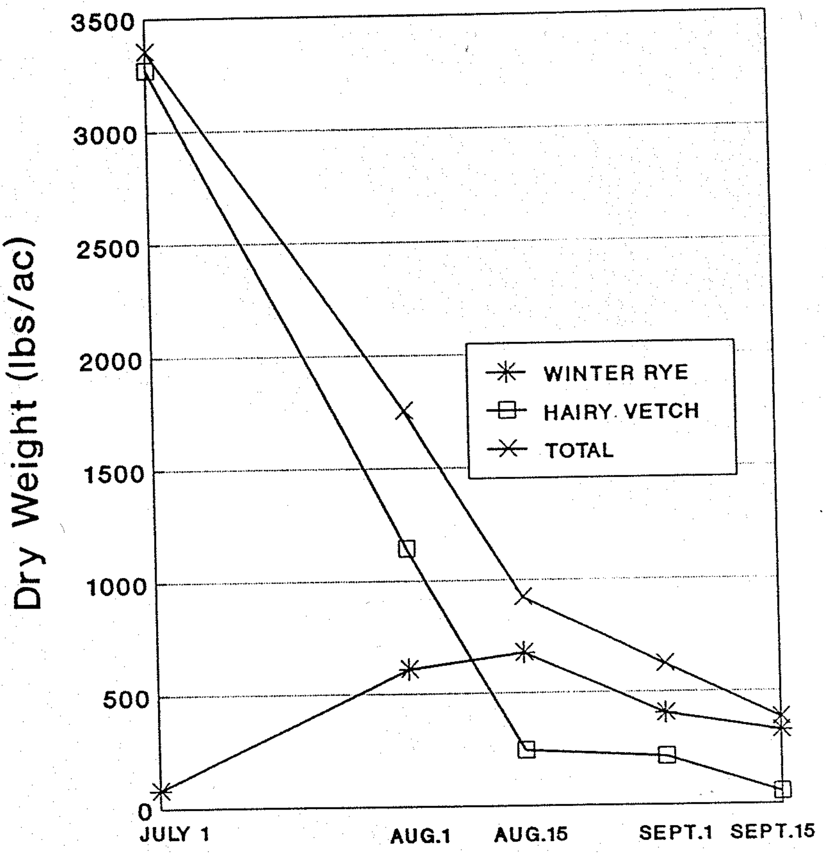

Figure 1. Fall biomass data for winter rye and hairy vetch planted at five different dates in 1989.

The three mowing dates were May 3, May 16 and May 31. Above-ground biomass samples were taken before each mowing date to determine the spring plant growth of the two cover crop species. Figure 2 reports the total biomass accumulation for the hairy vetch and rye at the three mowing dates. Both the rye and vetch winterkilled for the July 1 planting. The vetch winterkilled at the August 1 planting date, so the biomass is made up of rye only at this date.

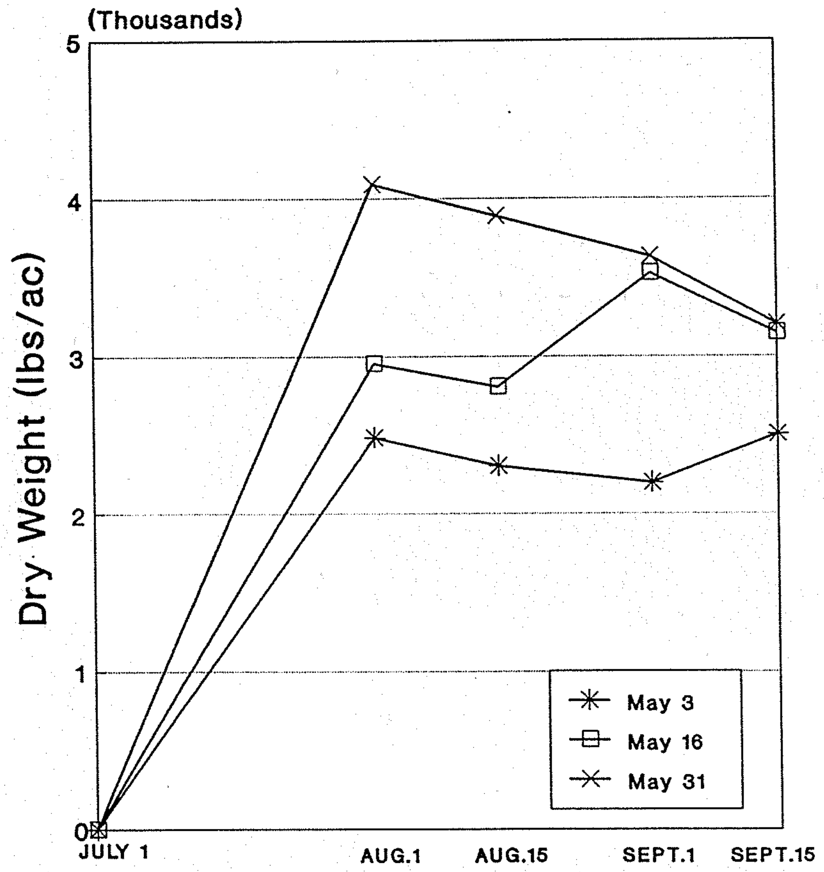

Figure 2. Spring biomass data for winter and rye planted
at five different dates in the summer and fall of 1989
and then mowed at three different dates in the spring of 1990.

Soil samples were taken May 9, six days after the first cutting, to compare the soil moisture content among the six treatments (Table 1). There was no statistical difference in the percent soil moisture among treatments.

Table 1. Soil moisture content for five planting dates and a control. Samples were taken May 9 from plots that were mowed May 3.

Treatment	% Soil Moisture*
Bare Ground	16.2
July 1	17.7
August 1	16.3
August 15	16.6
September 1	16.8
September 15	16.8

*not significant at the 0.05 level

The number of rye and vetch plants that regrew after being mowed was determined on July 20, 1990. Figures 3 and 4 report the number of live rye tillers and vetch plants per square foot. Figures 5 and 6 report the height for the two cover crop species.

The rye proved to be more persistent than the vetch (Figures 3 and 4). The third cutting (May 31) had the smallest regrowth for both the rye and vetch. There was no vetch regrowth at the last cutting for the August 15 and September 1 plantings. The time of mowing had a much more significant effect on the height of the cover crops than the population (Figures 5 and 6).

The percent weed cover was taken July 10 for the five planting dates and the control (Figure 7). Among the cover crop planting dates, the July 1 planting had the highest weed pressure. This was due to the fact that the cover crops had winterkilled. For the August 15, September 1 and 15 planting dates, no weeds were present for the first cutting due to the tremendous regrowth of the cover crops which was able to out-compete weed species.

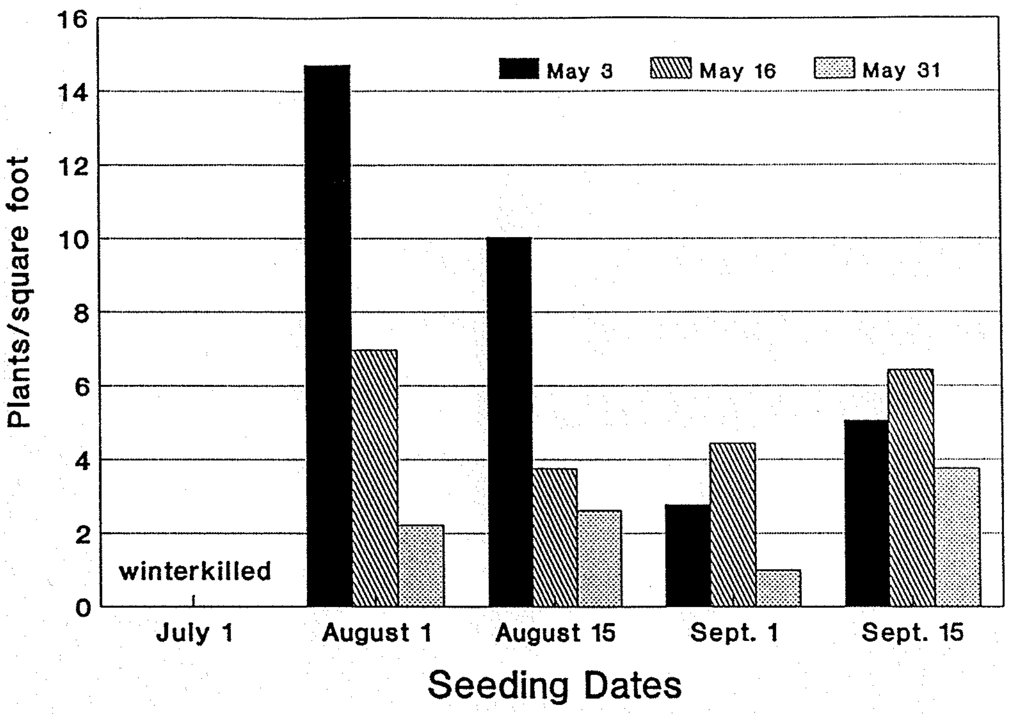

Figure 3. Number of live tillers per square foot of winter rye for winter rye and vetch planted at five different dates in 1989 and mowed at three different dates in the spring of 1990.

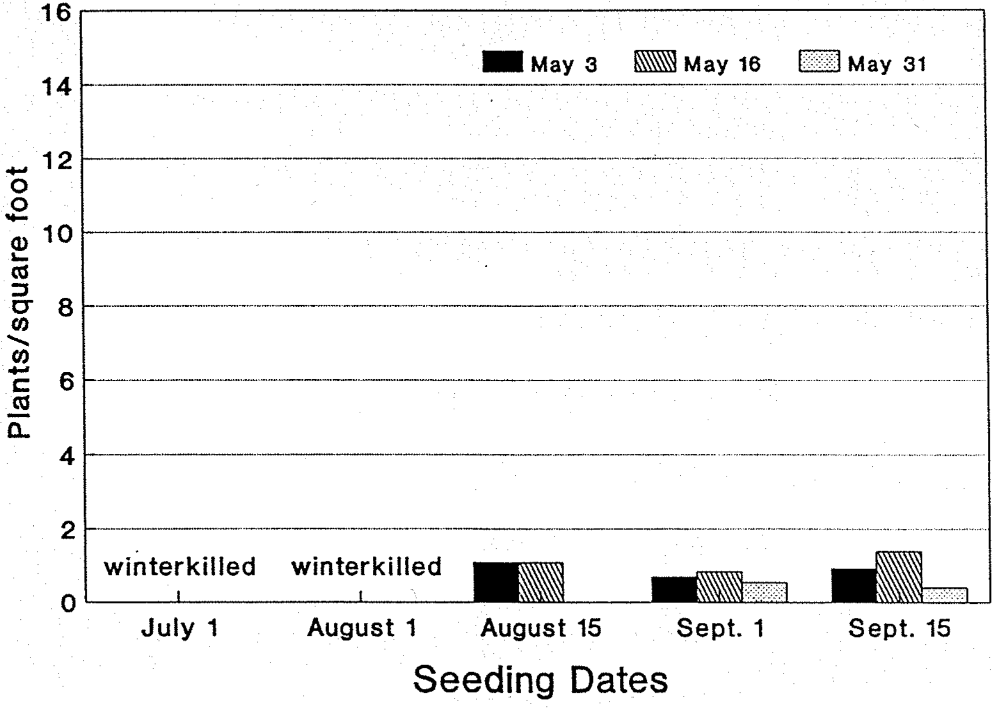

Figure 4. Number of live plants per square foot of hairy vetch for winter rye and vetch planted at five different dates in 1989 and mowed at three different dates in the spring of 1990.

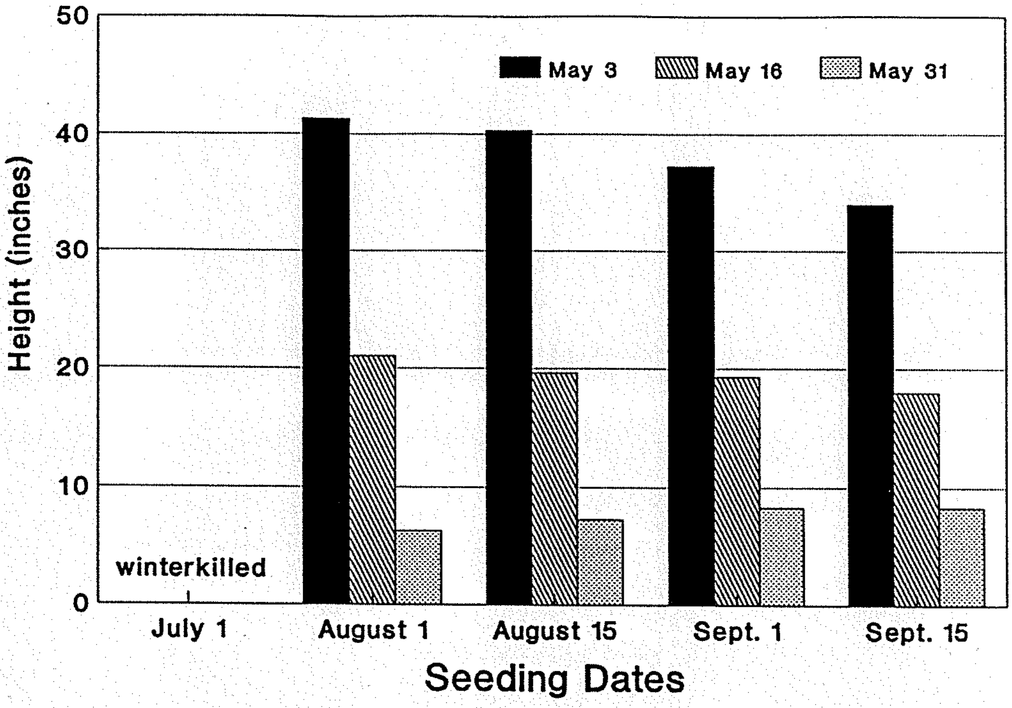

Figure 5. Height of live tillers per square foot of winter rye for winter rye and vetch planted at five different dates in 1989 and mowed at three different dates in the spring of 1990.

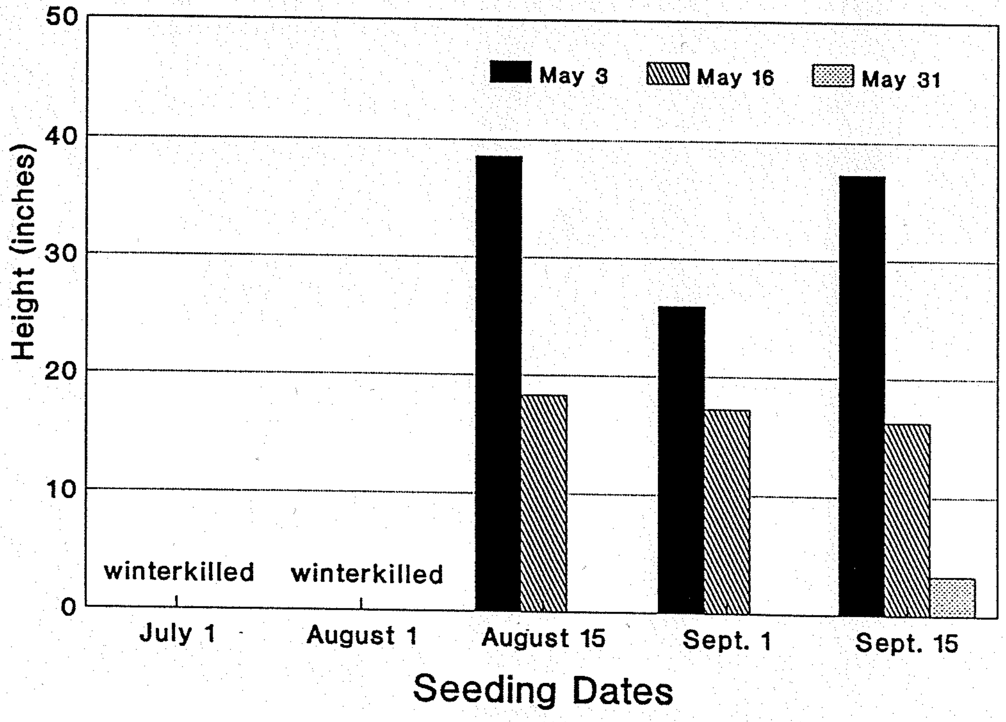

Figure 6. Height of live plants per square foot of hairy vetch for winter rye and vetch planted at five different dates in 1989 and mowed at three different dates in the spring of 1990.

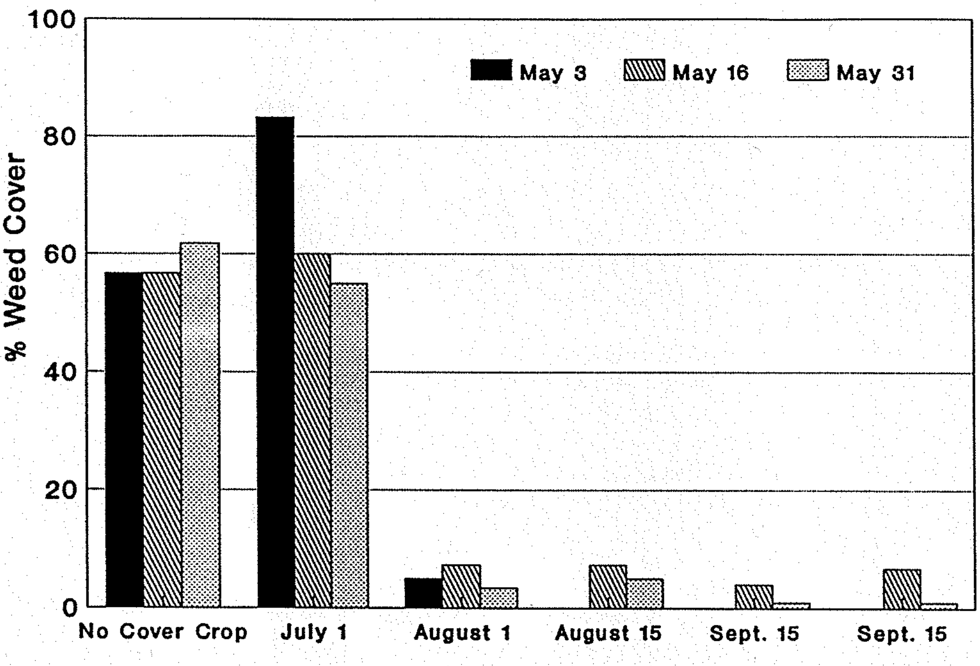

Figure 7. Percent weed cover for winter rye and hairy vetch plus a control planted at five different dates in 1989 and mowed at three different dates in the spring of 1990.

Conclusions

The best time of planting for vetch and rye in Western Massachusetts, based on this data, in this year, was between August 15 and September 1. Neither the rye or vetch survived the winter when they were planted July 1 and the vetch did not survive when planted August 1. Although the biomass accumulation was adequate in the spring, the fall establishment was sparse for the September 15 planting. This was too late in the year to provide good erosion control.

The mowing dates of May 3 and may 16 were not successful in controlling rye and , to a lesser extent, vetch regrowth. Both cover crop species would have to be tilled or chemically managed in order to be followed by cultivated crops. The mow date of May 31 was very successful in killing these cover crops. The regrowth that did occur was minimal.

A PTO-driven flail mower was used to mow this experiment. It did a thorough job of mulching the cover crops. However, the mulch that was left on top of the soil was much thinner than when a cycle-bar mower was used in other experiments. The thicker mulch appeared to aid in inhibiting the rye regrowth.

ii. Tillage and Nitrogen Effects for Rye and Vetch in Broccoli

This experiment was initiated to quantify the nitrogen response from the rye alone and in combination with hairy vetch compared to no cover crop seeded. The replicated main plots were three cover crop combinations: hairy vetch in combination with rye (*Secale cereale*) at the seeding rate of 40 lbs/acre and 56 lbs/acre, respectively; rye alone at 90 lbs/acre; and no cover crop. Each cover crop was combined with two tillage treatments: conventional tillage and no-till, and two rates of nitrogen: 0 and 100 lbs/acre of N.

Cover crops were sown 25 August, 1989 and were allowed to regrow in the spring. On 22 May, 1990 when rye seed heads had emerged, all cover crop treatments were mowed with a PTO-driven sickle-bar mower, and left on top of the soil. A PTO-driven rotovator was then used to incorporate the conventional-till cover crop treatments into the soil. Broccoli plants were transplanted into the field on 23 May, 1990. Nitrogen, as ammonium nitrate, was applied to appropriate treatments on 20 June, 1990. Broccoli heads were harvested, and the field weights recorded, when the heads reached a minimum width of four inches or if they began to flower.

Addition of inorganic nitrogen resulted in a significant increase in yield of broccoli heads (Figure 8). Average yield for the 4 treatments in the rye/vetch cover crop combination was higher than the averages for the other 2 cover crop combinations. The vetch/rye, tilled with no nitrogen, had similar yield to tilled rye with 100 lbs/acre of added nitrogen. Yield was greater with no cover crop than with rye alone. Results were probably due to the higher C:N ratio of rye immobilizing N, whereas vetch/rye added N as the legume decomposed.

Harvest date of no-till treatments for each cover crop combination was significantly delayed compared to tilled treatments (Figure 9). Differences in soil temperature and nitrogen availability among the treatments are thought to be responsible for this response. Soil temperature readings taken for the duration of the experiment showed tilled treatments had significantly higher temperatures, especially after a period of sun, than the no-till

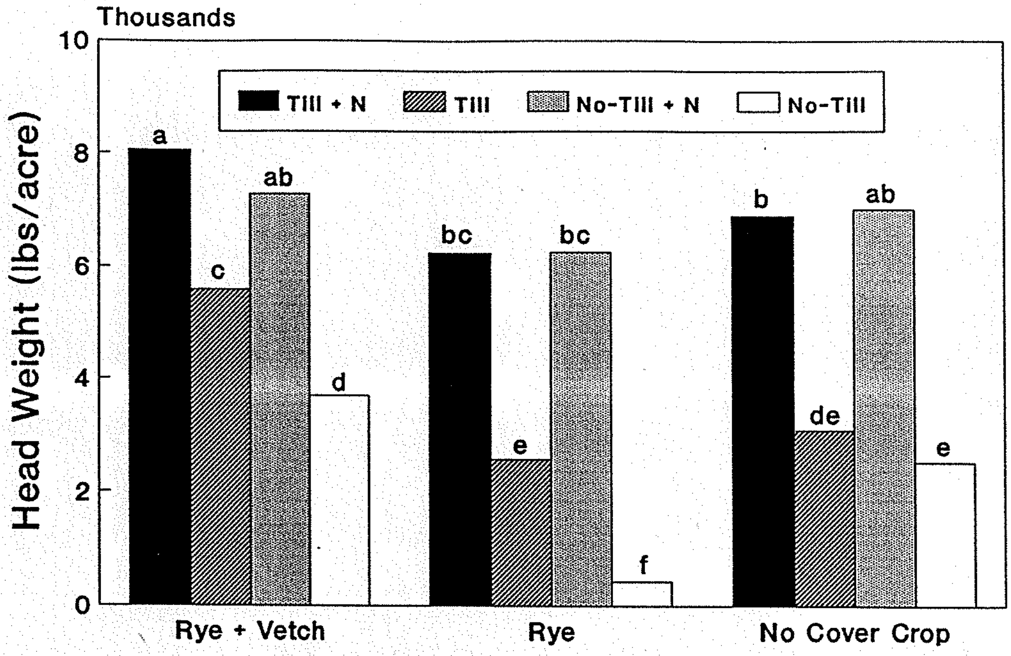

Figure 8. Head weight of broccoli for three cover crop combinations, two tillage regimes and two nitrogen rates.

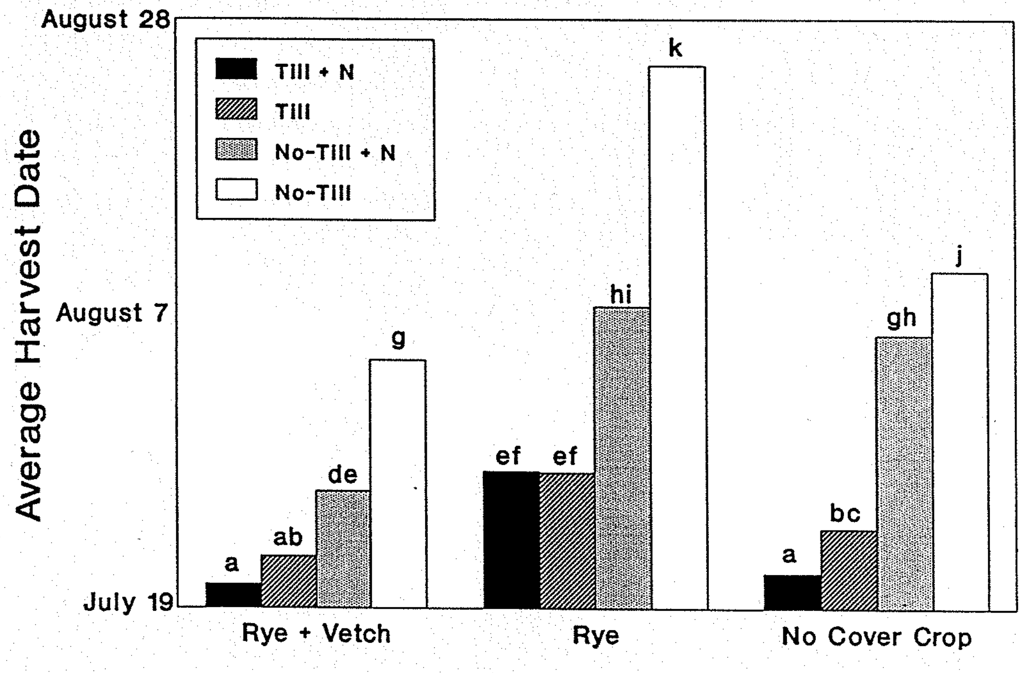

Figure 9. Average harvest date of broccoli heads for three different cover crop combinations, two tillage regimes and two nitrogen rates.

treatments. Figure 10 reports the soil temperatures for four treatments taken May 30. The conventional tillage treatment had much higher temperatures than the no-till treatment without cover crops. Rye left on the soil surface had a lower soil temperature while rye in combination with hairy vetch had the lowest soil temperatures due to the thicker mulch.

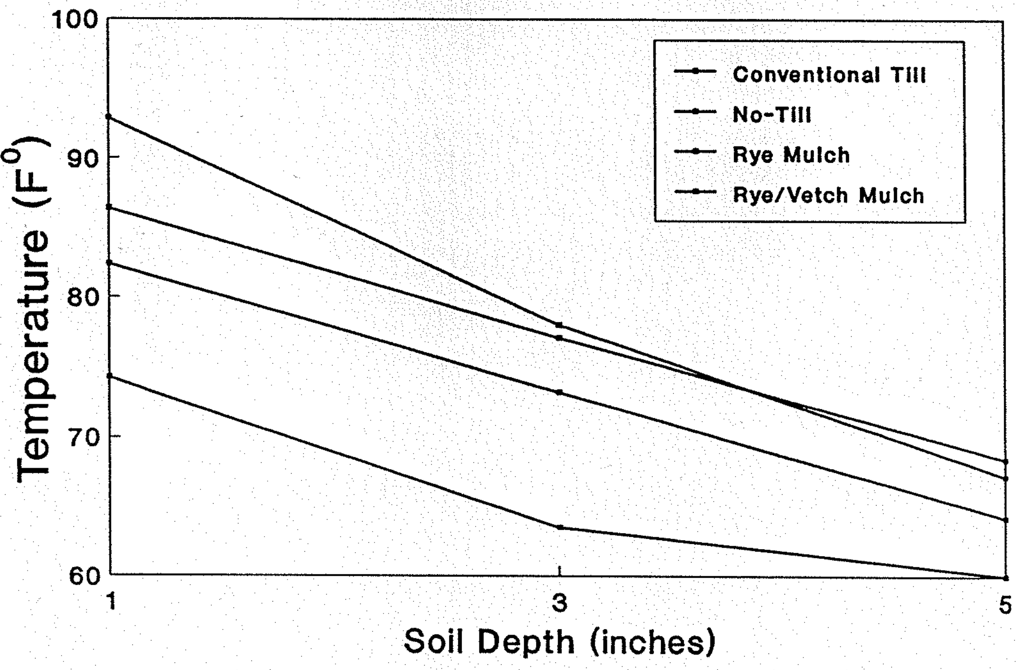

Figure 10. Soil temperature at three depths for different tillage and cover crop treatments in broccoli.

Another reason for the difference in harvest maturity could be the difference in fertility between the two tillage systems. Previous research has shown that nitrogen will be made more readily available with the use of cover crops when they are incorporated into the soil compared to leaving the above-ground biomass on top of the soil.

Conclusions

The legume hairy vetch added significant amounts of nitrogen to the soil which contributed to the growth of broccoli. The rye appeared to immobilize nitrogen due to the higher C:N ratio. The no-till treatments delayed the harvest of the broccoli due to the cooler soil temperatures and possibly slower degradation of the plant material which could cause a slower release of nitrogen.

The delay in harvest could be a disadvantage to the no-till production of vegetables. However, this delay would have to be evaluated against the cost of plowing and disking the fields in conventional systems. In addition, the no-till rye/vetch system provided excellent weed control without the use of synthetic herbicides.

iii Tillage, Weed Control and Insect Effects for Rye and Vetch in Broccoli and Cabbage

In two experiments similar to the one described above were initiated to quantify the weed control achieved by these systems with broccoli and cabbage. For each cover crop and tillage treatment there were two weed control treatments: presence or absence of herbicide. The herbicide Dacthal was used for the tilled treatments and the herbicide Poast was used postemergence for the cover crop treatments.

At the first site with broccoli, Figure 11 reports weed dry weights taken July 26. The highest weed pressure was observed without the use of cover crops, no-till and no herbicide. The dominant weed species in this treatment was horse weed (*Erigeron canadensis*). This weed species was not a significant problem in any of the other treatments demonstrating the effectiveness of these cover crops and Dacthal in controlling this species (Table 2). This winter annual will often germinate in the fall and continue to grow in the spring. Both the rye/vetch and rye alone cover crops, without herbicide, were able to out-compete this weed species.

Among the treatments that did not have a cover crop seeded, the tilled treatments with the use of Dacthal had significantly better weed control than the other three. In the rye/vetch and rye alone tilled cover crop treatments, the herbicide Dacthal gave statistically significant control of weed species compared to the control.

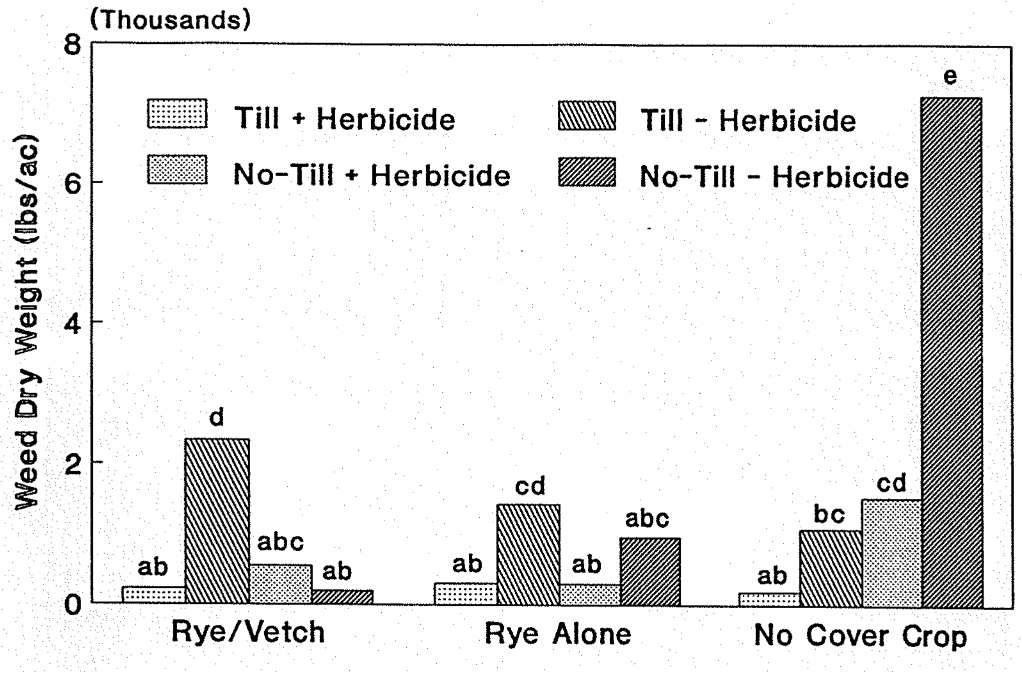

Figure 11. Weed dry weight for three cover crop combinations, two tillage regimes ans two herbicide effects.

The tilled treatment in the rye/vetch without the use of the herbicide Dacthal had more weed biomass than the same treatment without the use of cover crops. This is probably due to the nitrogen that is made available from the legume hairy vetch.

The use of sethoxydm (Poast) was very effective in controlling rye regrowth (Table 2). This is important to be able to show growers that this herbicide was effective. Growers who may be interested in adopting this system will now feel more confident knowing that they have a control measure against possible rye regrowth. There was twice the rye regrowth (both in numbers of plants and weight) in the rye alone than in the rye/vetch. The thicker mulch in the rye/vetch is thought to be the factor responsible. However, the rye regrowth did not effect yield (Figure 12).

The cabbage maggot egg incidence per plant was higher in the tilled plots for each of the three cover crop treatments for the June 6 sampling date (Table 3). Previous research has shown that there is

a linear response to maggot landings and leaf size. The tilled plots yielded plots with larger

Table 2. Weed species dry weights (grams/m^2 and plant numbers/m^2 for cover crop, tillage and herbicide effects.

COVER CROPS	TREATMENTS	crabgrass		fall panicum		winter rye		lambsquarters		pig weed		horse weed	
		#*	weight*	#ns	weightns	#*	weight*	#*	weight*	#*	weight*	#*	weight*
RYE/VETCH	till - herb.	54.8ab	26.0ab	0.0	0.0	0.0c	0.0c	13.2ab	84.8ab	13.2ab	356.8a	0.0b	0.0b
	till + herb.	0.0b	0.0b	0.0	0.0	0.0c	0.0c	0.0b	0.0b	2.8b	45.2bc	0.0b	0.0b
	mow - herb.	0.0b	0.0b	0.0	0.0	32.0b	29.2b	2.0b	10.0b	0.0b	0.0c	0.0b	0.0b
	mow + herb.	0.0b	0.0b	0.0	0.0	0.0c	0.0c	6.0b	110.0a	0.0b	0.0c	0.0b	0.0b
RYE ALONE	till - herb.	220.0ab	88.8ab	1.2	2.0	0.0c	0.0c	6.8b	48.4ab	22.8a	147.2b	0.0b	0.0b
	till + herb.	9.2b	2.8b	0.0	0.0	0.0c	0.0c	0.0b	0.0b	8.0b	57.6bc	0.0b	0.0b
	mow - herb.	94.8ab	27.6ab	0.0	0.0	66.8a	52.8a	24.0a	83.2ab	0.0b	0.0c	6.7b	29.6b
	mow + herb.	1.2b	0.8b	0.0	0.0	1.2b	0.8b	2.8b	13.2b	4.0b	8.0b	8.0b	37.2b
NONE	till - herb.	170.8ab	59.6ab	0.0	0.0	0.0c	0.0c	2.8b	7.2b	21.2a	149.2b	0.0b	0.0b
	till + herb.	8.0b	5.6b	1.2	2.8	0.0c	0.0c	0.0b	0.0b	4.0b	29.6bc	0.0b	0.0b
	mow - herb.	10.8b	2.4b	0.0	0.0	0.0c	0.0c	0.0b	0.0b	0.0b	0.0c	48.0a	1450.4a
	mow + herb.	280.0a	132.4a	5.2	4.8	0.0c	0.0c	8.0b	66.4ab	2.8b	47.2bc	10.8b	54.8b

*significant at the 0.05 level

**letters indicate significance at the 0.05 level for Duncan's multiple range test treatments, the incidence was least for the rye plus vetch and highest for the no cover crop treatment. This trend was also observed among the no-till treatments. This correlates with the temperature gradients that were observed for these treatments, especially early in the season.

There was a tillage effect for the diamond back larvae for the 21 June date (Table 3). There was no incidence of this pest for both the hairy vetch + rye and rye alone treatments when they were mowed. When these cover crop treatments were tilled in there was a significant increase in the pest incidence. The only pest incidence for the no-till treatments was found with no cover crop.

Table 3. Insect incidence for cover crop and tillage efects. Cabbage Maggot data taken June 6, 1991 and Diamondback Moth data taken June 21, 1991.

Cover Crops	Treatment	Cabbage Maggot Egg	Diamond Moth Larv.
Rye + Vetch	till	0.333	0.82a
	no-till	0.033	0.00
Rye alone	till	0.133	0.57
	no-till	0.067	0.00
No Cover	till	0.400	0.32
	no till	0.167	0.12
		C^{ns}	C^{ns}
		T^{*}	T^{***}
		CT^{ns}	CT^{ns}

The overall broccoli yields among the four rye/vetch cover crop treatments yielded better than the rye alone and the no cover crop treatments (Figure 12). The nitrogen that is available with the legume is suspected to be responsible for this response. There was no statistical difference among the four treatments in the rye treatment. The same was observed for the no cover crop effect except for the no tillage without herbicide. There was no appreciable yield in this treatment. The tenacity of the horse weed is responsible for this lack of yield. The weed pressure did not effect the yield in the other treatments.

In the cabbage experiment, the no-till treatments were not as effective (data not shown). In the tilled treatments, the hairy vetch plus rye provided much higher yields to the no cover crop treatment. The delayed mineralization of nitrogen and reduced weed control in the no-till plots are suspected to be responsible for the yield reductions.

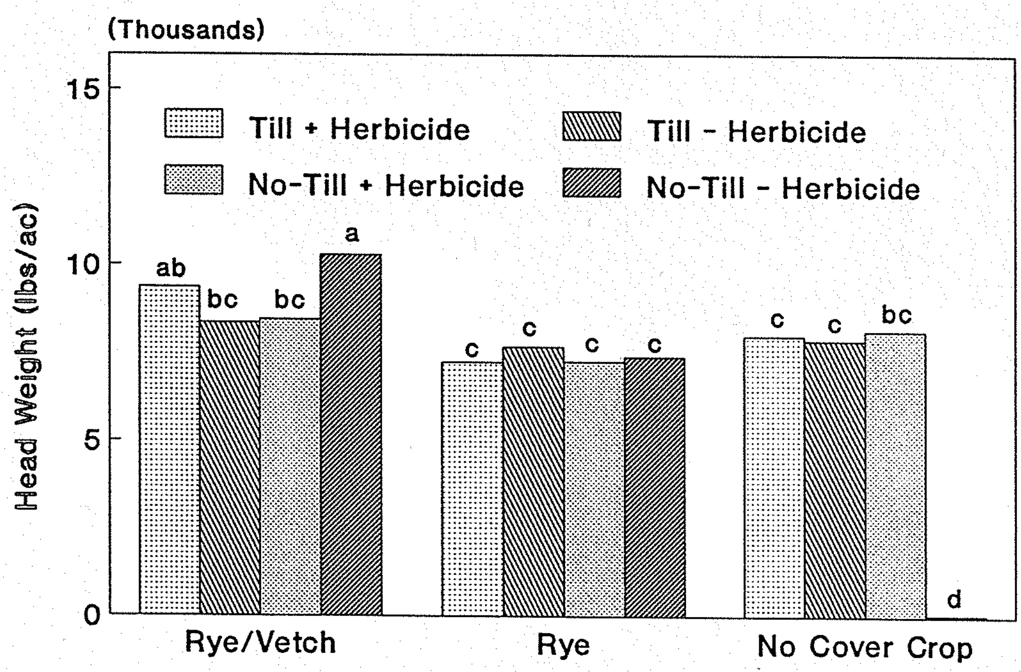

Figure 12. Broccoli yield data for three cover crop combinations, two tillage regimes and the presence or absence of herbicide.

iv. Winter-Kill Cover Crops for Corn.

Leguminous cover crop species planted late in the fall will make little growth prior to freezing conditions as was indicated by the seeding date study. Late planted leguminous cover crops need to regrow in the spring and early summer the following season to achieve a significant nitrogen contribution. Such systems would not be suited to early spring planting. In addition, some growers may find a large accumulation of biomass from spring/summer growth difficult to manage.

A potential solution to these difficulties is early planting of cover crop species that will not overwinter. An early seeding date will allow these species to grow sufficiently in the fall enabling them to contribute nitrogen to the soil in the spring as they decompose. Since they will not overwinter, the above-ground trash would be easier to manage in the spring.

Oat (*Avena sativa*) was planted alone and in combination with purple vetch (*Vicia benghalenis*), lana (*Vicia villosa*) and hairy vetch, white lupin (*Lupinus albus*), and Austrian winter field pea (*Pisum sativum* spp. arvense) as main plots in early August of 1989 in South Deerfield. Previous research has indicated that most of these species will not overwinter in this region when planted this early. In addition, the winter killed cover crops have been less complicated to no-till plant/transplant cultivated crops into in the spring than conventional rye which is either mow killed or desiccated with a contact herbicide.

Above-ground biomass was sampled in the fall of 1989 from each plot and separated into oat and legume (Figure 13). Sweet corn (*Zea mays* cultivar 'Harmony', Harris Moran) was planted no-till into this experiment April 24, 1990 as a bioassay. The above-ground, dead oat and legume stalks were mowed two days later with a PTO driven flail mower and the mulch was left on the surface to help augment weed control and conserve soil moisture.

Soil samples were taken May 9 to compare the soil moisture content among the seven treatments (Table 4). There was no statistical difference in the percent soil moisture among treatments.

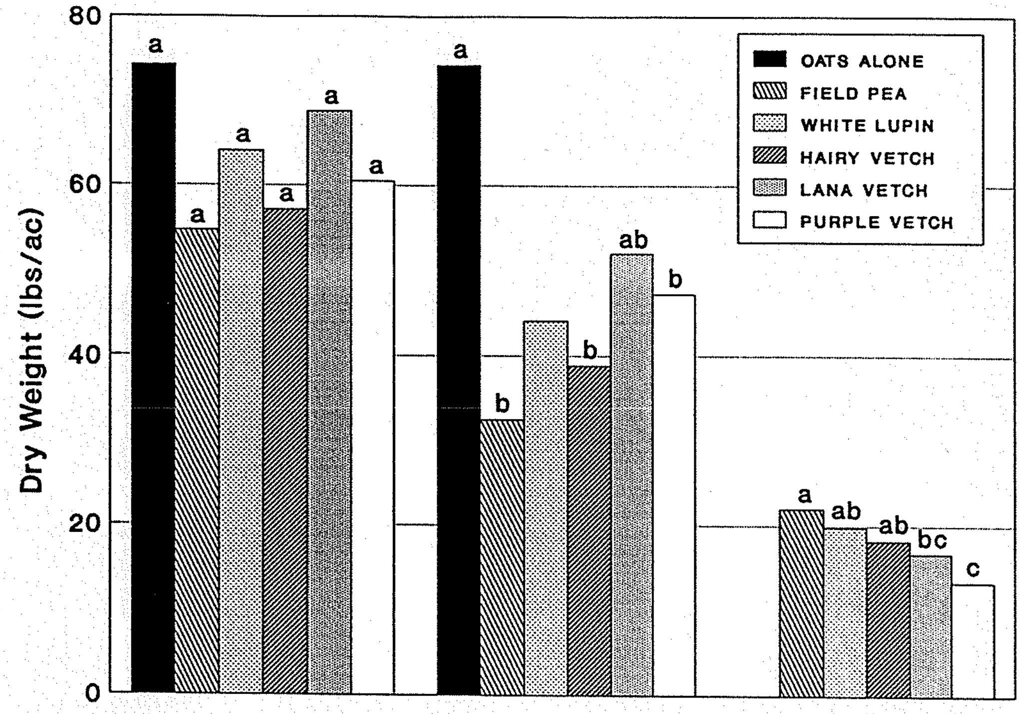

Figure 13. Fall biomass data for six cover crop combinations.

Table 4. Soil moisture samples taken May 9, 1990.

Treatment	% Soil Moisture*
Control	15.8
Oat alone	15.8
Hairy Vetch + Oat	15.5
Lana Vetch + Oat	16.4
Purple Vetch + Oat	16.3
White Lupin + Oat	15.8
Field Pea + Oat	15.6

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*= not significant at the 0.05 level

A concern with the use of mulch crops is that they can retard the growth of cultivated crops due to the cooling effect of the dead mulch on of the soil surface. To quantify the temperature difference between the respective treatments, soil temperature probes were placed at three different depths (1, 3 and 5 inches) in ten plots on April 9, 1990. Soil temperatures at three depths for selected dates and treatments are reported in Figure 14.

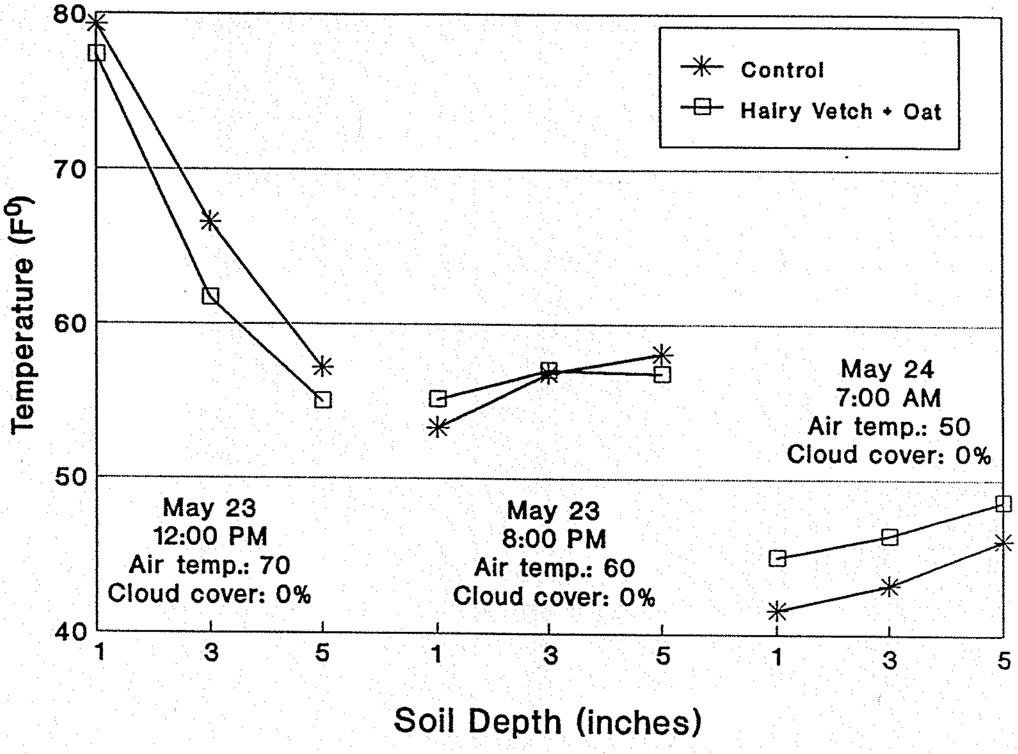

Figure 14. Soil temperature at three depths for hairy vetch in combination with oat and no cover crop seeded at three different depths.

Herbicide and nitrogen rates were applied as sub-plot treatments. The herbicide treatment was applied to the appropriate plots on April 24 in order to quantify the weed suppression that is contributed by the different cover crop combinations. The two rates used were 1 pound ai/acre Atrazine, 1.75 pounds ai/acre Metolachlor, 1 quart/acre crop oil (Booster+E, Agway) and no herbicide applied as a control. Two rates of nitrogen fertilizer (30 and 120 lbs/acre actual N) were applied as a side dress application May 5, 1990 to evaluate nitrogen combination from cover crop species.

The corn was harvested July 25. Ears were separated into marketable and non-marketable ears, counted and weighed. Figure 15 reports the marketable ear weight for the cover crop treatments with the two nitrogen rates.

The only treatment that had a significant yield increase from 30 to 120 lbs N/acre was the no cover crop effect. All cover crop combinations with legumes yielded as high with 30 lbs N/acre as the control with 120 lbs N/acre. Hairy vetch and field pea yielded higher with 30 lbs N/acre than the oat alone with 120 lbs N/acre. This response is probably a combination of the ability of the legumes to fix nitrogen and oat alone to sequester it.

Percent weed cover observations were taken at six different times during the season (Table 5). The herbicide treatment gave excellent season-long weed control for all cover crop combinations. The mulch did not interfere with the activity of the herbicides.

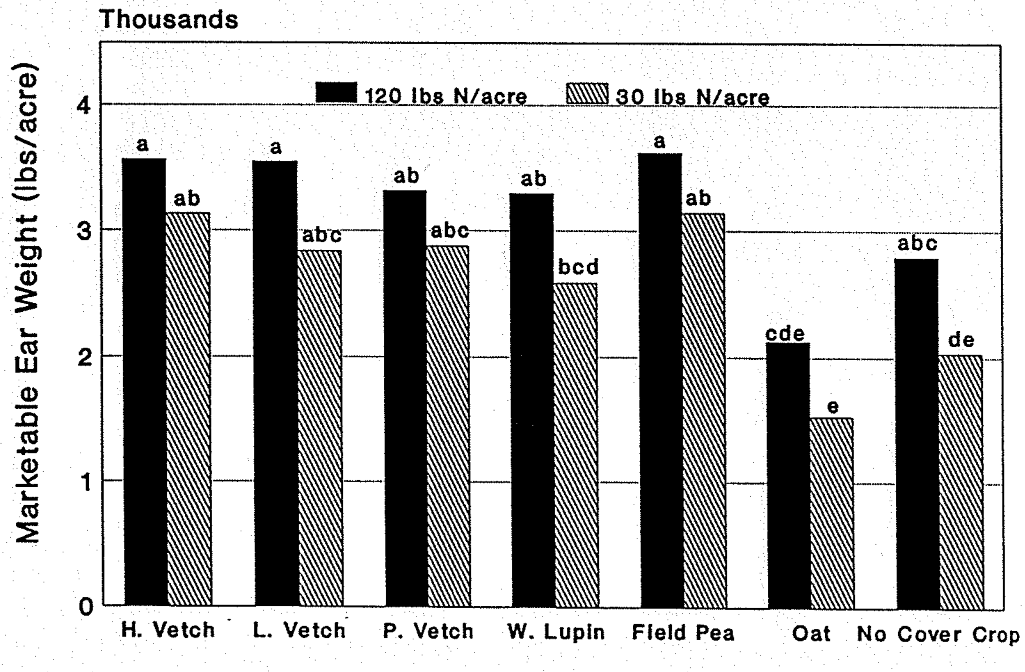

Figure 15. Yield data for six cover crop combinations and a control with two nitrogen rates.

Table 5. Percent weed cover of six cover crop combinations plus a control with and without herbicide.

Main Plot		% Weed Cover					
Treatment	Weed Control	May 9	May 20	June 5	June 15	June 25	July 10
Control	+ Herbicide	0d	0c	0e	2d	5c	27c
	- Herbicide	10a	23a	78a	93a	100a	100a
Oat alone	+ Herbicide	0d	0C	0e	0d	3c	28c
	- Herbicide	0d	3C	27cd	45bc	78ab	93a
H. Vetch/Oat	+ Herbicide	0d	0C	0e	0d	1c	3c
	- Herbicide	4b	10B	52b	70ab	100a	100a
L. Vetch/Oat	+ Herbicide	0d	0C	0e	0d	0c	2c
	- Herbicide	0d	3C	13de	25cd	73ab	97a
P. Vetch/Oat	+ Herbicide	0d	0C	0e	0d	2c	6c
	- Herbicide	1c	4C	32cd	58b	82ab	97a
W. Lupin/Oat	+ Herbicide	0d	0C	0e	1d	2c	4c
	- Herbicide	0d	3C	32cd	47bc	65b	68ab
Field Pea/Oat	+ Herbicide	0d	0C	0e	0d	3c	8c
	- Herbicide	1c	3C	42cb	72ab	95a	100a

Most of the cover crop combinations without herbicide gave good weed control early in the season. Six weeks after the corn was planted (June 5), lana vetch + oat had 13% weed cover compared to 78% weed cover for the no cover crop control. Hairy vetch and Austrian winter field pea did the poorest of the cover crops with 52 and 42% weed cover, respectively. In the case of hairy vetch, this was due mostly to vetch plants that did not winterkill.

The weed control that was observed early in the season broke down as the season progressed. There was no statistical difference among the no cover crop control and all other cover crop combinations, except white lupin which had 65% weed cover. This led to severe yield reductions. Figure 16 reports the weight of marketable ears for the seven cover crop combinations with and without herbicide.

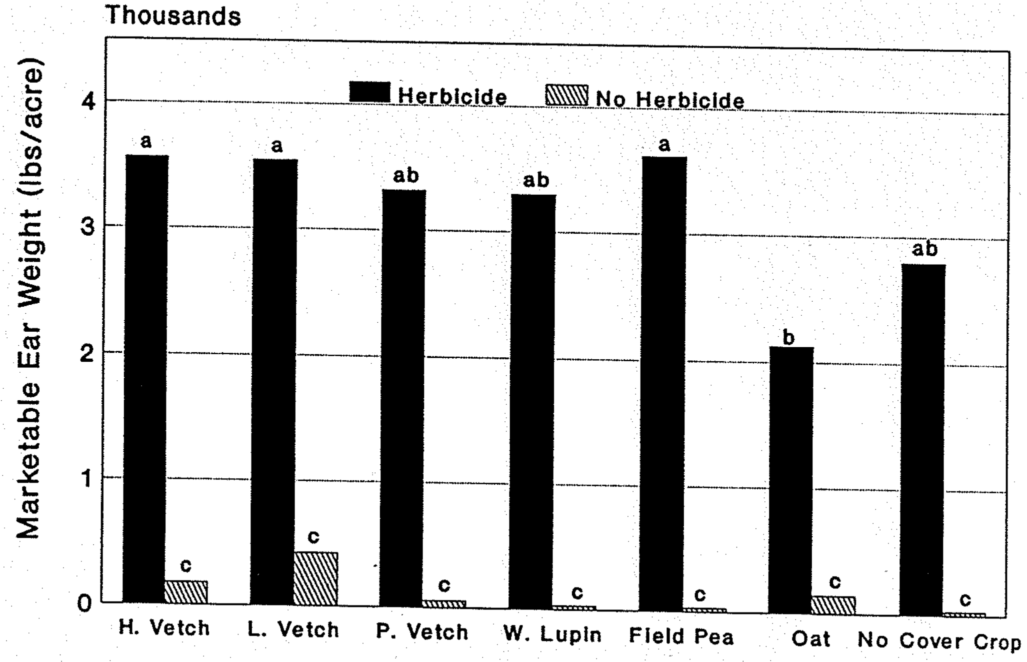

Figure 16. Yield data for six cover crop combinations plus a control with and without herbicide applied.

v. Rye and Hairy Vetch for Peppers

Rye and hairy vetch were planted in the fall of 1990 at the rate of 56 lbs/acre of rye and 40 lbs/acre of vetch to study the effects of tillage and plastic on peppers. The cover crops were managed June 7, 1991 and plastic was layed. All treatments were hand-weeded throughout the season. Peppers were harvested on a weekly basis starting August 10 and ending October 19. Peppers were sorted into marketable and non-marketable fruit according to blemishes and size, counted and weighed in the field.

Figure 18 reports the marketable number of peppers harvested over the course of the season and Figure 19 reports the marketable weight for the two tillage treatments. The incorporation of the rye/vetch cover crops enhanced the yield early in the season. However, the no-till yield caught up and surpassed the tilled plots at the end of the season. Figure 19 reports a similar trend although the no-till peppers were smaller than the peppers in the tilled plots.

Figures 20 and 21 report the same information for the use of plastic for both tillage regimes. The use of plastic greatly enhanced yield.

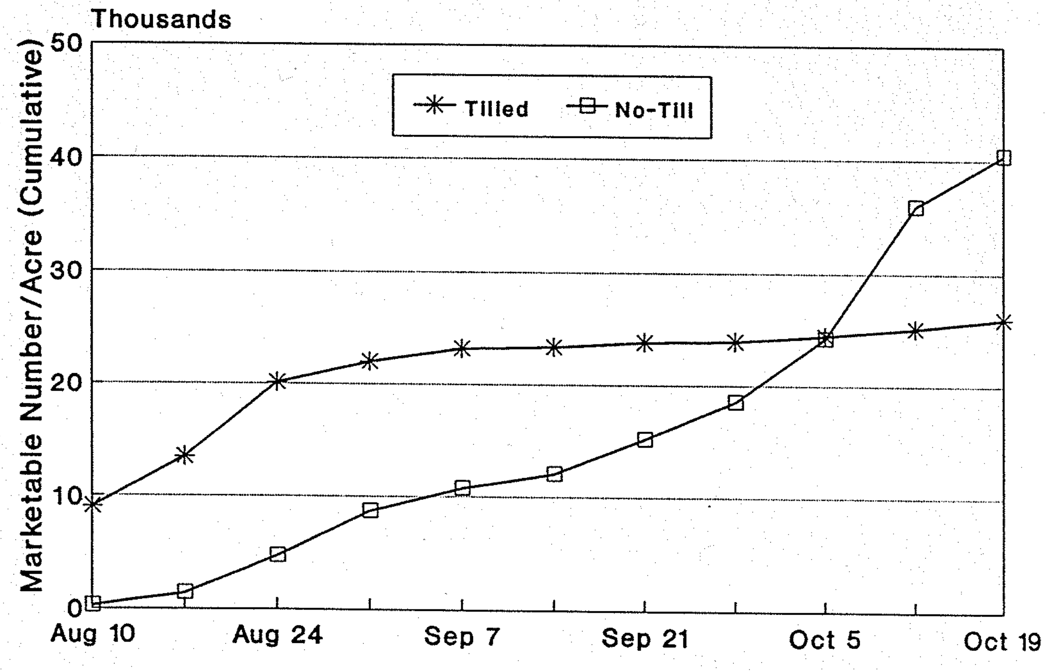

Figure 17. Cumulative fruit number for till and no-till peppers.

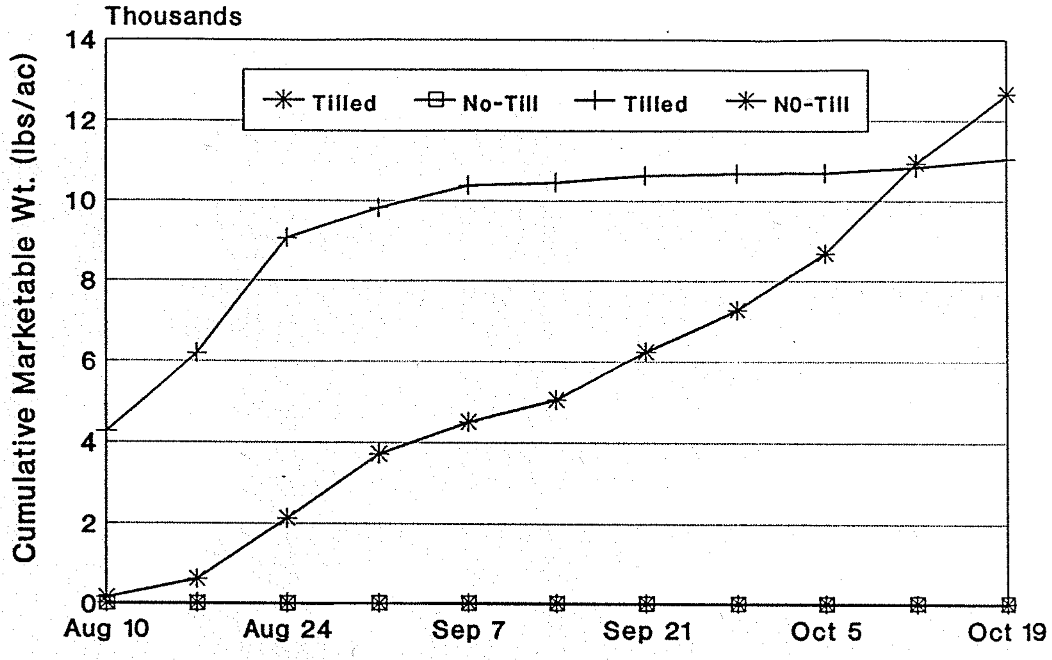

Figure 18. Cumulative fruit weight for till and no-till peppers.

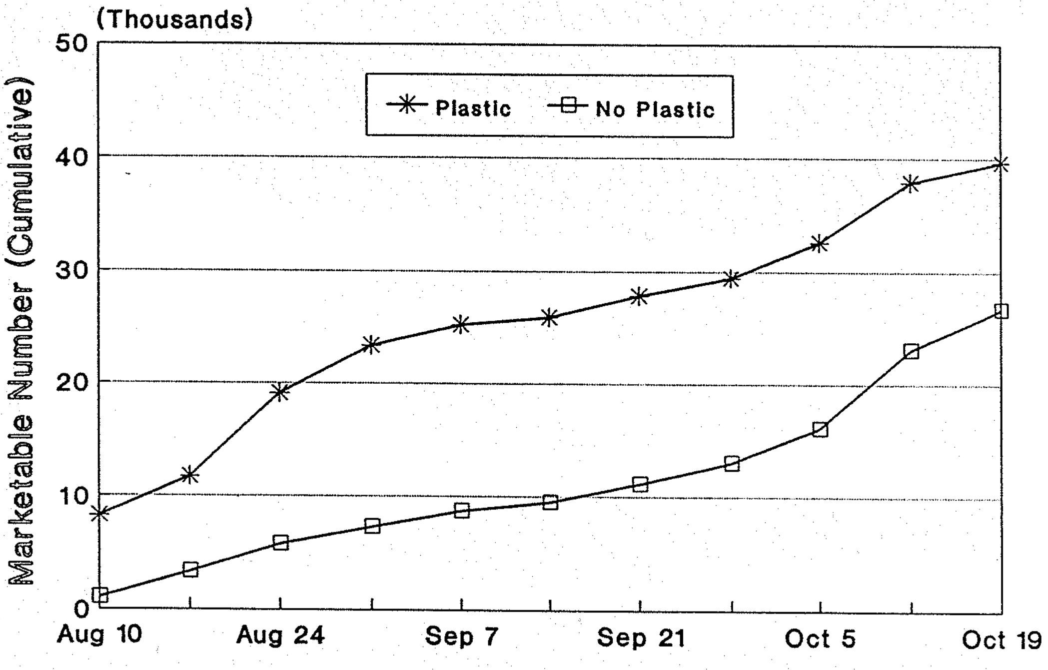

Figure 19. Cumulative fruit number for peppers grown with and withou plastic.

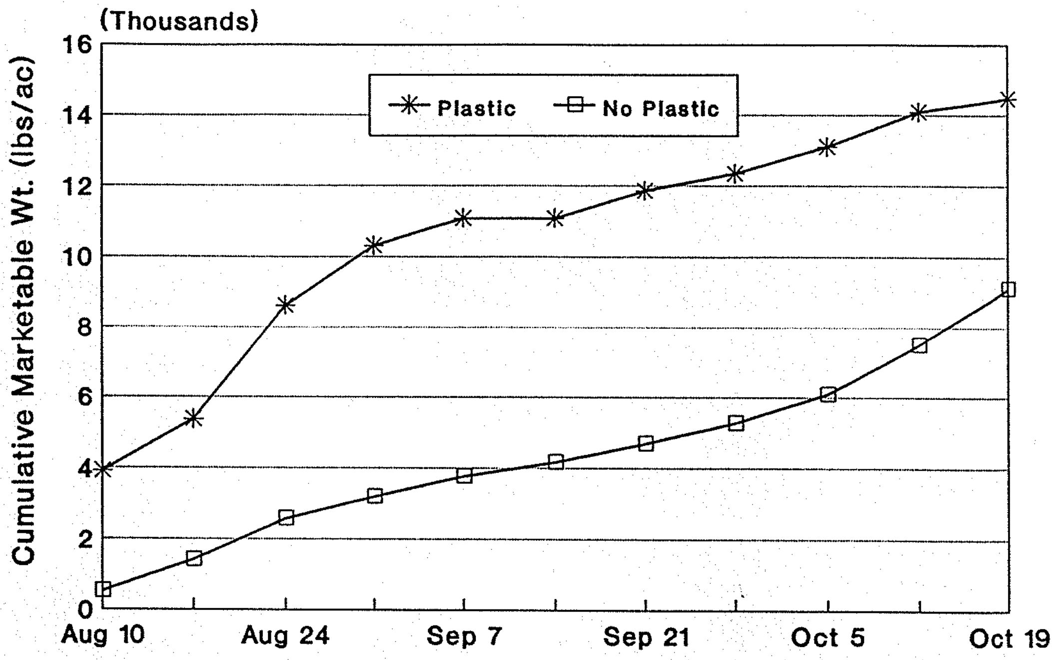

Figure 20. Cumulative fruit weight for peppers grown with and withou plastic.

vi. <u>Hairy Vetch/Rye Density and Nitrogen Rate Experiment</u>

Hairy vetch seed is relatively expensive. To reduce grower seed costs, it is necessary to quantify the density response of the hairy vetch and winter rye mixture. To determine the contribution of nitrogen and weed control for various density combinations of rye and hairy vetch, an experiment employing a central composite design was initiated in the summer of 1989. This experiment was set up to examine the interaction of 5 densities of rye, 5 densities of hairy vetch, and 5 rates of nitrogen. The vetch and rye were planted in August of 1989 while the nitrogen was applied as a side dress application in the early summer of 1990.

Biomass samples were taken from all plots in the fall of 1989, separated into hairy vetch and rye, dried, and weighed. There was a linear increase in biomass for both hairy vetch and rye with an increase in their respective seeding rates (Figures 21 and 22). Increasing seeding rate of rye resulted in a linear decrease in biomass of the hairy vetch component (Figures 21). Similarly, increasing hairy vetch seeding rate decreased biomass of the rye component (Figure 22). However, increasing seeding rate of either cover crop species resulted in a linear increase in total biomass (hairy vetch and rye) (Figure 23).

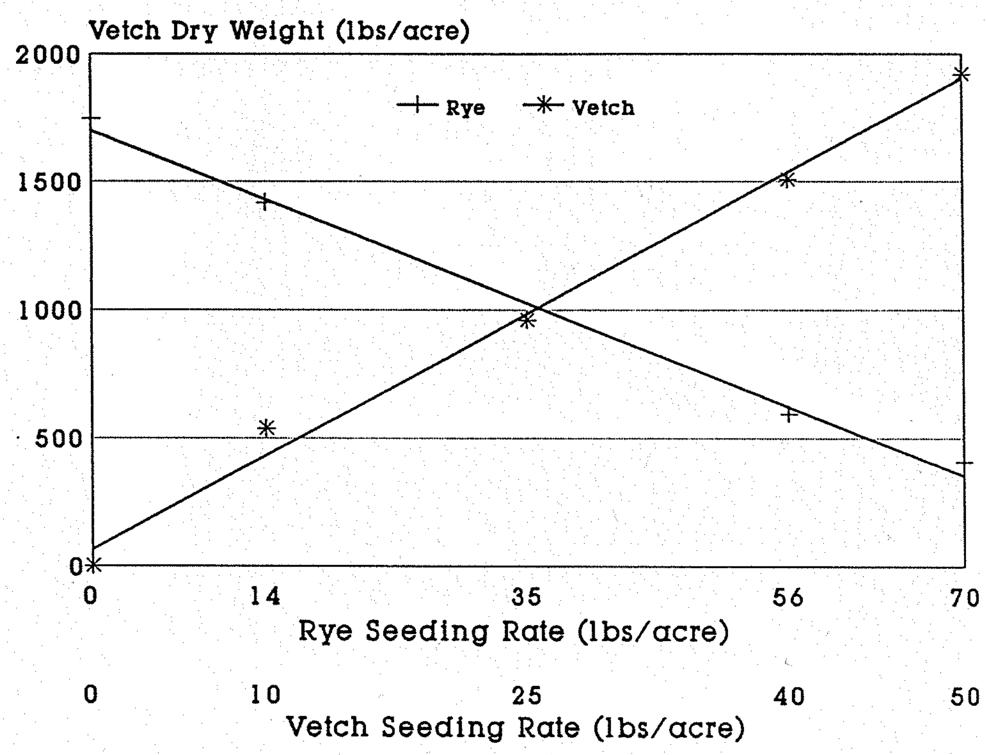

Figure 21. Hairy vetch above-ground biomass as it varies according to rye and vetch seeding rates.

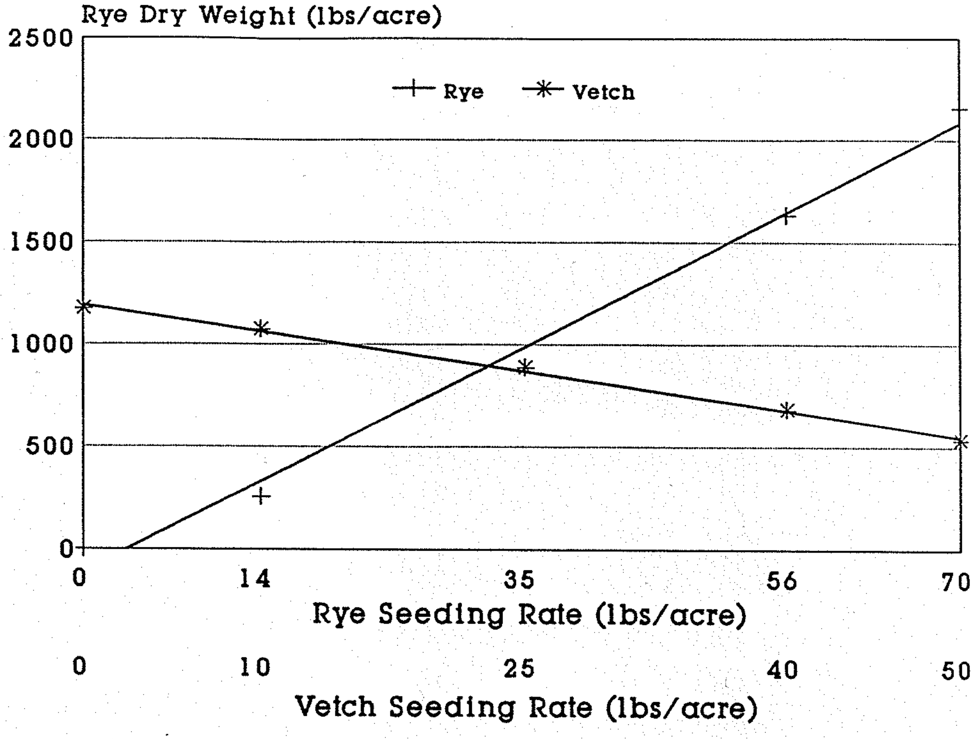

Figure 22. Winter rye above-ground fall biomass according to winter rye and hairy vetch seeding rates.

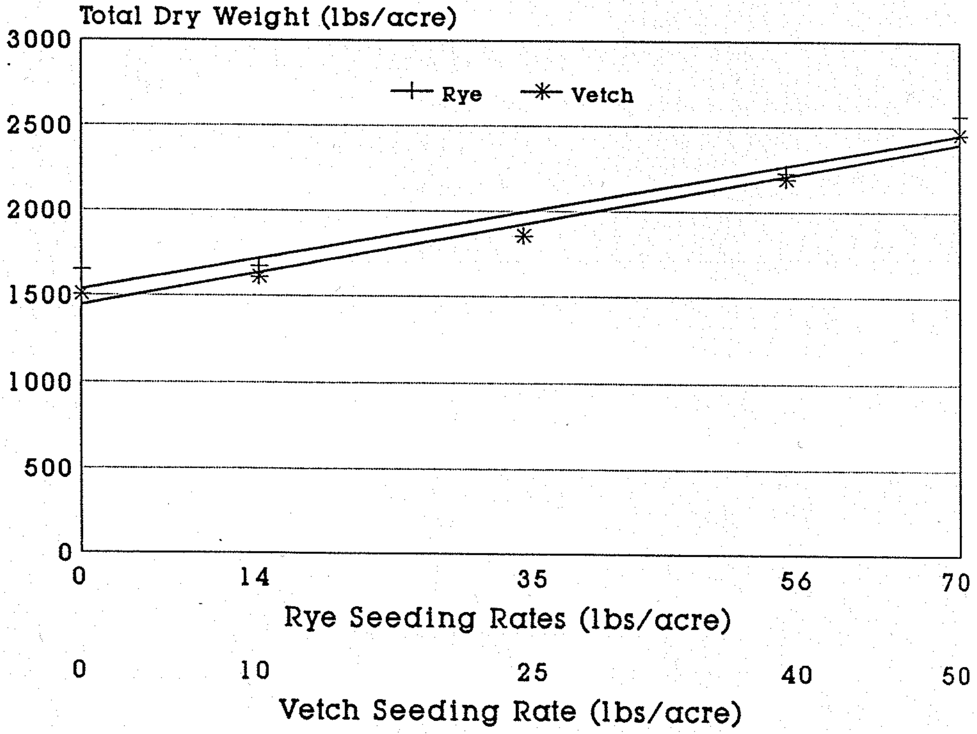

Figure 23. Total above-ground fall biomass according to the rye and vetch seeding rates.

Table 6. Sensitivity analysis comparing hairy vetch seeding rate, nitrogen contriution and nitrogen fertilizer price.

The economic benefit of the hairy vetch/rye cover crop over the conventional rye cover crop, is in part a function of the price of nitrogen fertilizer (N), the residual N, and the hairy vetch seeding rate. Given the assumptions from the previous work-sheet, this table calculates the benefit at three different seeding rates for a specified range of N prices and a specified residual N.

ASSUMPTIONS (from the worksheets as in tables 7 to 10):

Cover Crop		
Rye:	Rye seed ($/lb)	$0.11
	Rye rate (Lbs/ac)	112
Hairy Vetch/Rye:	Vetch seed	$0.55
	Rye rate	56

NITROGEN ASSUMPTIONS:

	Price of N fertilizer = $0.30	Residual N Lbs./acre @	Vetch seed rate:
		40	20
Price range (%+/-)	30%	55	30
		60	40

BENEFIT/(COST) OF HAIRY VETCH/RYE MIXTURE OVER RYE ALONE
at different prices of N and different seeding rates of vetch.

VETCH SEED RATE (Lbs/acre)		20	30	40
	$0.21	$3.39	$0.77	($3.96)
Price of N ($/lb)	$0.30	$6.99	$5.72	$1.44
	$0.39	$10.59	$10.67	$6.84

Table 7. Economics of hairy vetch/rye vs. Rye cover crops

				Cover Crop	
Cover Crop Inputs:	Unit:	Amount:	Price: ($/unit)	Rye	Hairy Vetch/Rye
Rye seed (straight rye)	Lbs.	112	$0.11	12.32	
Rye seed in mixture	Lbs.	56	$0.11		5.88
Hairy vetch seed	Lbs.	40	$0.55		22.00
Vetch innoculant	Bag	0.12	$1.75		0.21
Herbicide for rye	Gals.	0	$35.65		
Herbicide for rye/vetch	Gals.	0	$35.65		
Mowing straight rye	Acres	0	$7.00		
Plowing & disking rye	Acres	1	$25.00	25.00	
Mowing mixture	Acres	0	$7.00		
Plowing & disking mixture	Acres	1	$25.00		25.00
Interest (6 months)	%	10.0%		1.87	2.65
Total Cost (per acre)				$39.19	$55.74
Cover Crop Outputs:					
Nitrogen for next crop	Lbs.	50	$0.30	0.00	15.00
Net Cost of Cover Crop				$39.19	$40.74
Benefit / (Extra Cost) of Hairy Vetch/Rye Cover Crop:				**($1.56) per acre**	

Table 8. Economics of hairy vetch/rye vs. Rye cover crops

				Cover Crop	
Cover Crop Inputs:	Unit:	Amount:	Price: ($/unit)	Rye	Hairy Vetch/Rye
Rye seed (straight rye)	Lbs.	112	$0.11	12.32	
Rye seed in mixture	Lbs.	56	$0.11		5.88
Hairy vetch seed	Lbs.	25	$0.55		13.75
Vetch innoculant	Bag	0.12	$1.75		0.21
Herbicide for rye	Gals.	0	$35.65		
Herbicide for rye/vetch	Gals.	0	$35.65		
Mowing straight rye	Acres	0	$7.00		
Plowing & disking rye	Acres	1	$25.00	25.00	
Mowing mixture	Acres	0	$7.00		
Plowing & disking mixture	Acres	1	$25.00		25.00
Interest (6 months)	%	10.0%		1.87	2.24
Total Cost (per acre)				$39.19	$47.08
Cover Crop Outputs:					
Nitrogen for next crop	Lbs.	50	$0.30	0.00	15.00
Net Cost of Cover Crop				$39.19	$32.08
Benefit / (Extra Cost) of Hairy Vetch/Rye Cover Crop:				**$7.10 per acre**	

Table 9. Economics of hairy vetch/rye vs. Rye cover crops

				Cover Crop	
Cover Crop Inputs:	Unit:	Amount:	Price: ($/unit)	Rye	Hairy Vetch/Rye
Rye seed (straight rye)	Lbs.	112	$0.11	12.32	
Rye seed in mixture	Lbs.	56	$0.11		5.88
Hairy vetch seed	Lbs.	40	$0.55		22.00
Vetch innoculant	Bag	0.12	$1.75		0.21
Herbicide for rye	Gals.	0	$35.65		
Herbicide for rye/vetch	Gals.	0	$35.65		
Mowing straight rye	Acres	0	$7.00		
Plowing & disking rye	Acres	1	$25.00	25.00	
Mowing mixture	Acres	0	$7.00		
Plowing & disking mixture	Acres	1	$25.00		25.00
Interest (6 months)	%	10.0%		1.87	2.65
Total Cost (per acre)				$39.19	$55.74
Cover Crop Outputs:					
Nitrogen for next crop	Lbs.	40	$0.30	0.00	12.00
Net Cost of Cover Crop				$39.19	$43.74
Benefit / (Extra Cost) of Hairy Vetch/Rye Cover Crop:				**($4.56) per acre**	

Table 10. Economics of hairy vetch/rye vs. Rye cover crops

				Cover Crop	
Cover Crop Inputs:	Unit:	Amount:	Price: ($/unit)	Rye	Hairy Vetch/Rye
Rye seed (straight rye)	Lbs.	112	$0.11	12.32	
Rye seed in mixture	Lbs.	56	$0.11		5.88
Hairy vetch seed	Lbs.	40	$0.55		22.00
Vetch innoculant	Bag	0.12	$1.75		0.21
Herbicide for rye	Gals.	0	$35.65		
Herbicide for rye/vetch	Gals.	0	$35.65		
Mowing straight rye	Acres	0	$7.00		
Plowing & disking rye	Acres	1	$25.00	25.00	
Mowing mixture	Acres	0	$7.00		
Plowing & disking mixture	Acres	1	$25.00		25.00
Interest (6 months)	%	10.0%		1.87	2.65
Total Cost (per acre)				$39.19	$55.74
Cover Crop Outputs:					
Nitrogen for next crop	Lbs.	70	$0.30	0.00	21.00
Net Cost of Cover Crop				$39.19	$34.74
Benefit / (Extra Cost) of Hairy Vetch/Rye Cover Crop:				**$4.44 per acre**	

3. FIELD DAYS AND WORKSHOPS - University of Massachusetts

Soil Conservation Service and Cooperative Extension field people were invited to participate in a field days in an effort to familiarize them with the cover crop work in progress. The field first day was held October 26, 1989 at the research farm in South Deerfield. A follow-up inter-agency (Cooperative Extension, Agricultural Stabilization and Conservation Service, and Soil Conservation Service) field day was held May 30, 1990. Two field days presenting cover crops to vegetable growers were held in the summer of 1990.

A further workshop was held for Cooperative Extension, USDA-ASCS and USDA-SCS for march 12, 1991 which discussed results of cover crop studies.

4. FIELD STUDIES: 1990-91

Five experiments were initiated in the summer and fall of 1990 in an effort to augment the studies that were implemented with partial funding from the 1990 LISA grant and funds from Cooperative Extension (Water Quality) and the University of Massachusetts. The information that will be collected from these experiments will be important in the eventual on farm implementation of the cover crop strategies.

i. Hairy Vetch, Rye Density and Nitrogen Rate Study

Five rates of hairy vetch were combined with five rates of rye. This experiment was repeated because of encouraging results in 1989-90, and to further quantify the hairy vetch and rye seeding rate relationship to biomass and nitrogen contribution. The cost of hairy vetch seed is several times more than the price of rye. For this reason it is important to examine the effects of hairy vetch rates that are lower than the standard rate of 40 lbs/acre.

ii. Hairy Vetch Seeding Rate and Time of Planting

This is a second experiment to determine nitrogen contribution with varying dates to examine any vetch seeding rates. This has been factorially combined with two planting dates to examine differences due to the time of planting. Treatments include seven seeding rates combines with two planting dates.

iii. Time of Seeding/Mowing Experiment

This is a repeat of the experiment from the previous season. This will help confirm the results from the previous year which showed the optimum time to plant vetch and rye to obtain the optimum biomass and cover for soil erosion control. Hairy vetch and rye were planted on six dates between July 1 and September 15. A non-planted check plot has been included.

iv. Fall Growth of Winter-killed cover crops - Cabbage

The results for 1989 showed that there was a nitrogen response for fall planted legumes that winter-kill. The advantage for the system will be to be able to plant into these cover crops very early in the spring without tillage or herbicide. The weed control that was achieved with the corn was substantial early in the season, but broke down later in the season. Early season control may be sufficient for a shorter season crop like cabbage to become established and complete its life cycle.

v. Fall Growth of Winter-killed cover crops - Corn

The experiment from 1989 is being repeated to further determine nitrogen contribution for summer planted legume cover crops that winter-kill. In this study, three nitrogen rates will be combined with each cover crop treatment plus a no cover check.

5. PROGRESS REPORT OF RESEARCH AT NEW ALCHEMY INSTITUTE AND MAINE ORGANIC FARMERS AND GARDENERS ASSOCIATION.

Progress Report: work done by New Alchemy Institute and by Maine Organic Farmers and Gardeners Association between June, 1990 and March, 1991.

I. Completion of revised manuscript on cover crops for weed control in lettuce.

A rough draft of a report describing a field study conducted at three locations during 1988-89 was submitted to LISA with the June, 1990 progress report. A revised version was submitted to *Biological Agriculture and Horticulture* on March 11, 1991, entitled "Comparison of Weed Biomass and Flora in Four Cover Crops and a Subsequent Lettuce Crop on Three New England Organic Farms," a copy of which is enclosed with this report.

II. Completion of field work, data analysis and report writing on different cover cropping systems for brassicas.

During 1990, field experiments were completed at four locations in cooperation with University of Massachusetts and Maine Organic Farmers and Gardeners Association. Cover crops of rye and/or vetch, and a control (no cover crop) were either mowed or tilled, and broccoli or cabbage was planted, grown to maturity and assessed for yield, weed pressure and other parameters. Data collection was completed in September, 1990, with the exception of total nitrogen analysis on cover crop tissue, with which there has been a delay that was beyond our control. We enclose rough drafts of two articles describing this work, entitled "Effects of Different Cover Cropping Systems on Broccoli and Cabbage. 1. Nitrogen, soil temperature and moisture, and vegetable yields," and "Effects of Different Cover Cropping Systems on Broccoli and Cabbage. 2. Weeds and Other Pests." When the nitrogen analyses are completed, we plan to submit these articles for publication in the Journal of Sustainable Agriculture.

III. Optimum Seeding and Mowing Dates for Hairy Vetch + Rye Cover Crops.

Cover crops of hairy vetch + rye (45 + 63 kg ha^{-1}, respectively) were planted at the beginning of July, August and September, 1989 at East Falmouth, MA, and Pownal, ME. At each site, they were mowed on three different dates, and each date of planting/date of mowing combination was replicated 3 times in a randomized complete block. Measurements of cover crop biomass and N, soil moisture and cover crop and weed regrowth after mowing (East Falmouth only) and data analysis have been completed since June, 1990.

At East Falmouth, rye in the July 5 and August 4 plantings headed prematurely in autumn, and vetch was winterkilled. Weight and N concentration of residues were measured on the first mowing date only, May 3. Mild autumn weather encouraged rapid growth in these two plantings, and was followed by an abnormally cold December with little snow protection which killed the vetch. The September 1 planting thrived, yielding more than 6 Mg ha^{-1} biomass by June 1 (Table 1). Also, this planting did not significantly deplete soil moisture as of May 3 compared to the winterkilled plantings. Cover crop regrowth occurred after May 3 mowing, but was negligible after mowing May 18 or June 1 However, considerable weed growth occurred in all three treatments, and differences in total vegetation biomass on July 19, 1990 were nonsignificant (Table 2).

Table 1. Biomass, nitrogen content and soil moisture levels in rye + hairy vetch cover crops planted and mowed at different dates at East Falmouth, MA, and regrowth of cover crops and weeds after mowing.

Planting Date	Mowing Date	Dry weight, Mg ha^{-1} Live	Dead	Total	%N	Total N, kg ha^{-1}	Soil moisture 5/3/90, g kg^{-1} dry wt.
7/5/89	5/3/90		2.43	2.43 d[z]	-[y]	-[y]	237
8/4/89	5/3/90		2.37	2.37 d			230
9/1/89	5/3/90	4.04	0.15	4.19 c			232
	5/18/90	5.70	0.00	5.70 b			
	6/1/90	6.77	0.00	6.77 a			

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[z] Means within a column not followed by the same letter are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test. Columns with no letters indicate nonsignificant ($P > 0.05$) treatment effects according to ANOVA.

[y] N analyses not completed at this time.

Table 2. Biomass of cover crop regrowth and weeds on July 19, 1990 in rye + hairy vetch planted September 1, 1989 at East Falmouth, MA and mowed on three dates in 1990.

Mowing Date	Dry weight, Mg ha^{-1} Rye	Hairy vetch	Weeds	Total
5/3/90	0.89	0.55	1.96	3.40
5/18/90	0.01	0.01	3.06	3.08
6/1/90	0.00	0.00	1.60	1.60

At Pownal, ME, all three plantings of rye + hairy vetch overwintered. Cover crop biomass was significantly ($p < 0.01$) influenced by mowing date but not by planting date (Table 3). Cover crops mowed in June contained substantially more biomass than cover crops mowed May 21. Soil moisture at time of mowing was likewise influenced by mowing date but not planting date. Soil moisture was partially depleted by crop growth between May 21 and June 6, then replenished by rains between June 6 and 26.

Table 3. Cover crop biomass and nitrogen, and soil moisture in rye + hairy vetch planted and mowed on different dates at Pownal, ME.

Seeding date	Mowing date	Dry weight, Mg ha-1	% N	kg N ha-1	Soil moisture, g kg-1 dry wt
7/1/89	5/21/90	1.09			312
	6/6/90	2.64			235
	6/26/90	3.61			302
8/1/90	5/21/90	1.53			296
	6/6/90	4.40			257
	6/26/90	3.45			306
9/1/90	5/21/90	1.26			310
	6/6/90	2.92			229
	6/26/90	3.12			297

IV. Distribution of Free Cover Crop Kits

Between June 1988 and May 1990, a total of 825 free cover crop seed kits were distributed to gardeners and farmers at conferences of the Natural Organic Farmers Association (NOFA), other agricultural workshops and field days, and through the New Alchemy Institute farmstand. Each kit consisted of sufficient hairy vetch and rye seeds to sow a 46 sq m (500 sq ft) area, inoculant for the legume, planting instructions and a stamped addressed post card so that the grower could inform us about cover crop performance. We also collected names and addresses from 520 participants to assist in followup.

Brief articles have been published in the *New Alchemy Quarterly*, the NOFA Massachusetts and NOFA New York newsletters, and the regional NOFA newspaper, *The Natural Farmer*, asking growers who took cover crop kits to report their results, particularly planting date, overwintering by hairy vetch and overall satisfaction with the cover crop. Letters and reply forms were also sent to 320 participants who received their samples in time to plant in September, 1989. Thus far, we have received 46 replies that give useful data on vetch overwintering as a function of location and planting date. About 60% of participants reported success with the vetch, including some in northern New England and New York, and others who planted as late as October 1 in southern New England.

In April, 1991, letters and reply forms will be sent to 200 participants who took samples during 1991. In July, results from this program will be collated, analyzed and communicated to farmers and gardeners in an oral presentation at the annual NOFA summer conference in Amherst, MA; and in a written article to be submitted to *The Natural Farmer*.

Cover crop progress: miscellaneous experiments, June 1, 1990 to April 15, 1991

1. Hairy vetch seed from northern Nebraska planted near the Canadian border (Presque Isle, ME) showed no evidence of winter injury on April 12, 1991. Although only 10-20% of the 3800 sq. ft. area was devoid of snow on this date, all vetch plants appeared green and vigorous (J. Sisson, pers. commun.). It is unlikely that cold injury will seriously affect hairy vetch from April 13 onward (heaving should not be serious due to inclusion of winter rye, the fibrous roots of which bind soil). Thus it appears that this commercial strain, reportedly derived from 'Madison' (which is no longer commercially available), survived at Presque Isle for two consecutive winters. This strain could not only be a new cover crop/green manure for potato and other farmers in the upper northern United States, but also a rotation crop to provide a break in pest (potato diseases, Colorado potato beetle, and weeds) infestation. This is especially so if the seed can be harvested for a cash crop (cover crop seed) to offset the loss of not growing potatoes, broccoli, or other high value crops. Seed harvest removes little of the organic matter and, it is estimated, only 40% of the nitrogen produced. This site is on U.S. Highway 1, from which the vetch is visible, and is very accessible for inspection by farmers (it is a Univ. of ME farm and the seeding is adjacent to a paved parking lot). Plans include combining and grading seed.

2. The hairy vetch *variety* trial at the same location as above was under drifted snow, so no observations could be made.

3. Hairy vetch at E. Falmouth, MA was planted on several dates up to Oct. 20, 1990; no sign of winter injury has been observed. A 1948 extension publication suggested the last planting date for this vetch should be Sept. 10 in southeast Massachusetts. However, the above experiment and others we have done suggest Sept. 10 may be unnecessarily conservative, especially if a bushel of rye is simultaneously sown to protect soil. Seed was from northern Nebraska and sown with grain rye.

4. Hairy vetch seed was either soaked in water or not and seeded by hand. A no-till (slot) seeding was made in a perennial grass sod on Sept. 17, 1990, and a seeding on tilled ground made on Sept. 19, 1990. Recently, reduced tillage has improved winter wheat survival in Canada and the northern Great Plains, and soaking rye has been shown to be advantageous. No signs of winter injury or field mice (voles are sometimes a problem in overwintering legumes) damage were observed. No differences due to planting date or seedbed were apparent; stands from soaked seed seemed to be equal to or better than unsoaked seed on April 10, 1991 but this was not always true during fall and winter. Soaked seed could be sown with a broadcast seeder and simultaneously covered with a plank drawn behind the seeder, if not with a drill (dusting with lime has been recommended to dry the seed surface after wetting). Most vegetable growers in southern New England seed cover crops with a broadcast seeder.

5. Bigflower vetch at E. Falmouth, MA reseeded itself in 1990. Unlike previous years, this past winter a fence prevented rabbit and woodchuck grazing. Bigflower vetch survived this past winter at E. Falmouth with no sign of winter injury. This experiment was seeded in late summer, 1988, so self-seeding has occurred for the past two years. Bigflower vetch stand (population) in the fall of 1991 appeared higher than that of hairy vetch newly seeded at 40 lbs./acre in an adjacent experiment. Self-seeding reduces seed and seeding costs of cover cropping. Thus, bigflower vetch, which is sown at 20 lbs./acre, can be cost competitive with hairy vetch, which is sown at up to 40 lbs./acre. Growers having difficulty buying, inoculating, and seeding legume cover crops early enough to provide for winter survival may want to consider bigflower vetch.

6. No signs of crimson clover (KY-C1 and 'Dixie') or common vetch (*Vicia sativa*; formerly*V. angustifolia* ; strain from Rodale Res. Center) injury was noted at E. Falmouth from a Sept. 19, 1990 planting. However, Austrian winter field pea suffered considerable winter injury in the same experiment, as it has in previous years at this location, western Massachusetts, Storrs, CT, and central Maine. This seed was derived from 'Melrose', the most winterhardy pea variety (certified seed of Melrose is no longer commercially available).

7. Grain rye sown Oct. 20, 1990 on a compost (manure and sawdust bedding) pile survived. This is the third consecutive year of successful establishment and overwintering of rye on windrows of composts. In all three years rye growth on compost piles appears to surpass that anywhere else on our extensively cover-cropped 12 acre site. Cover cropping compost piles should reduce leaching of nitrate, runoff and erosion of soil and water carrying nitrogen and phosphorus, and volatilization of ammonia, and thus increase the nutrient value of compost applied to crops in lieu of fertilizer. See item 8 below for an additional benefit of cover cropping compost piles.

8. In a similar experiment, we found significantly less weed biomass where grain rye was planted on a compost (tree leaves) pile than where no cover crop was seeded. Several sources indicate compost piles, especially during curing, can be infested with weeds, which may grow rapidly, very large, and mature seed, reducing the value of the compost This is especially so if compost is to be sold as a high-value soil amendment to landscapers, etc.

All of the above are replicated, controlled experiments except item 1.

R. DeGregorio, New Alchemy Inst., E. Falmouth, MA.

5. Bigflower vetch at E. Falmouth, MA reseeded itself in 1990. Unlike previous years, this past winter a fence prevented rabbit and woodchuck grazing. Bigflower vetch survived this past winter at E. Falmouth with no sign of winter injury. This experiment was seeded in late summer, 1988, so self-seeding has occurred for the past two years. Bigflower vetch stand (population) in the fall of 1991 appeared higher than that of hairy vetch newly seeded at 40 lbs./acre in an adjacent experiment. Self-seeding reduces seed and seeding costs of cover cropping. Thus, bigflower vetch, which is sown at 20 lbs./acre, can be cost competitive with hairy vetch, which is sown at up to 40 lbs./acre. Growers having difficulty buying, inoculating, and seeding legume cover crops early enough to provide for winter survival may want to consider bigflower vetch.

6. No signs of crimson clover (KY-C1 and 'Dixie') or common vetch (*Vicia sativa*; formerly*V. angustifolia* ; strain from Rodale Res. Center) injury was noted at E. Falmouth from a Sept. 19, 1990 planting. However, Austrian winter field pea suffered considerable winter injury in the same experiment, as it has in previous years at this location, western Massachusetts, Storrs, CT, and central Maine. This seed was derived from 'Melrose', the most winterhardy pea variety (certified seed of Melrose is no longer commercially available).

7. Grain rye sown Oct. 20, 1990 on a compost (manure and sawdust bedding) pile survived. This is the third consecutive year of successful establishment and overwintering of rye on windrows of composts. In all three years rye growth on compost piles appears to surpass that anywhere else on our extensively cover-cropped 12 acre site. Cover cropping compost piles should reduce leaching of nitrate, runoff and erosion of soil and water carrying nitrogen and phosphorus, and volatilization of ammonia, and thus increase the nutrient value of compost applied to crops in lieu of fertilizer. See item 8 below for an additional benefit of cover cropping compost piles.

8. In a similar experiment, we found significantly less weed biomass where grain rye was planted on a compost (tree leaves) pile than where no cover crop was seeded. Several sources indicate compost piles, especially during curing, can be infested with weeds, which may grow rapidly, very large, and mature seed, reducing the value of the compost This is especially so if compost is to be sold as a high-value soil amendment to landscapers, etc.

All of the above are replicated, controlled experiments except item 1.

R. DeGregorio, New Alchemy Inst., E. Falmouth, MA.

6. PUBLICATIONS AND PRESENTATION - PARTIAL LISTING

University of Massachusetts At Amherst

Maine Organic Farmers and Gardeners Association

Rye

The Most Commonly Grown Cover Crop in New England

History:

Rye was common as a weed in wheat and barley fields for hundreds of years until its value as a food crop was recognized. Cultivated rye (*Secale cereale*) was brought to the United States by the English and Dutch when they settled parts of the northeast.

Uses:

Less than half of the rye grown in the United States is for grain. More rye is grown as a cover crop, pasture or hay. A rye cover crop adds organic matter and helps reduce the erosive forces of water and wind by means of the canopy intercepting rain and acting as a wind break. An extensive root system further stabilizes the soil, reducing erosion. A rye cover holds more snow and rainfall than does a bare field. Early establishment of a rye cover crop may also reduce the leaching loss of nitrate nitrogen from soil after crop removal. Nitrogen contribution from fall incorporated animal manure will be enhanced when a rye cover crop is grown and plowed under in the spring.

Some research data suggest rye may reduce weed growth through allelopathic effects. In addition to these chemical effects from the rye residue, when the rye residue is left on the soil surface the physical environment may be so changed to result in weed suppression.

Rye fits well as a cover crop because of its water hardiness and rapid early spring growth.

Environmental Requirements:

<u>Climate</u>

Rye is the most winter hardy of all small grain cereals. Rye will make considerable growth during cool temperatures in fall and early spring. Ice sheets and extremely wet areas will reduce its winter survival.

<u>Soils</u>

Rye is suited to a wide range of soils but grows best on fertile well drained soils having a pH of 5.6 or higher. It is more productive than other cereals on infertile, sandy or acid soils, and is suited better to loams than to heavy clay soils.

Cultural Practices:

<u>Seeding Dates</u>

Winter rye should be planted by early September in Northern New England and mid-September in southern New England. Consult your local Extension, ASCS or SCS office for

New Alchemy Institute

precise guidelines. Later plantings, although they may grow well in the spring, will offer little protection from soil erosion during winter and snow melt. Early seeding is important if the cover crop is expected to extract excess nitrate nitrogen after the harvest of the previous crop.

Seeding Rate

Plant normally 90 lb to 112 lb (2 bu) per acre of seed. Higher rates (3 to 4 bu/ac) may provide greater cover when planting has been delayed past the optimum seeding dates. If seeded with a legume cover crop such as hairy vetch, seeding rate should be reduced to 30 to 50 lb per acre.

Seeding Method

Rye can be direct seeded with a grain drill into corn stubble or broadcast on the surface and lightly worked into the soil with a disk harrow. Rye seed should not be placed deeper then 1 1/2 to 2 inches. Aerial seeding before harvest or broadcasting seed during harvest and allowing harvest machinery to work the seed in the soil is an alternative. This may be necessary to ensure early seeding on the most erosion prone fields if crop harvest is delayed past the optimum seeding date.

Fertility

No applications of lime or fertilizer should be needed for the rye cover crop if soil fertility is maintained for other crops. Applications of lime and phosphorous and potassium fertilizers or manure at this time may be advantageous for the succeeding crop. This may reduce the workload during spring and reduce spring compaction due to fewer trips on fields. In addition nitrogen taken up by the fall cover crop will become available to the spring crop as the rye decomposes.

Variety Selection

Several alternative varieties are available for grain production, but none have been evaluated for this purpose in New England. For cover crops, common seed of the Balbo type is normally grown without variety designation. Arootstock rye was selected from Balbo by USDA Soil Conservation Service in New York for its good winter hardiness and early growth. It was released by USDA, Cornell University, and Main Department of Agriculture in 1981.

Weed Control

Herbicides are generally not needed since rye competes well with weeds. Higher seeding rates may be needed when perennial weed control is important.

Further Information:

Seeding rate recommendations for a winter rye cover crop based on expected leaf area index. 1983. W. J. Grant, C. D. Stanley, G. R. Benoit, and D. B. Torrey. J. Soil and Water Conser. Vol. 38, p.

Rye. 1990. E. A. Oelke, E. S. Oplinger, H. Bahri, B. R. Durgan, D. H. Putnam, J. D. Doll, and K. A. Kelling. Alternative Crops Manual. Minnesota Extension Service, University of Minnesota.

An examination of cover crop seeding dates. 1986. S. J. Herbert, G. V. Litchfield and Lui Zhi-yi. Applied Agricultural Research. 1:91-5.

by: S. J. Herbert[1], R. E. DeGregorio[2], E. J. Sideman[3], F. X. Mangan[1], and M. W. Schonbeck[2]
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University of Massachusetts
At Amherst

Maine Organic Farmers
and Gardeners Association

Lupin

Winter Killing Cover Crop, Green Manure, or Seed Crop

History:

There are over 300 species of lupin (Lupinus (L)). Earliest known cultivation for food dates back to 2000 B.C. in Egypt. The three commercial grain crop species L. albus, white lupin, L. angustifolius, blue or narrow-leaf lupin, and L. luteus, yellow lupin, all originated in the Mediterranean area. The Andrean lupin L. Mutabilis occurs in South America. Many of the lupin species contain high levels of bitter tasting alkaloids which render the seed and forage unpalatable. In the 1920's alkaloid-free (sweet) types were first selected in Germany.

Uses:

Ancient writers stress the ability of lupins to grow on poor and roughly cultivated land and their usefulness as a nitrogen fixing green manure crop for soil improvement. For minimum tillage systems, lupin sown in late summer in New England will winter kill eliminating the need for knock-down herbicide in spring. Lupins are herbaceous to woody annual legumes with maximum vegetative growth rate occurring during flowering. Early seed producers had to contend with hard-seededness, pod shattering at maturity, and bitter alkaloids. Renewed interest in lupin as a seed crop has accompanied the introduction of new improved cultivars that are sweet, non shattering and soft seeded. Lupin seed is high in protein (28-46%) and low to moderate in oil (4 to 15%) and does not contain trypin digestive inhibitors like soybean. Occurrence of bitter alkaloids is not a problem for green manure crops and may discourage grazing by large animals and attack by insects.

Environmental Requirements:

Climate

Lupins are cool season crops with variable tolerance of frost. In Mediterranean climates lupins are seeded in the fall and harvested for seed in the spring. In temperate climates lupins are sown in early spring and harvested in late summer or fall, or plowed under in mid summer for green manure. If planted in late summer or fall as cover crops, lupins will continue growing until killed by freezing temperatures.

Soils

Lupins are adopted to coarse-textured, well drained soils of acid to neutral reaction. They have a deep root system which is sensitive to waterlogging. Planting on poorly drained soils prevents normal root development and may result in root rots leading to stand loss.

Cultural Practices:

Seeding Dates

For seed production, plant in early April in southern New England and until early May in northern New England. With later sowing, maturity may be delayed and seed yield reduced. As a cover crop, lupins should be seeded in early August to make sufficient growth before winter-killing.

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Seeding Rate

A high seeding rate of at least 6 seeds per ft^2 (260,000 seeds per acre) in narrow rows (6 to 10 inches) is needed for high seed yields. Because of its large seed size, seed costs may limit seeding rate. As a cover crop, 2 to 3 plants per ft^2 when grown with 40 to 50 lb per acre of oat maybe better than lupin alone. However, more research data is needed to establish seeding rates for cover crop mixtures. Vegetative profuse branching types (L. angustifolius) may produce adequate biomass at lower seeding rates than the white lupin, L. albus.

Seeding Method

Precise placement of seed is necessary for rapid even emergence and establishment. Lupins can be seeded into a relatively rough seed bed provided seeding depth is between 3/4 to 1 3/4 inches with good seed-soil contact. Placing seeds too shallow in dry soils contributes to poor germination and poor seedling survival. Placement too deep slows emergence and may increase seedling diseases. No-till seedings are possible into previously cropped fields. However, adequate seed-soil contact and proper depth are still important.

Fertility

Inoculation of seed with the specific nitrogen fixing bacteria for lupin is necessary to ensure nitrogen fixation. Inoculant is relatively inexpensive and should be available through seed suppliers. Maximum nitrogen fixation rates are reached at or near first flower and continue almost to maturity. Recommendations for other nutrients have not been established. Usually no response will be observed so long as soil nutrients are kept in the medium to high test range. No applications of phosphorous or potassium should be needed when lupin is grown as a cover or green manure crop.

Variety Selection

Several varieties of blue, white, and yellow lupins have been developed worldwide. Germplasm trials are currently being conducted in New England and western states. White lupin is most readily available and is probably the preferred species for seed production. Blue lupin may be the better choice for cover cropping but seed availability is limited.

Weed Control

Lupins are poor competitors with weeds because of their slow initial growth especially in spring when temperatures are cool. For seed production, herbicide application or tillage will be necessary for weed control. Grass herbicides are available, but currently no broadleaf herbicide is registered for lupin. Late-germinating summer annual broadleafs, such as lambs quarters, pigweed and ragweed, can be a problem especially when crop density is inadequate. When lupin is fall seed as a cover crop no weed control measures will be necessary.

Diseases and Insects

Lupin disease organisms are present in most fields. Root rot fungi, *Fusarium* and *Rhizoctonia*, cause most damage. Lupins are most susceptible on heavier, poorly drained soils. Corn seed maggot may severely reduce seedling establishment. Potato leaf hopper and tarnished plant bug may also affect pod set. Diseases and insects should not be a concern for fall sown cover crops.

Further Information:

Cultural practices and production constraints in lupines. 1987. S. J. Herbert. In Grain Legumes as Alternative Crops, a symposium sponsored by the Center for Alternative Crops and Products. University of Minnesota, pp. 185-194.

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University of Massachusetts
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SOIL MANAGEMENT - COVER CROPS

Cover crops are often grown because they help prevent soil erosion. We encourage farmers to make them an integral part of their cropping program because use of cover crops do have positive environmental consequences.

First, control of soil erosion. Loss of top-soil robs productive fields of soil fertility and therefore is a real economic loss to farmers even if not recognized. Loss of soil loaded with nutrients by wind and water contributes to pollution of surface waters resulting in an environmental loss for all society. Certainly, local farmers seem more conscious of the need for clean rivers than has been observed in other parts of the world. Cover crops help to reduce soil erosion by water and wind because their canopy of leaves intercepts rain and acts as miniature wind breaks. An extensive root system further stabilizes the soil by holding soil particles together.

Cover crops can be an important part of nutrient management on farms. Research has shown that after crops mature or are harvested, there can be a release of nitrogen from the soil root-zone to subsurface layers and to the groundwater. Often on dairy farms nitrogen from animal manure can be in excess of the corn crop requirements. This is especially true on many farms where distant fields seldom, if ever, receive manure applications. Thus after corn is removed for silage making, considerable nitrogen may be lost to groundwater from some fields. Actively growing cover crops, especially cereal grasses (winter rye and oats), may remove substantial quantities of nitrogen from the root-zone preventing its movement to groundwater. Winter rye the most commonly grown cover crop will only be effective in removing residual root-zone nitrogen if cover crops are planted early. An extensive expanding root system is necessary for substantial uptake of nitrogen from soil.

Results from our studies in Massachusetts clearly show that early seeding is essential for the establishment of sufficient protective cover. In most years in most regions of Massachusetts, cover crops should be seeded by September 15, or earlier especially on the steepest fields and those most prone to erosion. In northern New England dates for planting cover crops may be two to three weeks earlier than for Massachusetts. Farmers should look for ways to establish cover crops early. This may involve combining cover crop establishment with crop harvest (corn chopping), or leaving sometime each day during harvesting for the establishment of cover crops.

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New Alchemy Institute

Hairy Vetch as a Cover Crop for New England Vegetable Growers

R.E. DeGregorio & M. Schonbeck, New Alchemy Inst., 237 Hatchville Rd. E.Falmouth, MA 02536. March 1991

Description Hairy vetch (*Vicia villosa* Roth) can be used as a winter annual legume to provide nitrogen to vegetables which follow it, and to suppress weeds. It looks very similar to other true vetches which grow wild in New England pastures and roadsides, but is a different species (mature seed may be necessary for positive identification). Such wild vetches may be perennial and weedy, unlike hairy vetch. True vetches have long, weak stems which climb like peas, and small, numerous pairs of leaflets opposite each other. Flower heads appear in late spring or summer and consist of a long cluster of small purple/blue flowers. Crownvetch and milkvetch, both perennials, are not true vetches, and do not climb.

Varieties The only variety certified in the US was 'Madison', a selection from a farm in Madison County, northeast Nebraska. Seed supposedly derived from 'Madison' is available from northeast Nebraska (for example, Reikofski Grain, Foster, NE 68737 tel. 402/329-4275; mention of a company or product does not constitute a guarantee or warranty of performance or an endorsement over products not mentioned). Woolypod vetch, the most common variety of which is 'Lana', was until recently considered a different species, but is now considered the same species as hairy vetch. It appeared less winterhardy than common (usually from western Oregon) hairy vetch in northeast Connecticut, consistent with reports outside New England. The hairy strain of hairy vetch is more winterhardy than the smooth strain, but is also slower growing, lower yielding, and harder to find. Beware of older literature concerning winterhardiness of hairy vetch; by 1947, over 90% of U.S. vetch was the smooth strain, replacing the older hairy strain.

Winter hardiness Hairy vetch, also known as winter vetch and Russian vetch, survived the winter of 1989-90 at Presque Isle, Maine when planted in August 14, and is being retested in 1990-91 at the same location. It also survived winter in central Maine, western Massachusetts, and central New Hampshire the same year. Failure to overwinter was not reported from Ithaca, NY in a four year study, nor from a 14 year vegetable study in northeast Connecticut, where one winter the air temperature reached -32 F. Hairy vetch survived the five winters it was used in central Vermont where it was drilled between rows of vegetables. Thousands of acres of hairy vetch seed have been produced in northeast Nebraska for the past 40 years, further evidence of this species' winterhardiness. Also, Michigan, including its upper peninsula, used to be among the top three hairy vetch seed producers. Hairy vetch has also survived two or more years in central Iowa. Failure to overwinter has occurred in northern Maine, Michigan, and southern New Hampshire. These failures may have been due to very acid soil, late planting, poor soil drainage, windswept conditions, or herbicide residue. Even alfalfa, the queen of forages in New England, will fail under certain circumstances. Indeed, one winter alfalfa did fail where hairy vetch did not.

Soils Hairy vetch, also known as sand vetch, is best suited to loamy sands and sandy loams, but will survive on other well-drained land. It is a waste of money to plant it on poorly drained soils. It is known that potassium acts like antifreeze for alfalfa, so ideally soil should test high for this nutrient, and in Connecticut, vetch ground cover increased as soil potassium increased. Hairy vetch has a relatively high phosphorus requirement. Phosphorus is necessary for rapid root growth, anchoring plants to resist heaving out of the soil when frost comes out of the soil. Hairy vetch has tolerated soil pH from 4.9 to 8.2, but 5.8 to 6.5 is recommended in the South. Using a molybdenum-containing inoculant may be beneficial on very acid soils, as in rotation with potatoes. Nitrogen should not be applied for vetch.

Inoculation Beneficial bacteria live in swellings on the roots of vetch. These harmless microbes take nitrogen (N) from the air and convert it to a form that plants can use. If you have not inoculated (applied the correct strain of live bacteria to) true vetch or pea seed in the past five years, you should do so to hairy vetch just before planting. Preinoculated seed is available, but sometimes contains insufficient live bacteria. Most farm suppliers in New England do not stock the correct strain of bacteria for true vetches or peas in farm-scale quantities. Ask your farm supplier to order this inoculant for you, or order from, for example, Adams-Briscoe, Box 18, Jackson, GA 30233 (tel. 404/775-7826). Ideally, apply four times the amount of inoculant recommended on the inoculant label, and add sugar to the water used to stick the inoculant to seed to improve sticking. To check inoculation, dig (don't pull) a plant from several places in a field and gently wash roots. If you find swellings are 1) plentiful; 2) whitish outside; and 3) pink/red inside, N is probably being fixed (converted to a useful form).

Nitrogen Credit Hairy vetch can fix more N than any other legume during the fall, winter, and spring. How much will depend on when you kill it, preceding weather, soil fertility, date of planting, and other growing conditions such as herbicide residues. Removing top growth for feed or mulch can remove 80-90% of the N unless manure and feces are returned by pasturing or regrowth is permitted. Preliminary data suggest mid to late May killing dates may supply the equivalent of about 75 lbs N/acre to a following crop. The University of California reports that cutting a 4 ft. by 4 ft. area from a representative part of the field, weighing it fresh, and multiplying its weight by 18 gives an estimate of the N/acre in vetch or pea cover crops. This rule will not apply if there is significant grass or weeds present. Perhaps half of vetch's N may be available the first year (less for no-tillage), the other half in year 2 and 3.

Weeds While growing, vetch may compete for nutrients, water, and light, thus reducing weeds. By climbing it can keep up with tall growing companion grasses, and compete with weeds in a way that non-climbing/shorter legumes can not. Hairy vetch also contains substances inhibitory to other plants, although apparently not as much rye. To make best use of these substances and physically suppress weeds, kill vetch (for example, by a low flail/sickle mowing in mid-late May in southeast Massachusetts) and leave it on the soil surface as a mulch. After about a month, these substances break down, and weed suppression by other methods such as crop competition and cultivation are needed. Transplants and large-seeded crops are generally not significantly inhibited by such substances, but small-seeded crops like carrots have been. Such a dead mulch also increases water infiltration, and reduces erosion, water and chemical runoff, and, unfortunately, soil temperature. Clearing an eight inch wide strip of dead mulch, however, is about as good as removing all dead residue. A number of planting attachments are available to clear such a strip, or strip tillage (e.g., with a multivator or rotary tiller) can be used. Slugs, and to a lesser extent, cutworms and earwigs can be a problem without tillage and with a dead mulch.

An extensive investigation of farmers, seed dealers, researchers, extensionists, and publications indicates hairy vetch itself is not a serious weed except in producing certified winter wheat seed. Normal management practices necessary to control weeds will also prevent significant loss due to hairy vetch in annual vegetables. Many crops can volunteer seed which may carry over from one year to another: corn and sunflower in the Midwest, and winter rye in strawberries and tomatoes in compost piles in New England are common examples.

Seeding A 1948 Massachusetts publication recommended seeding hairy vetch (with winter wheat) by Sept. 10 in southeast Massachusetts, and August 20 elsewhere in the state. More recent observations support these dates (see also winterhardiness section above). Plant 0.5 to 1.5 inches deep. Drilling is preferable to broadcasting, as it uses less seed and can place seed more precisely. However, seeding during final cultivation or sidedressing, or by helicopter, have been successful and may reduce labor and machinery costs. Cornell University preliminary work suggests most herbicides used for field corn would not pose a threat to late cultivation or sidedressing. Plant 25-40 lbs seed/acre, the lower rate when seed is expensive/large acreage is involved. Preliminary work suggests 30 lbs/acre is adequate, but most recent research has been done with 40 lbs/acre.

Mix with a companion grass such as rye (1 bu/acre), winter wheat, "annual" ryegrass, or field brome. Such a grass-legume mix is safer in case of winterkill, because hairy vetch grows slow in the fall, often providing less than ideal ground cover. Companion grass also provides support for vetch, allowing to grow taller, absorb more light, not rot on the ground, and be mow-killed if you so desire. Grass will tend to mop up excess nitrate that might otherwise leach better than vetch, and produce more organic matter (and thus, dead mulch). Finally, a grass-legume mix lowers seed cost and is more genetically diverse than a monoculture, making the cover crop less susceptible to disease and insect pests.

Pest and Beneficial Organisms Do not plant hairy vetch in orchards as it is a host of Turner's plant bug. Hairy vetch is also a host of chocolate spot in Wisconsin, a bacterial disease of snap bean, so if snap beans follow vetch, at least one snap bean variety is resistant/tolerant. Michigan growers have apparently followed vetch with *dry* bean without problems from this disease, and hairy vetch is a preferred in dry bean rotations there. Many plants, including hairy vetch, host nematodes, but nematodes are generally not as serious a problem in New England vegetables as in warmer regions. The benefits of vetch outweigh this disadvantage, and at this time, other winterhardy legume cover crops for New England vegetables are less beneficial. Hairy vetch is not an overwintering host for corn earworm, as the insect does not overwinter in New England.

Because corn is a grass, following it with another grass (rye) as a cover crop may not provide a break from certain pests, especially with continuous corn. Common stalk borer can be a problem in no-till sweet corn in New England after rye. European corn borer (ECB) lays its eggs in grass and weedy areas, and there was a trend toward less ECB in Ontario where a legume cover crop was used. Some wireworm species seem to be associated with grasses, as do white grubs. Thus, hairy vetch may be better than a grass monoculture cover crop after corn. One study in the South found vetch supported more beneficial insects than did clovers. Others report that spiders, lady beetles, earthworms, etc. benefit from the food/cover that vetch provides. Rabbits were found in dense legume+grass cover crops in Connecticut and Massachusetts, and in the latter, destroyed broccoli transplanted afterwards. It has also been suggested that woodchucks might do the same if a legume cover crop were used in New Hampshire.

Economics Possible ways to minimize seed/seeding cost: drill seed; piggyback seeding onto final cultivation/sidedressing; mix in a companion grass; shop around for the best seed price* (considerable variation has been noted); buy when prices are low (certain years and time of the year; hairy vetch seed stored in a cool, dry place germination will not decline for five years due to hard seed); grow your own seed, or grow with a neighbor--trucking costs almost as much as the seed itself; buy cooperatively/in bulk, as Mass. NOFA has; consider buying from Nebraska, (closer than Oregon); consider buying vetch mixed with rye, avoiding the cost of separating the two (e.g., from farmer Emil Kastl, Stillwater, OK tel. 405/372-5748)*; try seeding 30 or even 25 lbs vetch/acre; use vetch as a weed-suppressing dead mulch to save on herbicide costs, not just as a N source, and give credit for the N available in years 2 and 3.

*Consider weed seed, crop germination, and inert matter when buying cover crop seed.

Crimson Clover as a Cover Crop for New England Vegetable Growers

R.E. DeGregorio & M. Schonbeck, New Alchemy Inst., 237 Hatchville Rd. E.Falmouth, MA 02536. March 1991

Description Crimson clover (*Trifolium incarnatum* L.) is a winter annual legume cover crop. It differs from our common red clover in having taller flower stems, long scarlet flower heads, and seeds about twice as large. Its showiness has allowed it to be used as a cut flower in arrangements, in a wildflower seed mix, and for roadside beautification plantings. It might attract customers to a roadside stand if planted along a road near the stand. Do not feed hay made from mature plants to horses.

Winter hardiness Examination of herbarium specimens in Connecticut, old seed catalogues from Massachusetts and Connecticut companies, and interviews with an elder Connecticut farmer and two Connecticut seed companies indicate crimson clover has overwintered in Connecticut and probably Massachusetts. A 1920 USDA Bulletin states "Hardy strains have been developed and used in a small way in Massachusetts...but...are not commercially available." A 1917 Connecticut Bulletin states crimson clover "deserves more attention as a...cover crop." Vegetable growers can suffer winterkill better than dairy farmers, and winterkilled cover crops may still protect the soil, especially if sown early and with a hardy grass like winter rye. Sown Aug. 6 in Connecticut, crimson clover+grass completely covered the ground in the fall; hairy vetch+grass in the same experiment did not do so until spring; similar results have been observed in the southeast parts of MA and PA. '   ' crimson clover failed to survive when planted **Sept. 8** at Amherst the one winter (1988-89) tested there. See section below entitled "Varieties."

Varieties Ky C-1, selected for winter hardiness and released by the University of Kentucky, has equalled or exceeded all other crimson clover varieties in yield at Lexington, KY. Its probable area of adaptation is reported to be the North Central and Northeast USA. It survived at Albion, ME the one winter (1989-90) it was tested there (planted Aug. 21 mixed with oats & rye), and efforts to commercialize it continue. Apparently 'Chief' is the most winterhardy commercial variety, and 'Dixie' next in winterhardiness. Dixie is available from, for example, Adams-Briscoe, Box 18, Jackson, GA 30233 tel. 404/775-7826; mention of a company or product does not constitute a guarantee or warranty of performance or an endorsement over products not mentioned. Common crimson clover survived the winter when planted Sept. 4, 1983 in northeastern Connecticut, but only where a companion grass was also sown (crimson actually suffered less winter injury than red clover in this test). Ky C-1, Dixie, and common survived the winter of 1984-85 at two sites (4 plantings) in north Connecticut. Dixie and Chief are reseeding (hard seed) types, and can be managed to self-seed in the South, but Ky C-1 is not. See section above entitled "Winter hardiness."

Soils Crimson clover is adapted to sandy, not poorly drained soils. It is tolerant of ordinary soil acidity. Potassium acts like antifreeze in alfalfa, so ideally soil should test high for this nutrient to facilitate overwintering. If a soil test indicates phosphorus is needed, it should ideally be placed in a band below and to the side of the seed at planting. Boron has improved growth and seed yield on some soils. Do not fertilize crimson clover with nitrogen.

Inoculation The same inoculant (beneficial bacteria) used for red & white clovers can be used for crimson. Ideally, apply four times the amount on the inoculant label the day of seeding, using water and sugar as a sticker.

Nitrogen Credit Crimson clover in the Northeast provides less nitrogen (N) to vegetables following it than does hairy vetch. However, broccoli following crimson clover + rye was significantly (55%) higher in N than following rye alone in a one year test in southeast Massachusetts. In southeast Pennsylvania, crimson clover without a companion grass contained 111 lbs. N/acre on May 10, 1985.

Ryegrass as a Cover Crop for New England Vegetable Growers

R.E. DeGregorio & M. Schonbeck, New Alchemy Inst., 237 Hatchville Rd. E.Falmouth, MA 02536. April, 1991.

Description Ryegrasses are cool season, non-creeping bunch grasses. Italian ryegrass (*Lolium multiflorum* Lam.), often called annual ryegrass,usually behaves as an annual, though biennials or sometimes short-lived perennials occur. Left uncut, it grows 2 to 4 ft. tall and reseeds itself. It is closely related to perennial ryegrass (*Lolium perenne* L.), a common turf and forage grass, which will reach 1.5 to 3 ft. Ryegrass is not the same as grain rye, also called winter rye (*Secale cereale* L.), which is taller, more winterhardy, and has a seedhead resembling wheat.

Winter hardiness and seeding dates In NE Connecticut, ryegrass forage varieties have survived most years planted, and common Italian ryegrass survived the one winter tested as a cover crop (1982-83). See "Varieties" section below. Ryegrass seeded by Sept. 1 was suggested as winter cover after potatoes in Maine. USDA-Soil Conservation Service (SCS) in Maine, however, recommends seeding annual ryegrass by Aug. 15 for fall cover (Sept. 15 for winter cover). July 15 and Sept. 15 are the latest annual ryegrass seeding dates recommended by SCS of for fall and winter protection, respectively, in Connecticut and Rhode Island. In NE Pennsylvania, ryegrass overseeded into vegetables in mid-late July is the preferred cover crop of dozens tested over eight years.

Varieties Common seed is less expensive than certified seed. It may be difficult to justify the extra expense of certified seed when used as a cover crop. However, some varieties of ryegrass appear more winterhardy than others. 'Marshall' Italian ryegrass was more winterhardy than 'Wintergro', which was more winterhardy than 'Gulf', the one winter tested in NE Connecticut (Marshall is available from Adams-Briscoe, Box 18, Jackson, GA 30233 tel. 404/775-7826; mention of a company or product does not constitute a guarantee or warranty of performance or an endorsement over products not mentioned). In five years of testing in the upper South, with temperatures below normal, Marshall showed considerably less cold damage than other varieties. This variety could extend the traditional range of Italian ryegrass for *pasture* to S. Illinois, says a university agronomist. Marshall was also equal to or higher yielding than other Italian ryegrass varieties tested in the South. 'Wimmera 62' is a true annual without awns which is more tolerant of drought and low fertility, and matures about two weeks earlier than, common ryegrass. Planted Sept. 3, 1985, Wimmera 62 did not overwinter well in NE Connecticut. However, some other species, including alfalfa, also did not overwinter well that winter.

However, if a cover crop makes enough growth before winterkilling (e.g., by seeding it early enough), it may still protect soil from erosion. Gardeners unable to turn under dense cover crops find a dead cover crop easier to manage in the spring. Mass. Coop. Ext. L-215 states that "After it [annual ryegrass] is killed it will form a mat which will protect the soil from erosion." Vegetable growers are not as adversely affected by winter injury of a cover crop as livestock farmers are by loss of forage.

Soils Ryegrass is adapted to a wide range of soils and is acid tolerant. Well-established ryegrass can withstand short periods of flooding. It is not adapted to drought and low fertility, especially low nitrogen.

Nitrogen Credit Some nitrogen (N) not used by the previous vegetable crop will be taken up by the dense root system of ryegrass. The Oregon Ryegrass Commission states that about 1.5 lbs. N are returned to the soil for every 100 lbs. annual ryegrass (dry matter) plowed down. Overseeded Sept. 7 into soybeans in SE Pennsylvania, annual ryegrass contained 24 lbs. N/acre (1.37% N). In New York, overwintered ryegrass (shoots + roots) in May contained 33 lbs. N/acre according to a four year study, and 30 lbs. N/acre according to another report. The higher N reports from New York than from Pennsylvania may be due to not harvesting roots in the latter.

Yield In New York, overwintered ryegrass (probably annual) produced 2.5 tons dry matter (roots + shoots)/acre by May, which is reported to be typical there. However, in a four year Aurora Research Farm, NY study, overwintered ryegrass (probably annual) averaged 1.42 tons dry matter (roots + shoots)/acre in May (42% more than grain rye). On Cape Cod (E. Falmouth), Italian ryegrass seeded Sept. 21 yielded 1.5 tons *aerial* dry matter/acre on May 31, not significantly different from grain rye. Overseeded Sept. 7 into soybeans in SE Pennsylvania, annual ryegrass yielded 0.87 ton aerial dry matter/acre in the second week of May, 1985. Roots in one study were almost half the total dry weight.

Weeds Annual ryegrass germinates quickly (7-10 days; less under ideal conditions). Annual ryegrass ground cover in December on Cape Cod, and in November in NY, was twice that of rye. Ryegrass has an extensive root system (not recommended for turning under by hand or small rototiller unless planted late enough to ensure winterkill) and is very responsive to N, so it can "mop up" residual soil N after vegetables and thus reduce accompanying weed growth. Several studies indicate perennial ryegrass is allelopathic (produces substances which inhibit weeds and other plants). In a one year Connecticut experiment, there were fewer common lambsquarters in Italian ryegrass than in grain rye. In another one year Connecticut experiment, annual ryegrass was one of the best of 56 cover crops for weed suppression in sweet corn.

Seeding Rototilling resulted in more Italian ryegrass winterkill than moldboard plowing followed by disking in Connecticut. It is ideal to pack tilled ground before and especially after seeding with a corrugated roller (e.g., Brillion seeder) to prepare a firm seedbed and to reduce heaving, especially for later plantings. One of the strengths of ryegrass is that it can be sown on dry or wet soil without covering the seed. However, it is best to cover seed with 0.5 inch of soil. In some areas no-till seed drills can be rented (contact SCS); ryegrass is commonly seeded in standing stubble. Usually 20 lbs.seed/acre is recommended for a ryegrass cover crop; halve this rate if a legume is also planted. Up to 37 lbs. seed/acre has been recommended for controlling soil erosion, and up to 48 lbs. Italian ryegrass seed/acre in Massachusetts. Do not seed ryegrass the year pendimethalin (e.g., Prowl) is used. Interseeding when field corn is 6-18 inches tall is the *preferred* way to establish ryegrass + red clover in New York. The Oregon Ryegrass Commission recommends interseeding annual ryegrass when corn is about 15 inches tall, and Rodale Research Center at final cultivation or thereafter. Rodale Research Center suggests seeding no later than 40 days before frost.

Pests Crown and brown rust are common fungal diseases in humid climates. Certain varieties offer some resistance and should be used where these diseases are a problem. It is best not to follow corn (a grass), especially continuous corn, with a grass monoculture cover crop; consider rotation and a legume or grass-legume cover crop after corn to increase biodiversity and minimize pest potential.

Economics Annual ryegrass seed is much less expensive, grows taller, and establishes more rapidly than perennial ryegrass, thus it suppresses weeds better. Seeding during final cultivation or sidedressing can reduce seeding cost. Common annual ryegrass can be less expensive than winter rye ($0.35/lb. seed from one dealer in 1990, x 20 lbs. seed/acre = $7.00/acre, + seeding cost). As little as 5 lbs. seed/acre has been recommended as a cover crop if drilled (10 lbs. if broadcast). Consult SCS for information on cost sharing cover crops. Ryegrass can also be used for pasture; better liveweight gains are generally obtained if the ryegrass is seeded with a legume. Left alone, it will reseed itself (in mid-June in SE Pennsylvania).

Cover crop progress by R. DeGregorio from June 1, 1990 to March 28, 1991

Publications

M. Schonbeck, R. DeGregorio, S. Herbert, F. Mangan, K. Guillard, E. Sideman, J. Herbst, and R. Jaye. 1991. Effects of different cover cropping systems on broccoli and cabbage. 1. Nitrogen, soil temperature and moisture, and yields. J. Sustainable Agric.: manuscript in preparation.

F. Mangan, S. Herbert, R. DeGregorio, M. Schonbeck, E. Sideman, K. Guillard, and A. Wurzberger. 1991. Effects of different cover cropping systems on broccoli and cabbage. 2. Weeds and other pests. J. Sustainable Agric.: manuscript in preparation.

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Gershuny, G. 1991. Soils. 43 pp. (single spaced). *In* M. Smith (ed.) Manual of current practices. Northeast Organic & Sustainable Farmers Network [USDA-LISA grant recipient]. J. Green, Cornell Univ., Ithaca, NY requested my review (received January 22).

Presentations

Weed management. Mass. NOFA Ann. Winter Conf., Ashland, MA, Jan. 20, 1991 (invited & paid).

Soil fertility. Mass. NOFA Ann. Winter Conf., Ashland, MA, Jan. 20, 1991 (invited & paid).

Cover crops and other tools for managing weeds and nitrogen on dairy farms. College of Agric. and Natural Resources Seminar, Univ. of Conn., Storrs, CT, Dec. 21, 1990 (invited as position candidate).

Cover crops. Drumlin Farm, Mass. Audubon Soc., Lincoln, MA, Oct. 6-7, 1990 (invited).

Weed management. NOFA (Natural Organic Farming Assn.) Summer Conference, Aug. 4, 1990, Amherst, MA (invited, paid, and **videotaped**).

Selecting plants for low input phosphorus, potassium, and boron. New Alchemy Inst. Seminar, Aug. 2, 1990.

Cover crops. Biennial vegetable growers field (machinery) day, Mass. Correctional Inst., Shirley, MA. Sponsored by the Coop. Ext. Ser., Univ. of Mass., Amherst, MA, July 10, 1990.

end

Comparison of Weed Biomass and Flora in Four Cover Crops and a Subsequent Lettuce Crop on Three New England Organic Farms

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Abstract

Many vegetable growers in the northeastern United States routinely utilize cover crops to suppress weeds as well as conserve and enrich the soil. An exploratory study was conducted to compare weed biomass and species composition in four different cover cropping programs, and in lettuce grown after the cover crops were incorporated into the soil. The treatments were: two plantings of buckwheat followed by winter rye (BW/R), sudangrass followed by winter rye (SG/R), mammoth red clover + oats (C+O), and Italian ryegrass (RG). Cover crops were grown from spring 1988 through spring 1989, then followed by lettuce.

Some buckwheat plantings suppressed summer weeds effectively, but others failed because of drought. Sudangrass tolerated drought, but grew rapidly and outcompeted weeds only at the most fertile site. Clover established slowly, but suppressed weeds more effectively than rye during fall 1988 and spring 1989. Ryegrass completed its life cycle in early summer 1988 and did not reseed itself effectively. Winter weed species composition differed significantly between treatments.

Biomass of weeds + cover crop regrowth in lettuce was significantly lower after BW/R and SG/R than after C+O. The lack of summer tillage in C+O, combined with slow clover establishment in 1988, may have allowed greater seed production by crabgrass in C+O than in other treatments. Buckwheat reseeded itself at one site, resulting in substantial cover crop regrowth in the lettuce, while regrowth of other cover crops was negligible. Weed biomass *excluding* cover crop regrowth was least after BW/R, followed by SG/R, RG and C+O in that order. Lettuce head weight was higher after BW/R than other treatments at one site, but was not significantly affected by treatments at a second site.

Introduction

Effective weed control is a challenge to farmers who avoid herbicides, and many organic farmers consider weeds their most serious problem (Peters 1986; Baker & Smith, 1987). Organic and low-input farms use cover crops as well as timely cultivation, rotation of crops and tillage methods, balanced soil fertility, and sanitation in their weed management programs (National Research Council, 1989; Hofstetter, 1990). Cover crops suppress weeds by competing for light, soil moisture and nutrients, and by allelopathy, which is the release of compounds that inhibit germination and early growth of other plants (Aldrich, 1984). In addition to suppressing weeds, cover crops protect soil from erosion, replenish organic matter, and, if legumes, add nitrogen. However, cover crop allelopathy may inhibit emergence or early growth of small-seeded crops such as lettuce (*Lactuca sativa* L.) or tomato (*Lycopersicon esculentum* Mill.) (Putnam *et al.,* 1983). These effects can be minimized by tilling the cover crop into the soil two to four weeks before sowing, but soil disturbance may compromise weed control by stimulating weed seed germination (Aldrich, 1984).

In a survey of 55 vegetable farms in the northeastern United States, over 90% of growers reported using cover crops regularly to maintain soil fertility, prevent erosion and/or control weeds (Schonbeck, 1988). Farmers reported mixed results with cover crops for weed control, and expressed a need for more research. The most frequently mentioned problem weeds were the summer annuals pigweed (*Amaranthus* spp.), galinsoga (*Galinsoga* spp.) and lambsquarters (*Chenopodium album* L.), the winter annual common chickweed [*Stellaria media* (L.) Vill.], and the perennial quackgrass [*Elytrigia repens* -(L.) Nevski.]. Some farmers rotate weedy fields into cover crops for a year, typically two successive plantings of buckwheat (*Fagopyrum esculentum* Moench) followed by winter rye (*Secale cereale* L.). Fast-growing cover crops such as buckwheat and oats (*Avena sativa* L.) are grown to suppress weeds during short fallow periods or between rows of widely-spaced crops like winter squash (*Cucurbita* spp.).

Several farmers in the survey reported success in suppressing weeds with sudangrass [*Sorghum bicolor* (L.) Moench], Japanese millet [*Echinochloa crus-galli* var. *frumentacea* (Roxb.) W. F. Wight] or mammoth red clover (*Trifolium pratense* L.). Sudangrass and Japanese millet are frost-sensitive, fast-growing summer annuals, like buckwheat, but the millet is more tolerant of cool wet soil conditions (Martin *et al.*, 1976). One grower recommended tartary buckwheat (*Fagopyrum tartaricum* (L.) Gaertn.) for colder climates (Schonbeck, 1988). Mammoth red clover is a hardy, shade-tolerant, short-lived perennial, and established stands have suppressed weeds almost completely in southeastern Canada (Samson, 1988) and in southern New England (personal observation). We have also observed good weed suppression by Italian ryegrass (*Lolium multiflorum* Lam), which is a strong competitor for soil moisture and nutrients (Heath *et al.*, 1985).

Crop-weed interactions are species-specific (Aldrich 1984, Putnam & DeFrank 1983, Barnes & Putnam 1983), and there is comparatively little information on the impact of different cover crops on weed flora under field conditions. In greenhouse experiments, residues of rye, oats and sudangrass (Barnes & Putnam 1983; Putnam *et al.*, 1983; Putnam & DeFrank, 1983) and some legumes (Teasdale, 1988; White *et al.*, 1989) have shown allelopathic activity against redroot pigweed (*Amaranthus retroflexus* L.) and other weeds. In field studies in Michigan, herbicide-killed rye, oats and barley significantly reduced populations and biomass of a weed complex that included pigweed and lambsquarters. Buckwheat apparently suppresses weeds by its rapid growth and heavy canopy, and some farmers and researchers speculate that buckwheat exerts an allelopathic effect after it is tilled into the soil. (Schonbeck, 1988). Buckwheat followed by rye has been recommended for controlling quackgrass (Eaton Valley Agricultural Services, undated). However, no comparative studies have been conducted on the effects of different cover crops on weeds in vegetable cropping systems managed without herbicides. We therefore conducted an exploratory field study at three locations comparing weed species composition and biomass in several cover crops and in lettuce grown after the cover crops were incorporated into the soil. Cover crops were also compared for ground cover, height, phenology, biomass and effects on lettuce yield. Our objective in presenting these preliminary findings is to stimulate further investigation by researchers and growers into more effective cover cropping strategies for managing problem weeds.

Materials and Methods

Experiment 1

The study was conducted at three commercial organic vegetable farms: New Alchemy Institute's market garden in East Falmouth, on Cape Cod, Massachusetts (Site 1); White Oak Market Garden in Belchertown, Massachusetts (Site 2), and Harlow Farm in Bellows

Falls, Vermont (Site 3). At each site, four cover crop treatments were grown between spring 1988 and spring 1989:

> **C+O** = combination of mammoth red clover at 9 kg/ha and oats (cv. 'Ogle') at 54 kg/ha, sown in spring 1988. Just prior to sowing, clover was inoculated with *Rhizobium trifolii*. Oats were mowed after heading, and clover was grown until spring 1989.
>
> **RG** = Italian ryegrass at 39 kg/ha sown in spring 1988, mowed once in mid summer, and grown until spring 1989.
>
> **BW/R** = buckwheat at 84 kg/ha sown in late spring 1988, turned under in late July or early August and replanted at the same rate, followed by winter rye at 126 kg/ha in September.
>
> **SG/R** = sudangrass (cv. 'Piper') at 39 kg/ha sown in late spring 1988, mowed once in midsummer, and followed in September by winter rye at 126 kg/ha.

Plot sizes, planting dates and methods of soil preparation, planting and crop management varied between sites according to each farm's soil conditions, available equipment and cultural practices.

At Site 2, a fifth treatment, consisting of managed weed fallow (**WF**), was included for comparison. A randomized complete block design was used with four replicates at Sites 1 and 2, and three replicates at Site 3.

Percentage ground cover by crop and weeds in each plot was estimated by observing the plot from each side, and recording the mean of the four estimates of cover. In fall 1988 and spring 1989, percent ground cover by residues (crop + weeds) was also recorded. Crop height was estimated as the mean of four random measurements from each plot. When cover crops were mowed, all clippings were left in place except small subsamples which were removed to determine dry matter content.

In spring 1989, cover crops were incorporated into the soil and lettuce seedlings were transplanted into the plots and grown to maturity. Weeds were collected from a measured area (0.6-0.8 m^2) in each plot, separated into grasses and broadleaf weeds, then dried and weighed. Eight to ten lettuce heads were harvested from each plot and weighed.

Site 1 (East Falmouth, MA)

The experiment was conducted in Merrimac sandy loam with pH 6.0, and low to medium levels of nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca). The field had been cropped with mixed vegetables during 1987, followed by a winter cover crop of rye + hairy vetch. Prior to planting cover crops, the soil was chisel plowed, rototilled and amended with 1,590 kg/ha rock phosphate (30% total P_2O_5). Individual plots measured 3.05 m by 3.05 m. On April 28th, 1988, clover + oats and Italian ryegrass were sown in treatments C+O and RG, respectively. On June 2nd, plots for BW/R and SG/R were hand raked about 5 cm deep to dislodge weeds, and buckwheat and sudangrass were sown, respectively. Seeds were broadcast, raked in about 1.3 cm deep (0.6 cm for clover), and rolled.

On July 27-29th, all crops were hand-sickled to a stubble height of 7.5-10 cm. Clippings from the central 1 m^2 of each plot were separated into cover crop and weeds, and weighed. A subsample (ca. 100 g) was weighed, dried for 72 h at 55-70 C and reweighed to determine percent dry matter. Remaining clippings were distributed evenly over the plot area. Buckwheat plots were spaded on July 29th and reseeded. On September 20th, rye was overseeded into treatments BW/R and SG/R, and vegetation was sickled and left in place. The rye seed lot used at this site and at Site 2 was later found to have 65% germination. However, rye was seeded at 126 kg ha^{-1}, whereas vegetable growers in the region commonly use 85-100 kg ha^{-1} (Christensen et al., 1978; Herbert, 1990, pers. comm). The plots received 82 kg ha^{-1} pure live seed, equivalent to a 100 kg ha^{-1} application of seed with 82% germination.

All plots were spaded on May 15-19th, 1989 and rototilled on May 31st. Lettuce seedlings (cv. 'Victoria') were transplanted into the plots on June 1st, spaced 25 cm apart in rows 30 cm apart. Each plant received 7 g bone meal (N-P_2O_5-K_2O = 4-12-0) at the bottom of the hole, and the crop was sidedressed on June 14th with 900 kg/ha of poultry manure compost (5-2-4). The fertilizers provided 81 kg/ha N, 128 kg/ha P_2O_5 and 36 kg/ha K_2O. No weeding or cultivation was performed. Lettuce and weeds were harvested and weighed on June 29th (two replicates) or July 4th (the other two replicates).

Site 2 (Belchertown, MA)

The experiment was established in a Hinkley fine sandy loam with pH 6.5, high K, and medium N, P and Ca. In 1987, onions (*Allium cepa* L.) and cabbage (*Brassica oleracea* L.) were grown, followed by an August planting of oats. The field was disked twice on

May 5th, 1988. Clover + oats and ryegrass were planted on May 8th, and buckwheat and sudangrass were planted on June 4-5th using the procedure described above. Individual plots measured 4.9 m by 3.8 m. On July 12th, all plots were rotary-mowed to a stubble height of ca. 7.5 cm. Treatments BW/R and WF (managed weeds) were rototilled on August 1st and buckwheat was replanted in BW/R. On September 9th, rye was overseeded into buckwheat and sudangrass, and all plots were mowed September 22nd.

Plots were mowed May 17th, 1989, disked twice on May 24th, then moldboard plowed and disked on June 1-2nd. On June 9th, Victoria lettuce seedlings were transplanted 30 cm apart in rows 30 cm apart. On July 12th, weed biomass samples were taken, and plots were hoed. The lettuce crop matured by July 19th, but was severely damaged by deer (*Odocoilus virginiana*) and head weights could not be measured.

Site 3 (Bellows Falls, VT)

The experiment was conducted on a Hadley silt loam in organic mixed vegetable production for eight years, with regular manure applications. It was very high in N and P, medium in K and Ca, with pH 7.1. Individual plots were 53 m by 10.7 m. The field was moldboard plowed, disked and springtooth harrowed prior to planting. Because of time constraints, all four treatments were planted on the same date, June 9th, 1988. All seeds except clover were broadcast and incorporated with the springtooth harrow. The clover was then broadcast, and the entire field was cultipacked.

On July 20th, weeds were counted by species in two randomly selected 0.25 m^2 quadrats within each plot. Immediately after, ryegrass, clover + oats, and sudangrass were mowed, and buckwheat was disked, reseeded and disked again. On August 28th, a randomly-selected 1.0 m^2 quadrat in each plot was hand-sickled (7.5-10 cm stubble height) and the clippings separated into crops and weeds, and weighed. On September 20th, treatments RG, BW/R and SG/R were disked and planted with rye. Ryegrass was treated in this way because it had established poorly. The rye seed used at this location had a higher germination (>80%), and was seeded at a rate of 63 rather than 126 kg/ha.

All plots were moldboard plowed on May 5th, then amended with 45 Mg/ha of a mixture of cow manure, hay and sawdust, and disked on May 12th. On May 30th, beds were prepared with a field cultivator and smoothing harrow, and 'Garnet' lettuce seedlings were transplanted. Weeds were managed by one pass with a rolling basket cultivator on June

6th, followed by shovel cultivators and within-row hand-hoeing on June 15th. On July 6th, lettuce and weeds were harvested and weighed.

Experiment 2

The experiment was planted in Site 1 on a Merrimac sandy loam with pH 6.3, medium-high P and very high K. The area had been used to grow a crop of spring peas (*Pisum sativum* L.), and was rototilled and planted on July 16th, 1988. Plots measuring 3.05 m by 3.05 m were planted with buckwheat, tartary buckwheat, Japanese millet or sudangrass, replicated four times in a randomized complete block. Percent cover by crops and weeds was estimated visually. On September 14-15th, crop and weed biomass were measured as described above, and crops were hand sickled to 7.5-10 cm and left in place. Percent cover by crop residue and weeds were recorded periodically through April 10th, 1989.

Statistical analysis

Data for each parameter were checked for homogeneity of variance using Bartlett's test (Steel & Torrie, 1960), and, if significantly ($p <0 .05$) heterogeneous, subjected to an appropriate transformation prior to analysis of variance. The arcsine square-root transformation was applied to percent ground cover data. The $\log_{10}X$ transformation was applied to biomass data for weeds in the lettuce crop, and for cover crop regrowth in lettuce at Site 1. Cover crop regrowth at the other two sites was negligible, and was not statistically analyzed. For parameters showing a significant F value ($p < 0.05$), treatment means were compared using Duncan's Multiple Range Test.

Because percent cover data for individual weed species at Sites 1 and 2 did not satisfy conditions for a valid analysis of variance, even when transformed, Friedman's nonparametric test for a randomized complete block design (*Ibid.*) was used to test the significance of trends observed.

Results

Experiment 1

At Site 1, treatment BW/R had significantly ($p < 0.05$) higher crop ground cover and lower weed cover in late July than other treatments (Figure 1). Aboveground biomass showed similar trends, though significant only for crop biomass (Table 1). The buckwheat was in full bloom and beginning to set seed, had formed a dense canopy and averaged 101 cm in height. Ryegrass was second in crop ground cover and weed suppression, reached 79 cm and set mature seed by late July. Clover + oats and sudangrass formed thinner stands through which many weeds grew, including crabgrass *(Digitaria* spp.), galinsoga, chickweed and red sorrel *(Rumex acetosella* L.). Oat heads had emerged but seeds were not mature, and the crop was 81 cm, while clover was only 13 cm. Sudangrass remained vegetative and reached 92 cm, but its leaves showed chlorotic streaks and purpling, which suggest N and P deficiencies.

[Table 1]

Due to drought, the second planting of buckwheat grew only 57 cm by September 14th, yet covered the ground and suppressed weeds significantly better than other treatments (Figure 1). Ryegrass regrew poorly after mowing, whereas red clover became well established. Crabgrass was the most prevalent weed in all treatments, and set seed before being killed by frost. Large individuals of pigweed, common lambsquarters, common ragweed (*Ambrosia artemesiifolia* L.) and galinsoga occurred sporadically in all treatments.

[Figure 1]

In November 1988 and May 1989, C+O had the greatest live crop cover (Figure 1). Clover top growth died in winter but regrew rapidly in April. Self-seeding of ryegrass was insufficient to reestablish the crop. Winter rye stands were thin, and in November showed a trend toward less cover after sudangrass than after buckwheat. In May, rye was significantly ($p < 0.05$) taller after buckwheat (62 cm) than after sudangrass (51 cm). Ryegrass and sudangrass both left persistent residues which contributed to ground coverage, whereas buckwheat residues decayed rapidly, leaving more of the soil surface exposed.

Although total weed cover did not differ significantly between treatments in May, species composition showed marked differences (Table 2). Common chickweed was the dominant weed in treatments BW/R and SG/R, but was much less abundant in RG and nearly absent from C+O. Substantially more red sorrel was observed in RG and SG/R than C+O and BW/R. Most of the weeds in C+O consisted of volunteer rye and hairy vetch, likely from the winter cover crop grown in 1987-88.

[Table 2]

At Site 2, red clover and ryegrass grew vigorously after mowing, and had significantly better ground cover than buckwheat in September 1988 (Figure 2). Both plantings of buckwheat had poor stands and reached average heights of 58 and 46 cm. Sudangrass grew slowly at first, but regrew rapidly after mowing, reaching 119 cm and covering 58% of the ground by September 9th. All cover crops significantly reduced weed cover compared to WF in July, though not in September probably because WF was rototilled in August. Major weeds included pigweed, common lambsquarters and crabgrass, with other grass weeds and galinsoga also present. In September, broadleaf weeds predominated in treatments BW/R and WF, whereas more grass weeds occurred in the other treatments, especially C+O. Again, crabgrass formed mature seed before frost.

[Figure 2]

Treatment C+O had the highest live crop ground cover, the lowest live weed cover and highest total cover, in October, April and May (Figure 2). Clover foliage died back in winter, but regrew vigorously in April and May. Much of the residue in this treatment consisted of dead crabgrass.

Although some ryegrass overwintered or self-seeded, live crop ground cover decreased sharply between September and April. Winter rye planted after buckwheat initially covered more ground than rye planted after sudangrass. In May, rye was significantly taller in BW/R (43 cm) than in SG/R (30 cm). Both ryegrass and sudangrass left much heavier and more persistent residues than buckwheat, which enhanced ground cover and possibly weed suppression in these treatments.

BW/R was the least effective cover crop treatment for suppressing winter weeds or covering the soil, although it was significantly better than WF in May. The large amount of bare soil in WF led to visible sheet and rill erosion in some plots. Decreasing amounts of erosion were noted in BW/R, SG/R and RG in that order, and essentially none in C+O.

Weed species composition in May differed substantially between treatments (Table 2). C+O, RG and SG/R greatly restricted ground cover by rough fleabane (*Erigeron strigosus* Muhl. ex Willd.) and shepherds purse [*Capsella bursa-pastoris* (L.) Medik.]. All four cover crops contained much less white cockle (*Lychnis alba* Mill.) than WF, but treatment differences fell just short of significance at the p=0.05 level. White clover (*Trifolium repens* L.) occurred in RG and SG/R, but was notably absent from BW/R and WF. No attempt was made to estimate white clover in the C+O treatment, because it is difficult to distinguish from red clover in the vegetative state.

At Site 3, the most common weeds observed on July 20th were pigweed, common lambsquarters, crabgrass, fall panicum (*Panicum dichotomiflorum* Michx.) and barnyardgrass (*Echinocloa crus-galli* (L.) Beauv.), with smaller amounts of common purslane (*Portulaca oleracea* L.), yellow nutsedge (*Cyperus esculentus* L.) and horsenettle (*Solanum carolinense* L.). BW/R and SG/R had significantly lower weed populations, especially pigweed, than C+O and RG (Table 3). Buckwheat was 76 to 91 cm tall and weeds beneath its canopy were small and etiolated.

[Table 3]

During August, only SG/R competed effectively against weeds (Table 3). Sudangrass regrew vigorously after mowing, reaching 137 cm by August 28th. The second planting of buckwheat emerged poorly, grew to 53 cm, and became infested with pigweed. Pigeons were observed feeding on the freshly sown seed, and dry weather probably hindered emergence of the remaining seed.

A heavy growth of crabgrass, other grass weeds and pigweed outcompeted RG and C+O. Some oats regrew after the midsummer mowing, probably because they were less mature than at Sites 1 and 2 due to late planting.

Weed levels in lettuce grown after different cover crops showed highly significant trends across the three sites (Table 4). Weed biomass (excluding cover crop regrowth) was least after BW/R, followed by SG/R, RG and C+O in that order. Both grass and broadleaf weeds contributed to this trend. Total competing vegetation (weeds + cover crop regrowth) was significantly greater after C+O than after SG/R and BW/R. At Site 1, considerable volunteer buckwheat grew in the BW/R treatment, probably because the first planting in 1988 had set seed. Volunteer buckwheat comprised 70% of the total, and may have depressed the growth of both lettuce and weeds. Regrowth of all cover crops at Sites 2 and 3 was negligible.

[Table 4]

Grass weeds predominated at Site 1, and consisted mostly of crabgrass except in treatment BW/R, in which they were about half crabgrass, and half quackgrass and other species. More broadleaf weeds occurred after RG and SG/R than after C+O and BW/R. Broadleaf weeds included pigweed, galinsoga, lambsquarters, common ragweed (*Ambrosia artemesiifolia* L.), common purslane, corn spurry (*Spergula arvensis* L.), carpetweed (*Mollugo verticillata* L.), smartweed (*Polygonum* sp.) and common chickweed.

At Site 2, broadleaf weeds predominated, especially pigweed, lambsquarters and carpetweed. Treatment differences were not significant, though trends were generally similar to the other two sites. Crabgrass was the most abundant grass. Biennial and perennial broadleaf weeds, including rough fleabane, white cockle, white clover and dock (*Rumex* spp.) occurred sporadically, with large amounts in two of the WF plots. At Site 3, two cultivations greatly suppressed weeds, yet treatment differences in grass and broadleaf weed biomass remained significant (Table 4).

At Site 1, cover crop treatment had no significant effect on lettuce head weight. At Site 3, lettuce grown after BW/R had significantly larger heads than after the three other treatments (Table 4).

Experiment 2

One heavy rain fell shortly after planting, followed by a prolonged spell of hot dry weather. All four crops performed well under these conditions and substantially outcompeted weeds (Figure 3). The grass cover crops showed a tendency toward higher crop biomass and lower weed biomass than the buckwheats, but the differences were not statistically significant (Table 5). Common purslane was initially the most prevalent weed in all treatments, with lesser amounts of pigweed, lambsquarters, galinsoga, ragweed and grass weeds. By September 14th, purslane was declining in all treatments, possibly because of shading from cover crops.

[Figure 3]

Tartary buckwheat was significantly shorter than other crops 29 days after planting (Table 5). Buckwheat was beginning to flower, whereas other crops were still vegetative.

Tartary buckwheat had reddish leaf margins and small pale spots on the leaves, while buckwheat had slight interveinal chlorosis and/or white speckling on some leaves.

In late August, buckwheat was in full bloom, tartary buckwheat was beginning to flower, and Japanese millet was heading, whereas sudangrass remained vegetative. By mid-September, buckwheat had mature seeds, tartary buckwheat was in full bloom with some seeds beginning to form, Japanese millet seeds were in the milk stage, and sudangrass had a few heads beginning to emerge from the boot. Sudangrass was much taller than the other crops on September 14th (Table 5). Buckwheat lodged severely, reducing the effective height and density of its canopy.

[Table 5]

After mowing, residues of the grass crops covered the ground more effectively and suppressed winter weeds (mostly common chickweed and grasses) better than residues of the buckwheats (Figure 5). By April, sudangrass had far more residue and less weed cover than did buckwheat or tartary buckwheat, with Japanese millet intermediate.

Discussion

Cover cropping is a standard practice on organic and low input farms, and our results suggest that the choice of cover cropping system may influence weed biomass, ground cover and flora. Treatment effects probably stemmed from different tillage and mowing schedules as well as cover crop species. In designing treatments, we attempted to simulate normal management practices for each cover crop rather than equalize tillage schedules across treatments. The two significant deviations from traditional practices were allowing buckwheat to self-seed at Site 1, and overseeding rye into buckwheat and sudangrass just prior to mowing in September at Sites 1 and 2. The latter was done to establish the winter crop without tillage, thus saving labor and fossil fuel. We also believed that weed germination and soil erosion would be minimized by omitting tillage and leaving summer crop residue on the surface.

Compared with a managed weed fallow, all four cover crops significantly suppressed weeds during winter and spring at Site 2. C+O appeared most effective and BW/R least so in suppressing common chickweed at Site 1 and total winter weed growth at Site 2. However, the reverse trend was observed after the cover crops were incorporated into the soil in May. At all three sites, weed biomass in lettuce was least after BW/R and greatest after C+O. Dominant weeds included crabgrass, pigweed and common lambsquarters, which are among the most prevalent weeds in vegetable crops in the Northeast (Schonbeck, 1988; Peters & Dunn, 1971).

At Site 1, the presence of self-seeded buckwheat may have suppressed other weeds in BW/R. However, across the three sites, biomass of weeds + cover crop regrowth after BW/R remained lower than that after C+O. BW/R entailed more frequent tillage (early spring, late spring and midsummer 1988; spring 1989) than C+O (early spring 1988; spring 1989), which suggests that additional tillage operations helped reduce weed levels in BW/R. In C+O, the clover's slow establishment permitted summer weeds, especially crabgrass, to set seed in 1988 at all three locations. Mowing did not remove the low seedheads of crabgrass, whereas tillage between the first and second plantings of buckwheat may have limited seed set. Each tillage would be expected to stimulate weed germination (Aldrich, 1984), but buckwheat and rye might interfere with weed reproduction, thus reducing the weed seed bank in the soil.

Two plantings of buckwheat grew vigorously and suppressed weeds, but the other four plantings suffered from drought and established poorly. Also, overseeding rye at Sites 1 and 2 was only partially successful, resulting in thin stands in spring 1989. At Site 1, rye seed from the same seed lot produced a satisfactory cover crop in an adjacent field where the seed was raked into tilled soil and rolled. Observations with other seed lots over three seasons have confirmed that rye must be incorporated 1-3 cm deep in the sandy soil at Site 1 to ensure a good stand. Had all buckwheat and rye plantings established well, weed levels in lettuce after BW/R might have been still lower. Farmer normally till the second buckwheat crop into the soil prior to planting rye, a practice which might further reduce seed set by late summer weeds as well as aiding rye establishment.

At Site 3, ryegrass and oats + mammoth red clover were planted late (early June), which may explain their failure at this location. Drought conditions in 1988 may have also retarded their establishment at the other sites, thus reducing their ability to suppress weeds. During 1989, a season with ample rainfall, spring-planted mammoth red clover in western Massachusetts had a nearly closed canopy with few weeds by mid-July. Although 1988 was considered an atypical season, climatological studies indicate that global climate change may increase the frequency of such droughts in the future (Schneider, 1990); thus information on crops that perform well under such conditions might become increasingly important.

Italian ryegrass has been described as "annual to biennial" (U. S. Department of Agriculture, 1948), but in this study, it formed seed heads early in the summer and showed little regrowth or reseeding after mowing. Although its residues suppressed winter weeds at Site 2, Italian ryegrass does not appear well-suited as a year-long cover crop for weed control.

Sudangrass grew poorly at Site 1, slightly better at Site 2, and vigorously at Site 3, which reflects this crop's requirement for ample soil N and P. In contrast, the first planting of buckwheat performed equally well at Sites 1 and 3, outcompeting weeds better than all other treatments. However, replanting buckwheat during hot summer weather appears risky, especially if seeds are not drilled and are planted into dry soil. Also, buckwheat has an extremely short life cycle, necessitating tilling and replanting every 4-6 weeks to ensure continued weed suppression and to prevent self-seeding. Volunteer buckwheat in lettuce at Site 1 suggests that letting buckwheat self-seed to effect the second planting may result in buckwheat becoming a weed problem the following year.

Weed + cover crop regrowth biomass in lettuce in treatments SG/R and BW/R were similar. However, lettuce yields were highest after BW/R at Site 3, and not significantly affected at Site 1 despite shading from volunteer buckwheat . Buckwheat is known to make P more available to succeeding crops (Drake & Steckel, 1955); however soil available P was already very high at Site 3. Lettuce is quite sensitive to allelopathy (Putnam *et al.,* 1983), and may be more adversely affected by sudangrass than by buckwheat. At Sites 1 and 2, rye established more quickly and grew taller in BW/R than in SG/R. This suggests an allelopathic effect by sudangrass residue, which may have persisted into the lettuce crop. Similarly, lettuce following RG and C+O may have suffered allelopathy from ryegrass and from clover and/or crabgrass residues, respectively.

One disadvantage to the BW/R treatment is cost. At 1988-90 prices (Schonbeck & DeGregorio, 1990), seeds for the two sowings of buckwheat and one of rye cost $128/ha, compared to seed costs of $60/ha for SG/R, $36/ha for C+O and $26/ha for RG. Also, the greater number of operations in BW/R would add fuel and labor costs.

Species composition of winter weeds responded dramatically to the treatments. Common chickweed has been reported to germinate in response to late summer tillage (Schonbeck, 1988) and was abundant at Site 1 in BW/R (last tilled July 29th) and SG/R (tilled June 2nd) but not in RG or C+O (tilled April 28th). However, the occurrence of red sorrel only in RG and SG/R, seems related not to tillage, but to the presence of heavy grass residues or specific cover crops.

At Site 2, winter weed flora may be related to time of last tillage, i.e., August 1st for BW/R and WF versus May or early June for the other treatments. Late summer rototilling seemed to discourage white clover and to stimulate rough fleabane, shepherds purse and possibly white cockle. The farmers at this location considered rough fleabane and white cockle serious weeds because of their large taproots. Our results suggest that cover crops and appropriate timing of tillage can control these weeds.

BW/R afforded least protection against winter erosion, largely because buckwheat residue decayed rapidly compared to that of sudangrass and ryegrass. Red clover provided living cover later in fall and earlier in spring than other treatments. Had the rye established better, treatment BW/R would have provided more winter soil protection.

Experiment 2 confirmed that, in comparison to buckwheat, sudangrass has a longer life cycle, more persistent weed-suppressing residues, and possibly higher biomass potential, but also greater need for warm and fertile soil. The soil in this trial was initially warmer and higher in P than the soil in Experiment 1 at the same site. Sudangrass growth reflected this difference, whereas buckwheat grew equally well in both experiments. Tartary buckwheat had a longer life cycle than buckwheat, but was not more competitive against weeds. Japanese millet showed no advantages over sudangrass in this experiment, but the millet is better adapted to cool, wet soils, and has outyielded sudangrass in New Hampshire (Koch & Mitchell, 1988).

Conclusions

1) In this study, two successive plantings of buckwheat followed by winter rye were most effective in reducing weed levels in a subsequent vegetable crop. Concerns include high cost, buckwheat's short life cycle and self-seeding potential, and difficulty in establishment during hot weather on dry soils. Tartary buckwheat has a longer life cycle, but its slower initial growth may make it less competitive against weeds.

2) Sudangrass followed by rye was second in effectiveness. Disadvantages include requirements for high soil fertility and warm temperatures for sudangrass, and possible allelopathic effects of both crops against vegetables, especially if the latter are direct-seeded. In cooler, heavier soils, Japanese millet may be a more appropriate summer crop.

3) Mammoth red clover sown with a companion crop of oats provided excellent soil protection and winter weed suppression, supported microbial N fixation, and entailed lower costs for seeds and field operations. Disadvantages include sensitivity to heat and drought, and failure to prevent low-growing summer weeds from setting seed.

4) Spring-sown Italian ryegrass behaved as a short-lived annual, and did not effectively reseed itself, and thus did not provide year-long living cover. However, its residues provided a degree of soil protection and weed suppression through the winter.

5) Frequency and timing of tillage appeared to modulate the effect of different cover crops on weeds, especially species composition of winter weeds.

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Table 1. Crop and weed biomass in four cover crops at Site 1 on July 28, 1988.

Treatment[x]	Dry weight, kg ha^{-1}		
	Crop	Weed	Total
C+O	2,660 a[y]	1,280	3,940
RG	2,270 ab	730	3,000
BW/R	3,540 a	350	3,890
SG/R	1,350 b	1,560	2,920
F ratio[z]	5.53 *	3.70 ns	2.63 ns

[x] C+O = mammoth red clover + oats; RG = Italian ryegrass; BW/R = buckwheat followed by rye; SG/R = sudangrass followed by rye.

[y] Means within a column not followed by the same letter are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test.

[z] Variance ratio. Significance of treatment effects: ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$.

Table 2. Weed species composition in four cover crops at two sites in May 1989.

Site 1:

	Ground cover (%)							
Treatment[x]	Common Chickweed	Red Sorrel	Vol. Rye	Vol. Vetch	White Clover	Grass Weeds	Other	Total[v]
C+O	0	0	9	15	-[w]	2	0	26
RG	4	8	2	16	5	5	2	41
BW/R	28	0	-	3	0	3	4	39
SG/R	20	8	-	2	0	2	2	35
Friedman test[u]	*	*	ns	ns	ns	ns	ns	
F ratio[z]								1.86 ns

Site 2:

	Ground cover (%)						
Treatment[x]	White Cockle	Rough Fleabane	Shepherds Purse	White Clover	Dandelion	Other	Total[v]
C+O	1	0	0	-[w]	1	0	3 d
RG	2	0	0	8	3	0	13 c
BW/R	1	12	7	0	0	3	24 b
SG/R	1	4	0	5	1	1	12 c
WF	12	18	12	0	1	4	48 a
Friedman test[u]	ns	**	*	*	ns	ns	
F ratio[z]							1.86 ns

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[u] Significance level according to Friedman's nonparametric test for randomized complete block: ns = $p>0.05$; * = $p<0.05$; ** = $p<0.01$.

[v] Total may differ slightly from sum of individual species because of rounding error.

[w] No attempt was made to distinguish white clover from red clover.

[x] C+O = mammoth red clover + oats; RG = Italian ryegrass; BW/R = buckwheat followed by rye; SG/R = sudangrass followed by rye; WF = managed weed fallow.

[y, z] See footnotes, Table 1.

Table 3. Weed populations, crop and weed ground cover and biomass in four cover crops at Site 3.

	Weeds (1000's ha^{-1}) on July 20, 1988				
Treatment[x]	Pigweeds	Lambs-quarters	Annual Grasses	Other	Total
C+O	1,950 a[y]	250	5,600	50	2,850 a
RG	1,030 b	290	1,030	30	2,380 a
BW/R	470 c	130	650	110	1,360 b
SG/R	490 c	250	760	10	1,520 b
Control[w]	2,600	600	2,200	0	5,400
F ratio[z]	29.0 **	<1.0 ns	2.35 ns		16.5 **

	Ground cover (%) on August 28th			Dry weight (kg ha-1) on August 28th		
Treatment[x]	Crop	Weeds	Total[v]	Crop	Weeds	Total
C+O	11 b	87 a	98 a	730 b	3,310 b	4,040 a
RG	9 b	87 a	96 a	280 b	4,340 a	4,610 a
BW/R	21 b	48 b	70 b	170 b	660 c	830 b
SG/R	85 a	12 c	97 a	2,920 a	970 c	3,890 a
F ratio[z]	60.0 **	132.9 **	24.1 **	16.4 **	42.5 **	53.7 **

[v] See footnote, Table 2

[w] Unplanted area adjacent to experiment, not replicated due to constraints of commercial farming, and not included in statistical analysis.

[x,y,z] See footnotes, Table 1.

Table 4. Weed and cover crop regrowth dry weight, and lettuce head weight following cover crops at three sites.

	Dry weight (kg ha^{-1})					
Site & Treatment[x]	Grass weeds	Broadleaf weeds	Weed total	Cover crop regrowth	Total[v]	Lettuce fresh weight, g head^{-1}
Site 1						
C+O	488 a[y]	28 b	516 a	20 b	537	129
RG	274 ab	86 a	360 b	4 c	364	157
BW/R	118 c	30 b	148 c	345 a	492	145
SG/R	207 b	73 a	280 b	1 c	281	169
F ratio[z]	12.0 **	21.9 **	30.9 **	95.8 **	3.84 ns	<1.0 ns
Site 2						
C+O	146	350	495	0	495	-[w]
RG	40	255	295	1	296	-
BW/R	30	150	180	2	182	-
SG/R	52	206	258	1	259	-
WF	66	336	402	-	402	-
F ratio[z]	1.77 ns	2.24 ns	2.73 ns	-[u]	2.68 ns	
Site 3						
C+O	39 a	38 a	77 a	0	77 a	365 b
RG	22 ab	35 a	57 a	0	57 a	346 b
BW/R	3 c	17 b	20 b	0	20 b	459 a
SG/R	11 bc	11 c	22 b	0	22 b	315 b
F ratio[z]	12.0 **	15.8 **	15.2 **	-[u]	15.2 **	7.96 *
Pooled means for 3 sites						
C+O	241 a	148 a	389 a	7	396 a	
RG	120 b	134 a	254 b	2	256 ab	
BW/R	55 c	70 b	125 d	126	251 b	
SG/R	97 b	104 ab	201 c	1	202 b	
F ratio[z]	14.5 **	5.62 **	25.0 **	-[u]	6.75 **	

[u] Analysis of variance not done.

[v,x] See footnotes, Table 2.

[w] Lettuce destroyed by deer at Site 2.

[y,z] See footnotes, Table 1.

Table 5. Crop height and crop and weed dry weight in four summer cover crops sown July 16, 1988 at Site 1.

	Crop height (cm)		Dry weight (kg ha-1)		
Crop[x]	Aug 13th	Sept 14th	Crop	Weeds	Total
BW	51 ab[y]	[w]104 b	3,510	650	4,160
TBW	28 c	97 b	3,100	810	3,900
SG	64 a	157 a	5,670	350	6,020
JM	43 b	112 b	4,550	480	5,030
F ratio[z]	13.6 **	11.7 **	2.69 ns	<1.0 ns	2.63 ns

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[w] Length from base to top of stem. Crop lodged, reducing mean canopy height to 64 cm.

[x] BW = buckwheat; TBW = tartary buckwheat; SG = sudangrass; JM = Japanese millet.

[y,z] See footnotes, Table 1.

Figure captions

Figure 1. Percent ground cover by crop, weeds and residues in cover crops at Site 1. C+O = mammoth red clover + oats; RG = Italian ryegrass; BW/R = buckwheat followed by rye; SG/R = sudangrass followed by rye.

Figure 2. Percent ground cover by crop, weeds and residues in cover crops at Site 2. C+O = mammoth red clover + oats; RG = Italian ryegrass; BW/R = buckwheat followed by rye; SG/R = sudangrass followed by rye; WF = managed weed fallow.

Figure 3. Percent ground cover by crop, weeds and residues in summer cover crops at Site 1. BW = buckwheat; TBW = tartary buckwheat; SG = sudangrass; JM = Japanese millet.

Figure 1

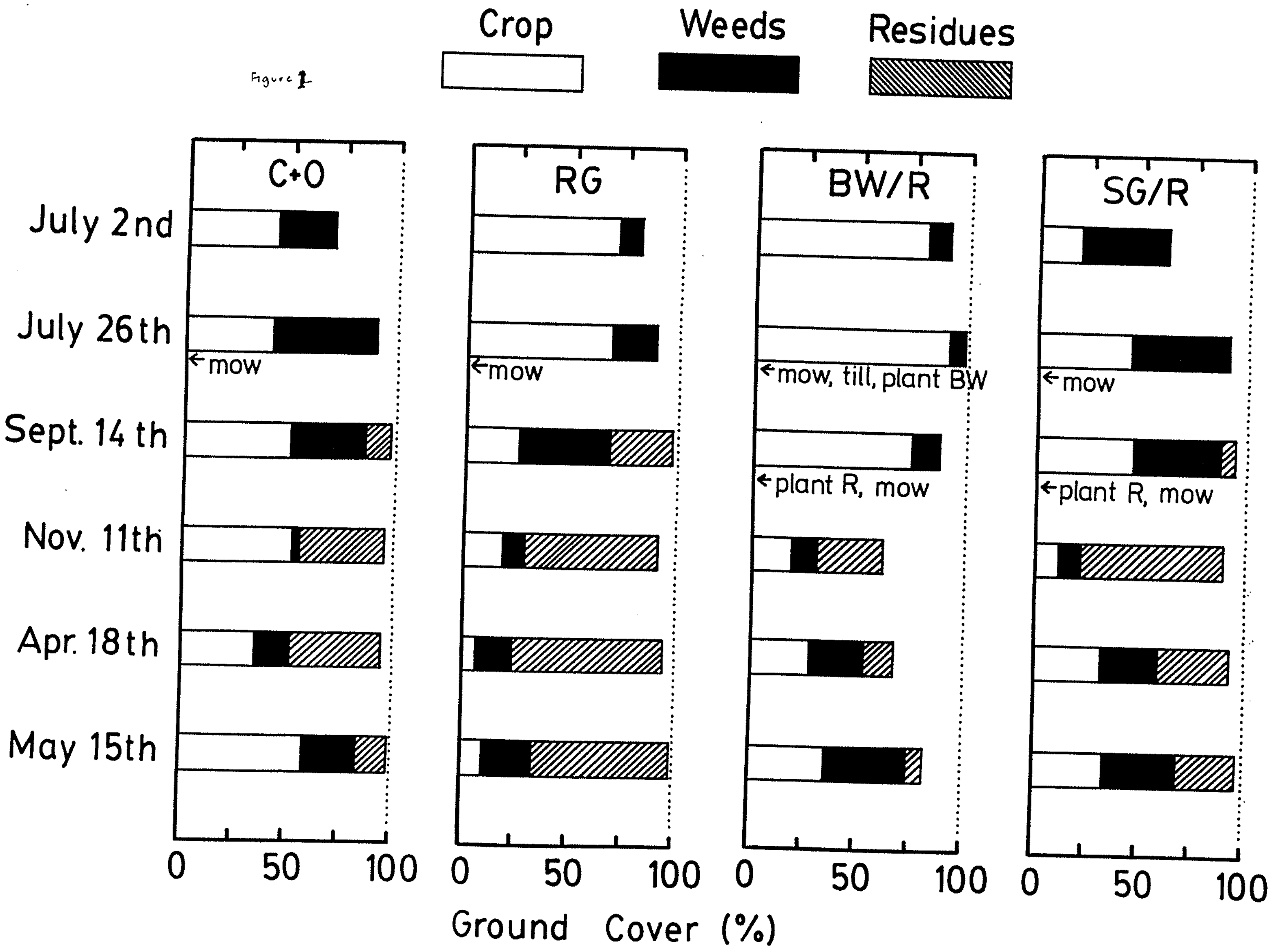
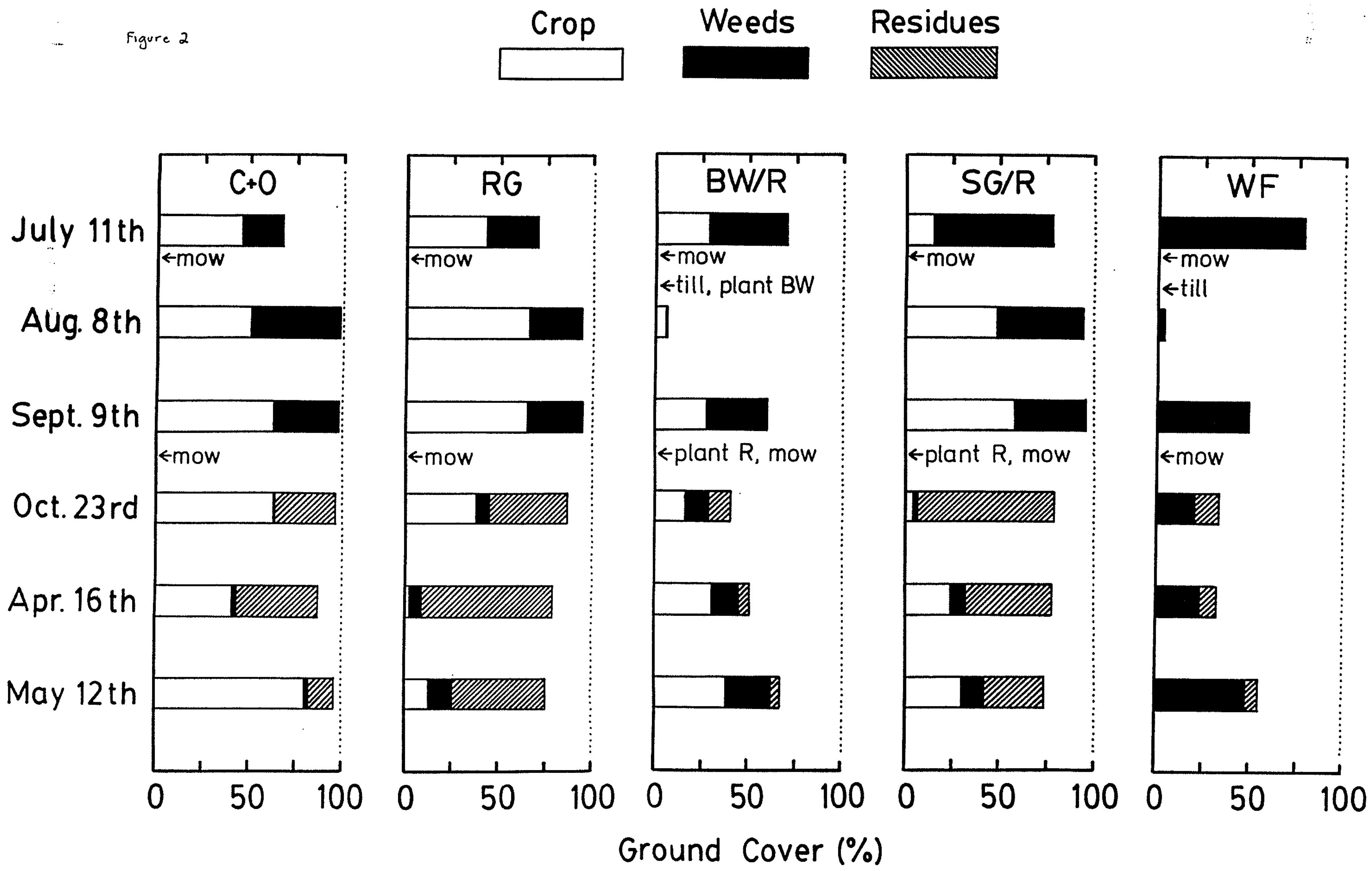
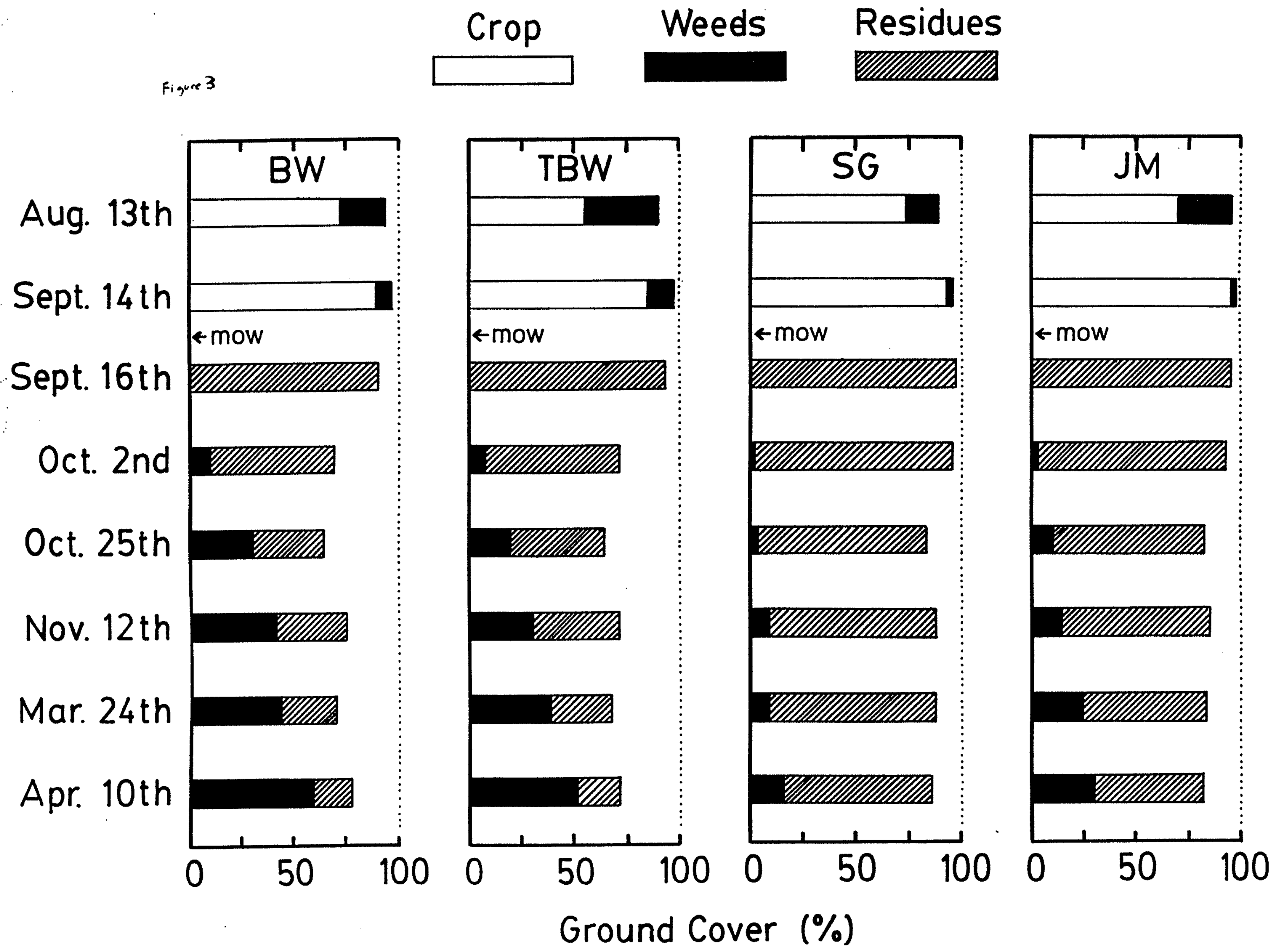

Crop
Weeds
Residues
C+O
RG
BW/R
SG/R
July 2nd
July 26th
Sept. 14 th
Nov. 11th
Apr. 18th
May 15th
mow
mow
mow, till, plant BW
mow
plant R, mow
plant R, mow
0
50
100
Ground Cover (%)

Figure 2



Crop
Weeds
Residues
C+0
RG
BW/R
SG/R
WF
July 11th
Aug. 8th
Sept. 9th
Oct. 23rd
Apr. 16th
May 12th
←mow
←till, plant BW
←plant R, mow
←till
0
50
100
Ground Cover (%)

Figure 3


Crop
Weeds
Residues
BW
TBW
SG
JM
Aug. 13th
Sept. 14th
Sept. 16th
Oct. 2nd
Oct. 25th
Nov. 12th
Mar. 24th
Apr. 10th
← mow
0
50
100
Ground Cover (%)

Effects of Different Cover Cropping Systems on Broccoli and Cabbage. 1. Nitrogen, Soil Temperature and Moisture, and Vegetable Yields.

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Abstract.

Vegetable growers in the northeastern United States commonly use cereal rye as a winter cover crop, but rye does not fix nitrogen (N) and may tie up N after it is incorporated into the soil. In this study, yield effects on broccoli and cabbage by cover crops of hairy vetch, grown alone or in combination with rye, were compared to rye alone and a no-cover control at four locations in New England. Cover crops were grown until flowering and were either tilled in or mowed and left on the surface. Brassica seedlings were transplanted into the plots, grown to maturity and assessed for yield, yield components and foliar nutrients. Soil moisture, temperature and inorganic N were measured at one site.

Cover crops of vetch and vetch + rye consistently produced higher broccoli and cabbage yields than rye alone or no cover. Foliar N concentrations indicated that N contribution was a major factor in the yield response, although cover crops sometimes affected phosphorus (P), cation and micronutrient concentrations. Rye alone tended to reduce yields, probably through N tie-up.

No-till cover crop management (mowing) severely cut brassica yields at two locations with silt-loam soils, but did not affect yield at a third location with light, sandy soil. At the latter site, soil incorporation of vetch or vetch + rye raised soil nitrate-N levels to 150 kg ha-1, which apparently exceeded crop needs. Mowed cover crops significantly lowered soil temperature and conserved soil moisture.

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Introduction

Cover cropping is considered a cornerstone of sustainable agriculture (Liebhardt *et al.*, 1989) because this practice can protect the soil from erosion, add organic matter and in the case of legumes, nitrogen (N), and suppress weeds with minimal inputs. Most vegetable growers in the northeastern United States use cover crops, especially winter rye (*Secale cereale* L) (Schonbeck, 1988). Rye is extremely cold-hardy, can be planted late in the fall, provides good wintertime soil protection and weed suppression, and produces considerable organic matter. However, rye does not fix N and may immobilize soil N, thus increasing the need for manure or N fertilizer on the following crop (Wagger, 1989b; Schonbeck, 1988).

Most vegetable crops utilize 50 to 150 kg N ha^{-1}, and N is the soil nutrient most frequently deficient (Parnes, 1986). N fertilizers represent a third of the fossil fuel used in conventional crop production (Verstraete, 1981, Phillips et al., 1980, Mitchell, undated) and nitrate (NO_3^-) leached from fertilized fields has become a serious pollutant of groundwater in agricultural regions (Papendick, *et al.*, 1987; National Research Council, 1989). Leguminous green manures use solar energy to fix N, and legume N is released more slowly than soluble fertilizer N, thus reducing the likelihood of NO_3^- leaching (Radke *et al.*, 1988). Although not all of the legume N is released to the following crop, the fertilizer equivalent of legume green manures commonly ranges from 40 to 135 kg ha^{-1} (Smith *et al.*, 1987; Blevins *et al*, 1990)

In the Northeast, mammoth red clover (*Trifolium pratense* L), biennial sweetclover (*Melilotus* spp.) and alfalfa (*Medicago sativa* L.) are included in crop rotations to add N (Schonbeck, 1988). However, these crops take land out of production for a year or longer, which vegetable growers with limited land area often cannot afford. Winter annual legumes such as hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.) and Austrian winter field peas [*Pisum sativum* ssp. *arvense* (L.) Poir.] can add N and organic matter without interrupting cash cropping for an entire season. In the 1980s, few growers in New York and New England used these cover crops because of doubts about their winter hardiness. However, USDA bulletins (1923, 1968) state that hairy vetch is winterhardy in most of the United States, and vetch has performed well in Ithaca, New York (Sarrantonio & Scott, 1988). Crimson clover has overwintered in Storrs, Connecticut (DeGregorio *et al.*, 198?) and Cape Cod, MA (Schonbeck & DeGregorio, 1989).

Vetch and other winter annual legumes have provided most or all the N required by field corn (*Zea mays* L.) and/or grain sorghum [*Sorghum bicolor* (L.) Moench] in Maryland (Holderbaum *et al.*, 1990), Delaware (Mitchell & Teel, 1977), North Carolina (Wagger, 1989b), Georgia (Hargrove, 1986; Ott & Hargrove, 1989), and Kentucky (Utomo *et al.*, 1990; Blevins *et al.*, 1990). However, Sarrantonio & Scott (1988) reported a relatively small N contribution to corn by hairy vetch in New York. Winter annual legumes have also shown promise for vegetables including snap beans (*Phaseolus vulgaris* L.) in Maryland (Skarphol *et al.*, 1987), sweet corn (*Zea mays* L.) in Connecticut (DeGregorio *et al.*, 1991) cabbage (*Brassica oleracea* var. *capitata* L.) in California (Gliessman, 1988), tomatoes (*Lycopersicon esculentum* Mill.) in Tennessee (Shelby *et al*., 1988), and beets (*Beta vulgaris* L.) though not lettuce (*Lactuca sativa* L.) or onions (*Allium cepa* L.) in Connecticut (Janes, 1955). More information is needed on winter annual legumes for vegetables in the Northeast, where colder climates and shorter growing seasons may affect total N fixation and subsequent mineralization.

Legumes grown with a cereal grain or other grass (eg. hairy vetch with rye) may produce more organic matter, protect the soil and suppress weeds better than either one grown alone (Holderbaum *et al.*, 1990; Gliessman, 1987). The fibrous root systems of grasses may reduce frost heaving, which is a major cause of winterkilling in legumes (Sheaffer *et al.*, 1990), and rye stems provide a support for vetch vines to climb, which may enhance light interception and therefore biomass production and weed suppression. Compared to all-legume green manures, legume + cereal combinations mineralize N more slowly, and sometimes give a smaller yield boost to the following row crop (Skarphol *et al.*, 1987; Holderbaum *et al.*, 1990; Smith *et al.*, 1987). However, substantial N leaching losses have been reported after an all-legume green manure is tilled in, especially on light, sandy soils (Radke et al., 1988). Also, in California, a cover crop of fava bean (*Vicia faba* L.) + cereal grains has resulted in significantly higher soil organic matter and organic N levels than fava bean alone (Gliessman, 1987), which suggests that a grass + legume combination may *improve* N efficiency in some circumstances.

Cover crops are normally turned under before planting vegetables, but an increasing number of farmers have adopted no-tillage systems to conserve soil and reduce fuel, machinery and labor costs (Phillips *et al.*, 1980; Mitchell & Teel, 1977). Although legume residues on the surface release inorganic N more slowly than incorporated residues (Smith, 1987; Lemon *et al.*, 1990; Skarphol *et al.*, 1987), legumes managed no-till have given excellent results with snap bean (Skarphol *et al.*, 1987) as well as corn (Holderbaum *et al.*, 1990; Ott & Hargrove, 1989) and sorghum (Mitchell & Teel, 1977). In these studies, as in most no-till applications, the cover crops were killed with paraquat, which is very hazardous to the applicator (Sine, 1991) and potentially damaging to nontarget organisms (Kosinski, 1984; Anon., 1975). Rye, hairy vetch and crimson clover can be killed by mowing close to the ground after they have begun to flower (DeGregorio *et al.*, 1991; Dabney & Griffin, 1987), and a no-till no-herbicide management system has been developed at Virginia Polytechnic Institute for small-scale tomato and cucurbit production after rye + hairy vetch (Luna & Rutherford, undated).

Yield responses of corn to legume cover crops sometime indicate benefits in addition to the N input (Wagger, 1989b; Smith *et al.*, 1987). Cover crops have been reported to bring phosphorus (P), potassium (K) and boron (B) to the surface in no-till corn (Mitchell, undated), and cation nutrient contents of vetch and wheat (*Triticum aestivum* L.) residues appear to complement each other (Shelby *et al.*, 1988). The organic mulch left by no-till managed cover crops helps retain soil moisture, although growing the cover crop to flowering (as needed for successful mow-killing) may consume additional moisture in the spring (Munawar *et al.*, 1990). Moisture consumption by a clover cover crop has seriously restricted yield in no-till sorghum in Texas (Lemon *et al.*, 1990) Organic mulches also lower soil temperature, which has reduced early-season yield in tomatoes transplanted into mow-killed rye + hairy vetch in Massachusetts (Schonbeck & Doherty, 1989). However, soil cooling might be advantageous to late plantings of brassicas and other cool-season crops.

We conducted an exploratory field study at four New England locations to evaluate different cover cropping systems for broccoli (*Brassica oleracea* var. *botrytis* L.) and cabbage in the Northeast bioregion. Our objectives were to compare hairy vetch, alone and in combination with rye versus rye alone, and mowing versus soil incorporation of the cover crop just prior to transplanting the brassicas into the field. This paper reports treatment effects on cover crop biomass and nitrogen, vegetable yield and foliar nutrients, and soil temperature and moisture. Effects on weeds and other pests are discussed in the following article (Mangan et al, 1991).

Materials and Methods

Studies were conducted at the New Alchemy Institute's market garden in East Falmouth, MA (Site 1), University of Massachusetts Agricultural Experiment Station in South Deerfield, MA (Site 2) and on commercial farms in Hadley, MA (Site 3) and Pownal, ME (Site 4). At each site, treatments were arranged in a randomized complete block design replicated three times.

Site 1 East Falmouth, Massachusetts

During 1988-89, a preliminary experiment was conducted to evaluate the feasibility of mow-killed winter annual cover crops for broccoli. Crops were grown in a Merrimac sandy loam with pH 6.0 and low to medium levels of N, P, K and calcium (Ca). The area had been in organic vegetable production (soil amended only with composted manure, leaf mold and ca. 4.5 Mg ha^{-1} agricultural limestone) during the 1987 and 1988 growing seasons. Cover crops and seeding rates (kg ha^{-1}) were: rye alone (126); hairy vetch (45) + rye (63); crimson clover (22) + rye (63); and Austrian winter peas (112) + rye (63). Plots measured 3.4 m by 2.8 m. On August 26-27, 1988, cover crops were broadcast, raked in ca 2 cm deep (1 cm for clover) and rolled.

On May 25-28, 1989, the aboveground vegetation in a 1 m^2 quadrat near the center of each plot was cut with a sickle (stubble height ca. 5 cm), separated into rye, legume and weeds, and weighed. Weighed subsamples (ca. 100 g fresh wt.) of each were dried for 72 hr at 55-70°C to determine percent dry matter and total kjeldahl N. Remaining vegetation was returned to the plot, the rest of the plot was sickled, and clippings were distributed evenly over the plot surface. Just prior to spreading the mulch, five soil cores (0-15 cm) were taken from each plot, pooled, weighed, dried to constant weight at 70°C, and reweighed to determine moisture content.

On June 3, broccoli (cv. 'Emperor') seedlings were transplanted into the plots without tillage. For each plant, a hole ca 6 cm diameter by 10 cm deep was dug with a trowel, 14 g bonemeal (4-12-0 N:P_2O_5:K_2O total analysis) was mixed into the soil at the bottom, then the seedling was planted and watered in with 240 mL tap water. Plants were set 51 cm apart in rows 69 cm apart, and each plot contained 4 rows of 6 plants each. Rabbits severely damaged some of the plants, shortly after transplanting, and these were replaced June 12. On July 3, each plant was side-dressed with dried composted poultry manure (5-2-4) and irrigated with 420 mL water. Total nutrients applied in bone meal and manure were (kg ha^{-1}) 36 N, 59 P_2O_5 and 15 K_2O.

bottom of the planting hole, and was watered in with 240 mL of a 64-fold dilution of fish fertilizer (2-4-2). Total nutrients applied at planting were (kg ha^{-1}): 7 N, 59 P_2O_5 and 2 K_2O. On July 11, each plant in treatment 11 was side dressed with 16.5 g bloodmeal (12-0-0), and each plant in treatments 3, 6, 9 and 12 received 33 grams bloodmeal. These rates corresponded to 56 and 112 kg N ha^{-1}. The crop was irrigated on June 28 and again August 5-6.

Weeds were pulled manually on July 3-5 and again July 30-31. Weeds from a 1 m^2 area were separated by taxon and dry weight was determined (Mangan *et al.*, 1991). Slugs and cutworms were hand-picked; other pests were negligible. An outbreak of downy mildew (*Pernospora parasitica*) was diagnosed and controlled effectively with an application of Kocide [a formulation of $Cu(OH)_2$] at 2 kg ha^{-1} on July 30.

Soil temperatures were measured at 7.5 cm in each plot on 11 dates between June 21 and July 18 under various weather conditions. On June 6-8, July 2 and August 14, three or four soil cores (0-30 cm) were taken from each plot and pooled for moisture and inorganic N determination. Soil samples were also taken on July 14 from treatments 1, 2, 4, 5, 7, 8 and 10 for moisture determination only.

Each pooled soil sample was mixed thoroughly, a 20 g subsample was extracted with 100 mL 1M KCl, and a 50 g subsample was dried at 105°C for 24 hr to determine dry weight. Ammonum N (NH_4^+-N) in the extract was determined using an ammonia electrode, and total inorganic N was estimated by reducing NO_3^- to ammonia (NH_3) with Devarda's alloy using a procedure modified from Keeney & Nelson (1982) as described elsewhere (Schonbeck *et al.*, 1991). Because the soil was well aerated at all sampling dates, nitrite (NO_2^-) was assumed negligible (Power, 1981), and NO_3^--N was calculated by subtracting NH_4^+-N from total inorganic N.

Between August 7 and August 21, plots were examined daily and main heads were harvested as they became market-ready. Heads were trimmed to a length of 15 cm, weighed, and their diameter measured. Yield assessments were done on the inner two rows, excluding the end plants, for a total of 16 plants per plot. The uppermost leaves having a blade length of 15 cm or more were taken from four heads in each plot for total nutrient analysis. On August 23, the 16 harvest plants were pulled, soil was shaken off the roots, and field and dry weights and total N were determined.

Site 2. South Deerfield, Massachusetts

A 3 x 2 x 2 factorial experiment was conducted, the factors being cover crop [rye (63 kg ha^{-1}) + vetch (45 kg ha^{-1}), rye alone (101 kg

Pests (primarily slugs, European earwigs and climbing cutworms) were controlled by hand picking and insecticidal soap. Weed pressure was light, and no hoeing or pulling of weeds was done. On 5 dates between June 23 and July 7, soil temperatures were taken at 7.5 cm depth in each plot, to determine whether mulches from different cover crops had differential effects on soil temperature.

Broccoli yield assessments were conducted on the eight central plants in each plot (4 plants from each of the two inner rows). Main heads of broccoli were harvested July 22-31, trimmed for market, weighed and measured (head diameter). Because heads from replacement plants (transplanted June 12) were much smaller than heads from original plants (transplanted June 3), plot means for head weight and head diameter were calculated for original plants only.

The next-to-uppermost leaf trimmed at harvest from each of four heads per plot (leaf blade length 12-20 cm) was collected and dried. Leaves from each plot were pooled and submitted to the Soil and Plant Tissue Testing Laboratory (Univ. Massachusetts, Amherst, MA) for complete nutrient analysis.

In 1989-90, nine combinations of cover crop, management method and N fertilization were evaluated against a N rate series without cover crop (Table 1). The experiment was conducted on a Merrimac sandy loam with pH 5.8, testing low in P, medium-low in CA, medium-high in N and very high in K and Mg. The field was amended in spring 1989 with ca 45 Mg ha^{-1} leaf mold and 1.8 Mg ha^{-1} rock phosphate (0-30-0 total analysis). Buckwheat (*Fagopyrum esculentum* Moench.) was planted in late May and incorporated into the soil July 5 to increase P availability (Drake & Steckel, 1955). The field was rototilled August 5 and again August 20 to reduce weed pressure and prepare the seedbed, and cover crops were planted August 26-27, 1989 as described above. Plots measured 3.0 m by 4.9 m.

On June 5-7, 1990, aboveground vegetation was collected from a 1 m^2 area near the center of each plot to determine biomass and N as described above. On June 13-14, plots were mowed with a sicklebar mower at a stubble height of ca. 5 cm. For treatments 1,3,4,6,7 and 9, clippings were distributed evenly over the plot surface. For treatments 2,5 and 8, clippings were chopped and spread evenly, then plots were spaded and rototilled between June 15 and 18. Treatments 10, 11 and 12 were also spaded and rototilled at this time.

On June 18-19, 'Emperor' broccoli seedlings were transplanted 46 cm apart in four rows spaced 76 cm apart running lengthwise through each plot. Each plant received 17 g bonemeal (1-11-0) in the

ha^{-1}) and no cover]; tillage (conventional = cover crop tilled in, and no-till = cover crop mowed) and nitrogen (0 or 112 kg ha^{-1} as NH_4NO_3). The experiment was conducted on a Hadley silt loam. Plots were 2.4 m wide by 6.1 m long. The cover crops were planted on August 25, 1989 with a cone seeder grain drill with 14 rows per plot spaced 18 cm apart.

On May 22, 1990, cover crops were sickle-bar mowed. Residues were left on the surface for no-till, and incorporated with a PTO-driven rotovator for conventional till. Aboveground vegetation was collected from 1 m^2 quadrats in three rye plots and three rye+ vetch plots to estimate cover crop biomass and N. On May 23, broccoli seedlings (cv 'Saga') were transplanted into the plots, spaced 46 cm apart in three rows 76 cm apart running lengthwise through each plot.

Early-season weeds were controlled in conventionally tilled treatments with DCPA applied at 11 kg ha^{-1} on May 15, and in no-till treatments with 1.7 L ha^{-1} Sethoxydim + 2.3 L ha^{-1} crop oil applied June 12. NH_4NO_3 was applied to appropriate treatments at 112 kg ha^{-1} on June 20.

Soil temperature probes were placed at 2.5, 7.5 and 12.5 cm depths in two plots each of conventional and no-till no cover treatments, no-till rye , and no-till vetch + rye. Soil temperatures were recorded during May 28-29.

Yield assessments were conducted on ten plants from the middle row of each plot. Broccoli heads were examined daily between July 17 and August 30, and were harvested when they either exceeded 10 cm diameter or began to separate. Heads were cut at the second node from the top of the plant, measured (length and diameter), weighed, dried and weighed again. Fresh and dry weights of the rest of the plant were also taken.

Site 3. Hadley, Massachusetts

Six combinations of cover crop, management and post-plant cultivation were evaluated (Table 2). The experiment was conducted on a Hadley silt loam. Cover crops were drilled September 11, 1989 as described for Site 2. Cover crops were managed in late May, and aboveground biomass was measured for a 1.m^2 area in each plot.. Cabbage seedlings were transplanted into the plots immediately after mowing or tilling the plots. A fertilizer (10-10-10) was applied at 280 kg ha^{-1} at planting, giving 28 kg ha^{-1} each of N, P_2O_5 and K_2O. No herbicides were used. Weeds were controlled by cultivation in Treatments 4 and 5, whereas no weed control was applied to the other treatments. Cabbage was harvested and weighed at maturity.

Site 4. Pownal, Maine

Four cover crop treatments were planted at the following seeding rates (kg ha^{-1}): rye (101); rye (63) + vetch (45); vetch (45); and no cover. The experiment was conducted on a Melrose fine sandy loam of high fertility, which had been in organic management with a rotation of two years vegetables and two years green manures. The field was planted to biennial white sweetclover (*Melilotus alba* L.) in spring of 1988, and the sweetclover was plowed on July 29, 1989. The experimental treatments were established August 22. Plots measured 3.0 m by 4.9 m, and cover crops were broadcast and raked in.

On June 19, 1990, aboveground vegetation was collected from a 1 m^2 quadrat in each rye, vetch and vetch + rye plot for dry matter and N determination. Weed growth was negligible in the cover crops, and light (5 to 20% ground cover) in the no-cover plots, from which no biomass samples were taken. Cover crops were sicklebar mowed, moldboard plowed and disked on June 26.

Broccoli (cv 'Premium Crop') seedlings were transplanted into the plots on July 2. Because of a shortage of seedlings at this location, only 12 were planted in each plot, and were set 81 cm apart in two rows 61 cm apart running lengthwise through the plot. No fertilizers, pesticides or herbicides were applied, and plots were hoed for weed control. Broccoli heads were harvested as they matured between August 30 and September 10, weighed, measured and rated for quality.

Statistical analysis

For Sites 3 and 4 and the preliminary experiment at Site 1, data were subjected to analysis of variance. When the F ratio for treatment mean square was found significant at the 5% probability level, means were separated using the Duncan Multiple Range Test at this significance level. Data for Site 2 were analyzed as a 3 x 2 x 2 factorial, and F ratios for main effects and interactions were tested for significance at the 5% level.

For the 1989-90 experiment at Site 1, data for the nine combinations of cover crop (rye alone, vetch + rye, vetch alone) and management (mowed, tilled, mowed +N) were analyzed as a 3 by 3 factorial. Treatments 10 through 12 were analyzed by orthogonal polynomials to determine significance ($p < 0.05$) of linear and quadratic responses to N rate, and a single degree-of-freedom contrast was made between cover cropped treatments (1-9) and no-cover treatments (10-12).

Results

Site 1, East Falmouth, Massachusetts, 1988-89.

All four cover crops yielded in excess of 4 Mg ha^{-1}, and weed biomass in the cover crops was negligible (Table 3).. Hairy vetch and crimson clover overwintered well, whereas Austrian winter peas were partially winterkilled. Rye grown alone or with peas had significantly higher biomass than rye grown with vetch, which climbed the rye, causing it to lodge by May 22. Crimson clover + rye showed a trend toward higher legume and total biomass than other cover crops, but the differences were not statistically significant. Austrian winter pea and hairy vetch had higher N concentrations than crimson clover, and rye growing with the vetch or peas had slightly but significantly higher N concentrations than rye with clover, which in turn had higher N concentration than rye alone. Total aboveground cover crop N was greater for legume + rye treatments than rye alone. Using the difference method, legume N contributions were approximately 60, 71 and 96 kg ha-1 for peas, clover and vetch, respectively. There were no differential effects of the cover crops on soil moisture at time of mowing.

Cover crop regrowth after mowing was negligible, and the mulch provided satisfactory weed control, especially in legume + rye treatments (Mangan *et al.*, 1991). Broccoli produced much larger heads after rye + legume cover crops than after rye alone (Table 4). Mean yields after rye + crimson clover were lower than after other legumes because a smaller percentage of plants formed heads, though yield differences were not statistically significant. Broccoli after rye + legumes had significantly higher foliar N levels than broccoli after rye alone, as expected (Table 5). Significantly higher zinc (Zn), B and iron (Fe) were also observed in legume + rye than rye only plots.

Site 1, East Falmouth, Massachusetts, 1989-90.

Rye and vetch + rye produced significantly more biomass than vetch alone, and much more than the natural weed growth in the no cover treatment (Table 6). Vetch + rye had significantly lower weed biomass than rye alone, possibly because the latter had a more open canopy and therefore allowed more light to reach sprouting weeds. The vetch treatment had somewhat higher soil inorganic N levels than other treatments, whereas treatment effects on soil moisture were not statistically significant.

Mowing effectively killed both rye and vetch, as virtually no cover crop regrowth was observed in no-till treatments.

Both cover crop and tillage significantly influenced soil inorganic N as of July 2 (Table 7). Vetch, either alone or with rye, resulted in higher NO_3^--N and total inorganic N levels than rye or no cover, and tillage further enhanced the release of NO_3^--N. No-till treatments maintained slightly but significantly higher moisture levels than tilled treatments, and soil under rye or vetch + rye mulch showed a trend toward higher moisture than soil under vetch mulch. Soil temperatures during sunny afternoons remained about 6°C lower under rye or rye+ vetch mulch than in tilled treatments. The vetch mulch cooled the soil by only 4°C, possibly because it was thinner, darker colored and more rapidly decomposed. Soil temperatures on cloudy mornings showed the same trends although over a much smaller range.

Broccoli yield and yield components showed a marked response to cover crop, but only a nonsignificant response to nitrogen in the tilled, no-cover treatments (Table 8). Yield, head weight and head diameter were higher after vetch + rye and vetch alone than after rye alone or no cover. Cover cropped plots that were mowed and sidedressed with N had the heaviest heads, and tilled plots had the lightest, whereas management had nonsignificant effects on head diameter and yield. Neither cover crop nor management had significant effects on maturity date. Plant biomass was highest after vetch and lowest after rye (Table 8). Plant biomass tended to increase with applied N in both cover cropped and no-cover treatments, but the trend was not significant.

Soil inorganic N levels at harvest were lower than on July 2, but NO_3^--N and total inorganic N levels remained higher after vetch or vetch + rye than after rye or no cover (Table 9). Tilled vetch or vetch + rye tended to result in higher N levels at harvest than the same treatments mowed or mowed and sidedressed with bloodmeal containing 112 kg ha^{-1} N.

Broccoli foliar N at harvest showed a quadratic response to applied N in no-cover plots, and was strongly affected by both cover crop and management (Table 10). Vetch alone or with rye resulted in higher N levels than rye alone or no cover, and either tillage or applied N tended to enhance foliar N compared to mowed cover crops without applied N.

In addition to N, cover cropping significantly increased levels of foliar P, Ca, Mg, sodium (Na) and manganese (Mn), with the highest levels of the cations observed after vetch or vetch + rye (Table 10). Tilled cover crops tended to enhance Mg levels, whereas higher Na levels appeared correlated with N inputs from either vetch or bloodmeal.

Site 2, South Deerfield, Massachusetts.

Soil temperatures were highest in tilled plots, followed by no-till no-cover, no-till rye and no-till vetch + rye in that order (Figure 1). Differences were greatest at noon of May 28, and subsided by early morning May 29. Greater cooling by vetch + rye was attributed to the heavier biomass of this cover crop compared to rye alone.

Cover crop, tillage and supplemental nitrogen (112 kg ha^{-1} as NH_4NO_3) all had strong effects on broccoli yield, maturity date and plant fresh weight (Table 11). Yield and plant weight were enhanced by a vetch + rye cover crop but depressed by rye alone. Yields in tilled and no-till (mowed) plots were similar when N was applied, but no-till reduced yield in the absence of N, especially in cover cropped treatments. Yield and plant weight showed a marked response to N regardless of tillage or cover crop. Maturity date was greatly delayed by no-till, especially in rye without N. Both vetch + rye and applied N generally hastened maturity by several days.

Site 3. Hadley, Massachusetts.

Cover crop, tillage and post-plant cultivation had a marked effect on cabbage yields (Table 12). The crop failed altogether after no-till rye, while yields after no-till vetch or vetch + rye were less than in the tilled and cultivated control. Lower yields in Treatment 6 showed that cultivation for weed control was important at this loction. In tilled and cultivated treatments, cabbage showed a strong yield response to vetch + rye. The lack of weed control in the mowed treatments may have contributed to the large yield differences observed (Mangan *et al.*, 1991)

Site 4. Pownal, Maine.

Rye and vetch + rye showed a trend toward higher biomass than vetch alone, although the difference was not statistically significant at this location (Table 13). Broccoli after rye tended to have lower yields and lighter heads than in the other treatments, but again the trend was not significant.

Discussion

Dry matter production of rye, vetch + rye and vetch alone at the five sites were similar to yields yields reported for winter annual cereal grains and legumes in Kentucky (Munawar *et al.*, 1990), Delaware (Mitchell & Teel, 1977),Kentucky (Utomo *et al.*, 1990), Maryland (Skarphol et al., 1987) and California (Gliessman, 1987). Hairy vetch yields of 5 to 9 Mg ha^{-1} containing 190 to 350 kg N ha^{-1} have been reported from Maryland (Holderbaum et al., 1990) and in one of two seasons in North Carolina (Wagger, 1989a) and New York (Sarrantonio & Scott, 1988). Holderbaum et al. (1990) observed wheat + hairy vetch yields of 6.8 to 7.4 Mg ha^{-1}, and rye alone at 7.6 Mg ha^{-1}, while Wagger (1989a) reported rye dry matter yields up to 9.1 Mg ha^{-1}. However, other studies in Kentucky and North Carolina showed rye and/or vetch yields of only 2 to 3 Mg ha-1 (Blevins et al., 1990; Utomo et al., 1990, Smith et al., 1987). These comparisons suggest that hairy vetch and vetch + rye cover crops in the Northeast can give organic matter and N yields approaching those of the same crops grown in the mid-Atlantic and southern states. However, in colder regions, the cover crop may have to be grown until early June to achieve this production and to ensure that the cover crop has become mature enough to kill by mowing. This restricts the range of crops for which this system is applicable in the Northeast, but vegetable growers commonly start fall brassicas, winter squash (*Cucurbita* spp.), late sweet corn, snap beans, and some other crops at this time.

The preliminary experiment at Site 1 indicated that mow-killed cover crops may have potential for brassicas in the Northeast, at least on light, sandy soils. Cover crops showed no regrowth after mowing, indicating that no burndown herbicide may be needed for rye and winter annual legumes mowed at flowering. Although broccoli yields were comparatively low in this experiment, Site 1 is an especially difficult location for brassicas, and our mow-killed rye + legume plots produced some of the best broccoli yields and quality realized at this farm (Suzanne Cady, New Alchemy Institute, East Falmouth, MA, personal communication, 1989).

Broccoli yields were higher after vetch or vetch + rye than after rye alone at all four sites, and also exceeded yields after no cover crop at three of the sites. Mowing the cover crop and leaving it as a surface mulch gave similar yield and slightly heavier heads than incorporating the cover crop into the soil at Site 1, but no-till cover crop management sharply reduced yields at Sites 2 and 3. At Site 1, the mulch lowered soil temperatures, slightly increased moisture levels and appeared to slow the release of inorganic N after vetch or vetch + rye. Other studies indicate that these effects can generally be expected with no-till cover crop management (Wagger, 1989a; Smith et al., 1987; Lemon et al., 1990). These effects might be expected to benefit the broccoli at Site 1, where the coarse, sandy soil appears unusually droughty and subject to rapid mineralization of organic matter. Soil beneath the mulch contained about 15 to 40 g kg^{-1} more moisture than tilled soil, which represents an additional 0.4 to 1.2 cm moisture in the top 30 cm of soil. Nitrate-N concentrations observed on July 2 in the tilled vetch and tilled vetch + rye treatments represented about 150 kg NO_3^--N ha^{-1} in the top 30 cm of soil, and were more than double the 21 mg kg^{-1} critical level for the June nitrate test for corn (Magdoff, 1990). These levels probably exceeded what the broccoli needed, as further indicated by broccoli yields in the corresponding mowed treatments containing half as much NO_3^--N. On this porous soil, it is likely that the excess was leached to the water table.

On the heavier soils at Sites 2 and 3, the cooling effect of a surface mulch might hurt yields by reducing N mineralization rate below that required to supply adequate N to the brassica crops. At Site 2, the dramatic response of broccoli grown in mow-killed rye to 112 kg ha^{-1} N as NH_4NO_3 indicates that inadequate available N was a major cause of reduced yield after no-till cover crops.

At Site 2, yields after vetch + rye without N compared with yields after no-cover with 0 and with 112 kg N ha^{-1}, suggesting that the cover crop gave a fertilizer equivalent of about 74 kg ha^{-1} when incorporated into the soil, and 29 kg ha-1 when mowed and left as a mulch. Rye alone clearly had a negative impact on yield at Sites 2 and 3, probably through immobilization of soil N.

At Site 1, broccoli yield response to the nitrogen fertilizer was nonsignificant, and yields after vetch or vetch + rye were either mowed or incorporated exceeded yields in no-cover treatments with applied N. Since the N source used at this site was bloodmeal, it undoubtedly released inorganic N more slowly than NH_4NO_3, and may have been applied too late to elicit an increase in the main head yield. The significant response of foliar N at harvest to applied N, either with or without cover crops, suggests that the bloodmeal had begun to release N to the crop at harvest, but did not do so soon enough to affect main head development.

At Site 4, the high fertility of the soil and the sweetclover green manure grown during 1988-89 apparently masked the N effects of the experimental cover crop treatments. The farmer's practice of rotating land into cover crops for two years out of four undoubtedly contributed to the overall fertility and specifically the N-releasing capacity of the soil.

Cover crop effects other than N might include modification of soil temperature and moisture, replenishment of soil humus and secondary effects on other crop nutrients. The higher C:N ratio and slower mineralization of a cereal + legume cover crop compared to a legume alone may encourage humus formation (Gliessman, 1987), and might be particularly beneficial on light sandy soils. Tilled cover crops did not seem to affect soil temperature or moisture levels at Site 1, while the cooling and moisture-conserving effects of mowed crops were probably beneficial at this site, though apparently detrimental on the heavier soils at Sites 2 and 3.

Some of the cover crop effects on broccoli foliar nutrients other than N were significant, though trends were not always consistent. That cover crops slightly increased foliar P levels may have horticultural significance, since broccoli shows strong yield responses to this element (Demchak & Smith, 1990). No-till vetch + rye appeared to enhance foliar Zn, B and Fe in 1989 but not in 1990. The fact that the 1990 trial was conducted on a somewhat more fertile field than the 1989 trial, and that the former was amended with 45 Mg ha-1 leaf mold followed by a buckwheat crop prior to starting the experiment may have masked any micronutrient effects of vetch *vs* rye. There is no clear explanation for the strong relationship between foliar Na and N inputs (vetch and/or bloodmeal) in the 1990 experiment.

In conclusion, replacing rye cover crops with vetch or vetch + rye appears beneficial to brassica yields in the Northeast. The combination may release less N than vetch alone, but it produces more biomass and potentially more soil humus (Parnes, 1986). No-till cover crop management without herbicides appears feasible before late-planted vegetables, but the impacts of no-till cover crops on vegetable yields is highly site-specific. No-till legume cover crops have given excellent results with corn and sorghum, providing fertilizer N equivalents of 75-125 kg ha-1 in Delaware (Mitchell & Teel, 1977), Kentucky (Blevins *et al.*, 1990) and Maryland (Holderbaum *et al.*, 1990). No till cover crops have given corn yields as high as cover crops managed conventionally (Utomo *et al.*, 1990) and in Maryland, snap beans yielded as well or better after no-till than conventional-till cover crops (Skarphol *et al.*, 1987). However, in the colder climates of the northeastern United States, it appears likely that slow mineralization of N under a no-till managed cover crop may limit vegetable crop yields in some soils. The small release of N to corn by vetch in Ithaca, New York (Sarrantonio & Scott, 1988) also indicates that this may be true. Soil texture appears to be an important factor, but soil biological activity and humus levels also affect residue decomposition and N mineralization. Sustainable agricultural practices that enhance soil biological activity and thus assist in the release of N from no-till managed cover crops in cooler climates should be investigated.

Table 1. Experimental treatments at Site 1 in 1989-90.

Treatment	Cover crops and seeding rates (kg ha^{-1})	Cover crop management	Nitrogen, kg ha^{-1}
1	Rye (101)	Mowed	0
2	Rye (101)	Tilled	0
3	Rye (101)	Mowed	112
4	Rye (63) + Vetch (45)	Mowed	0
5	Rye (63) + Vetch (45)	Tilled	0
6	Rye (63) + Vetch (45)	Mowed	112
7	Vetch (45)	Mowed	0
8	Vetch (45)	Tilled	0
9	Vetch (45)	Mowed	112
10	No cover	Tilled	0
11	No cover	Tilled	56
12	No cover	Tilled	112

Table 2. Experimental treatments at Site 3 in 1989-90.

Treatment	Cover crops and seeding rates (kg ha^{-1})	Cover crop management	Post-plant cultivation
1	Rye (101)	Mowed	No
2	Rye (63) + Vetch (45)	Mowed	No
3	Vetch (45)	Mowed	No
4	Rye (63) + Vetch (45)	Tilled	Yes
5	No cover	Tilled	Yes
6	No cover	Tilled	No

Table 3. Cover crop biomass and nitrogen, and soil moisture in late May, 1989 at Site 1.

Treatment	-----------Dry wt., Mg ha^{-1}-----------				--------% N--------		Total N, kg ha^{-1}	Soil H_2O, g kg^{-1}
	Rye	Legume	Weed	Total	Rye	Legume		
Rye	4.72 a[z]	-	0.14	4.87	1.02 d	-	48 b	160
Rye + peas	4.60 a	1.49	0.16	6.24	1.23 b	3.64 a	108 a	145
Rye + clover	3.33 ab	3.77	0.12	7.22	1.12 c	2.17 b	119 a	154
Vetch + rye	2.50 b	2.91	0.04	5.45	1.37 a	3.84 a	144 a	160
F test[y]	*	ns	ns	ns	**	*	**	ns

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[z] means within a column not followed by the same letter are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test.

[y] Significance level for treatment mean square: ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$.

Table 4. Yield and yield components in no-till broccoli grown after four cover crops at Site 1 in 1989.

Treatment	Yield, Mg ha^{-1}	% of plants bearing heads	Head weight, g	Head diameter, cm
Rye	1.11	79	59 b[z]	4.7 b
Peas + rye	3.22	75	186 a	10.1 a
Clover + rye	1.78	54	181 a	9.6 a
Vetch + rye	3.32	79	204 a	9.9 a
F test[y]	ns	ns	**	**

---

y,z See footnotes, Table 3.

Table 5. Foliar nutrient concentrations at harvest in no-till broccoli grown after four cover crops at Site 1 in 1989.

Treatment	------------------% of dry wt------------------						------------mg kg^{-1} dry wt-----------				
	N	P	K	Ca	Mg	Na	Zn	B	Cu	Fe	Mn
Rye	2.91 b[z]	0.43	2.72	1.55	0.27	0.06	35 b	26 b	5	83 b	29
Rye + peas	4.70 a	0.58	3.09	1.39	0.25	0.08	49 a	43 a	6	127 a	26
Rye + clover	4.52 a	0.50	2.92	1.23	0.22	0.06	46 a	40 a	5	104 ab	23
Vetch + rye	5.13 a	0.58	2.86	1.38	0.25	0.09	47 a	45 a	6	116 a	27
F test[y]	**	ns	ns	ns	ns	ns	*	**	ns	*	ns

[y,z] See footnotes, Table 3.

Table 6. Aboveground biomass and N, and soil moisture and inorganic N in three cover crops and control at Site 1 in June 1990.

Treatment	Dry weight, Mg ha^{-1} Cover crop	Dry weight, Mg ha^{-1} Weeds	Dry weight, Mg ha^{-1} Total	Total N, kg ha^{-1}	Soil H2O, g kg^{-1}	Soil inorganic N, mg kg^{-1} NH_4^+-N	Soil inorganic N, mg kg^{-1} NO_3^--N	Soil inorganic N, mg kg^{-1} total N
Rye	7.28 a[z]	0.65 b	7.94 a		216	10 ab	2 b	12 b
Vetch + rye	7.81 a	0.17 c	7.99 a		197	8 b	4 a	12 b
Vetch	4.67 b	0.54 b	5.21 b		197	11 a	5 a	16 a
No cover	0.37[x]	2.59 a	2.96 c		210	8 b	3 b	10 b
F test[y]	**	**	**		ns	**	**	**

---

[x] Volunteer crops, not included in statistical analysis of cover crop biomass

[y,z] See footnotes, Table 3.

Table 7. Soil inorganic nitrogen, moisture and temperature in broccoli after different cover crops and management sytems at Site 1 in 1990.

Cover crop & management	July 2 inorganic N, mg kg^{-1} dry wt[w] NH_4^+N	July 2 inorganic N, mg kg^{-1} dry wt[w] NO_3^-N	July 2 inorganic N, mg kg^{-1} dry wt[w] total N	Temp, °C[x] PM	Temp, °C[x] AM	Moisture, g kg^{-1} dry wt[x] July 2	Moisture, g kg^{-1} dry wt[x] July 14
Rye, mowed	2	10	13	21.5	18.9	222	239
Rye, tilled	2	13	15	27.6	20.5	186	185
Vetch + rye, mowed	2	23	25	21.2	19.0	211	222
Vetch + rye, tilled	4	48	52	27.6	20.5	187	184
Vetch, mowed	2	27	29	23.4	19.7	197	206
Vetch, tilled	2	51	53	27.5	20.5	178	186
No cover, tilled	2	18	20	27.3	20.6	189	186
F test, factorial[y]							
Cover crop	ns	**	**	**	**	*	ns
Management	ns	**	**	**	**	**	**
C x M	ns	ns	*	**	**	ns	ns
Contrast[z]							
cover vs no cover	ns	**	**	**	**	ns	ns

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[w] 0-30 cm depth

[x] PM = mean of eight readings taken between 1300 and 1900 on sunny days between June 21 and July 18; AM = mean of two readings on cloudy mornings (July 2, 1100 and July 9, 0900)

[y] Factorial ANOVA on cover cropped treatments only; ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$.

[z] One degree-of-freedom contrast of all cover cropped vs no cover treatments.

Table 8. Yield and yield components of broccoli grown in different cover crop, tillage and nitrogen treatments at Site 1 in 1990.

	Heads					Plant biomass after harvest			
Treatment	Yield, $Mg\ ha^{-1}$	% plants w/ heads	wt., g	diam., cm	Matur. date[w]	fr. wt., $Mg\ ha^{-1}$	dry wt., $Mg ha^{-1}$	% N	total N kg ha-1
Rye:									
1 Mow	3.57	98	127	8.3	4.6	14.76	2.64		
2 Till	3.39	98	123	8.5	3.5	16.83	2.92		
3 Mow+112N	4.02	96	151	8.5	4.6	17.73	2.96		
Vetch + rye:									
4 Mow	4.76	96	178	10.1	3.4	20.62	3.37		
5 Till	4.36	98	159	9.1	3.9	25.32	3.78		
6 Mow+112N	4.93	94	195	10.4	2.7	28.81	4.34		
Vetch:									
7 Mow	5.12	100	178	10.1	2.8	25.27	3.95		
8 Till	4.24	96	157	9.1	4.7	28.20	4.33		
9 Mow+112N	5.01	92	196	10.4	2.3	29.42	4.37		
No Cover:									
10 Till	3.42	98	126	8.5	3.2	16.77	3.12		
11 Till+56N	4.18	96	155	9.5	3.2	22.33	3.78		
12 Till+112N	3.93	98	143	8.8	3.5	21.04	3.57		
No cover, N response (trts 10-12)[x]									
Linear	ns	ns	ns	ns	ns	ns	ns		
Quadratic	ns	ns	ns	ns	ns	ns	ns		
Factorial F-test (trts 1-9)[y]									
Cover	**	ns	**	**	ns	**	**		
Management	ns	ns	**	ns	ns	*	ns		
C x M	ns	ns	ns	ns	ns	ns	ns		
Contrasts[z]									
cover vs no cover	*	ns	**	ns	ns	*	ns		

---

[w] Days; 1 = August 7.

[x] Linear and quadratic components of crop response to N in no-cover, tilled treatments. ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$.

[y,z] See footnotes, Table 7.

Table 9. Soil moisture and inorganic N at time of broccoli harvest (August 14, 1990).

Treatment	Soil moisture, $g\ kg^{-1}$ dry wt	Soil inorganic N, $mg\ kg^{-1}$ dry wt NH_4^+N	NO_3^-N	total N
Rye:				
1 Mow	162	2	8	10
2 Till	136	2	6	8
3 Mow+112N	147	2	8	10
Vetch + rye:				
4 Mow	151	2	8	9
5 Till	113	2	24	26
6 Mow+112N	135	2	10	11
Vetch				
7 Mow	126	2	11	13
8 Till	120	2	24	26
9 Mow+112N	141	2	18	20
No Cover:				
10 Till	120	2	6	8
11 Till+52N	136	2	9	10
12 Till+112N	123	2	8	10
No cover N response (trts. 10-12)[x]				
Linear	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns
Factorial F test (trts. 1-9)[y]				
Cover	ns	ns	*	*
Management	*	ns	*	ns
C x M	ns	ns	ns	ns
Contrast[z]				
cover vs no cover	ns	ns	*	*

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[x] See footnote, Table 8

[y,z] See footnotes, Table 7.

Table 10. Foliar nutrients in broccoli at harvest at Site 1 in 1990.

	% of dry wt.						mg kg-1 dry wt			
Treatment	N	P	K	Ca	Mg	Na	Zn	B	Fe	Mn
Rye:										
1 Mow	3.65	0.43	2.73	1.13	0.32	0.03	53	34	63	21
2 Till	3.52	0.40	2.89	1.21	0.37	0.03	50	35	74	23
3 Mow+112N	4.73	0.48	2.58	0.95	0.29	0.09	77	36	78	36
Vetch + rye:										
4 Mow	4.52	0.43	2.13	1.09	0.33	0.11	52	36	61	25
5 Till	5.38	0.48	2.58	1.31	0.42	0.14	56	39	69	34
6 Mow+112N	5.23	0.48	2.50	1.29	0.36	0.15	64	39	75	32
Vetch:										
7 Mow	4.85	0.43	2.54	1.11	0.37	0.11	62	36	70	28
8 Till	5.37	0.50	2.59	1.38	0.40	0.11	72	39	90	41
9 Mow+112N	5.14	0.44	2.50	1.40	0.39	0.16	61	34	75	36
No Cover:										
10 Till	3.57	0.40	2.73	0.99	0.30	0.04	49	36	56	26
11 Till+56N	4.15	0.41	2.66	1.06	0.32	0.07	56	37	78	22
12 Till+112N	3.95	0.43	2.61	0.95	0.29	0.06	59	37	73	23
No cover N response (trts. 10-12)[x]										
Linear	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
Quadratic	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Factorial F test (trts. 1-9)[y]										
Cover	**	ns	*	ns	ns	**	ns	ns	ns	ns
Management	**	ns	ns	ns	*	**	ns	ns	ns	ns
C x M	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Contrast[z]										
cover vs no cover	**	*	ns	**	**	**	ns	ns	ns	*

---

[x] See footnote, Table 8

[y,z] See footnotes, Table 7.

Table 11. Head yield, plant fresh weight after harvest, and head maturity date in broccoli grown in different cover crop, management and N treatments at Site 2.

Treatment	Head fresh wt., Mg ha-1	Maturity date[y]	Plant fresh wt., Mg ha-1
Rye:			
Till	2.96	9.7	11.57
Till+112N	7.16	9.9	27.35
Mow	0.49	38.7	5.26
Mow+112N	7.19	21.5	24.04
Rye+Vetch:			
Till	6.43	3.7	22.15
Till+112N	9.27	1.7	33.55
Mow	4.24	17.6	17.43
Mow+112N	8.37	8.4	33.32
No Cover:			
Till	3.54	5.7	15.03
Till+112N	7.92	2.5	25.74
Mow	2.88	24.0	7.53
Mow+112N	8.05	19.5	20.12
Factorial F test[z]			
Cover	**	**	**
Tillage	**	**	**
N	**	**	**
C x T	ns	**	ns
C x N	**	**	ns
T x N	**	**	ns
C x T x N	ns	**	ns

---

[y] Days; 1 = July 19.

[z] ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$.

Table 12. Cover crop biomass and N, and cabbage yield and yield components in six treatments at Site 3.

Treatment	Cover crop dry wt., Mg ha-1	Cover crop N, kg ha-1	Cabbageyield, Mg fresh wt. ha^{-1}
1 Rye, mowed			0.[x]
2 Vetch + rye, mowed			10.22 c
3 Vetch, mowed			11.92 c
4 Vetch + rye, tilled, cult.			44.21 a
5 No cover, tilled, cult.			27.58 b
6. No cover, tilled, no cult.			8.84 c
F test[y]			**

---

[x] No heads formed; no yield harvested. Treatment excluded from statistical analysis.

[y,z] See footnotes in Table 3.

Table 13. Cover crop biomass and nitrogen, and broccoli yield and yield components in four treatments at Site 4.

	----Cover crop, June 19-----			---------------Broccoli, Aug 30-Sept 10---------------				
Treatment	Dryt wt. Mg ha-1	%N	total N kg ha-1	yield kg plot-1	% plants w/ heads	head. wt., g	head diam., cm	Matur. date[w]
Rye	4.81			1.97	67	240	11.8	7.2
Vetch + rye	4.21			2.70	69	324	12.2	6.1
Vetch	3.06			3.38	81	356	13.9	6.7
No cover	-x	-x	-x	2.72	69	327	13.4	5.9
F test[y]	ns			ns	ns	ns	ns	ns

---

[w] Days (August 30 = 1)

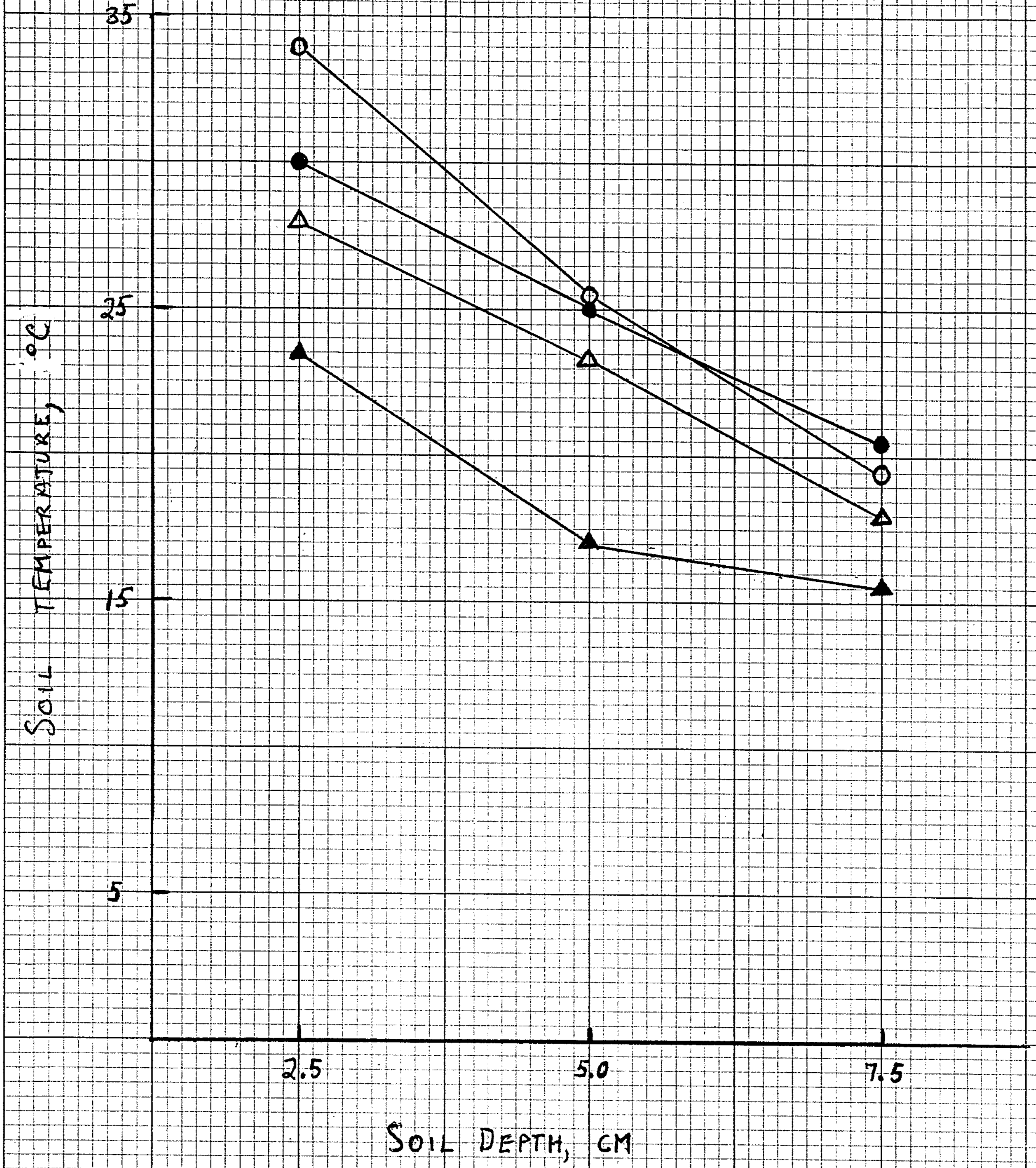
[x] No vegetation samples were collected

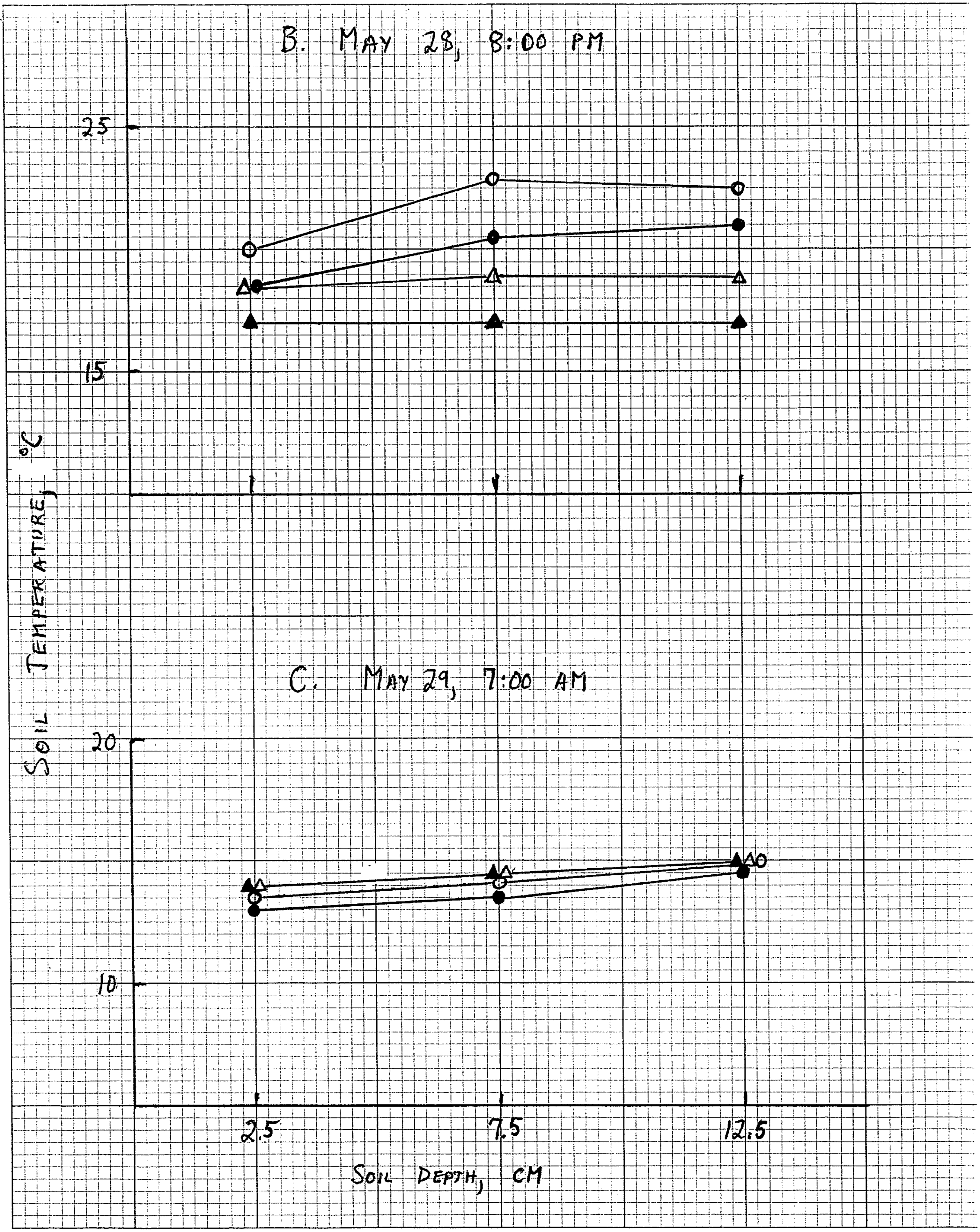
[y,z] See footnotes, Table 3.

Figure Captions:

Figure 1. Soil temperatures 6-7 days after cover crop management in conventionally tilled no-cover (○), no-till no-cover (●), no-till rye (△) and no-till vetch + rye (▲). A. May 28, 12:00 noon; B. May 28, 8:00 pm; C. May 29, 7:00 am.

A. MAY 28 12:00 NOON




B. MAY 28, 8:00 PM
25
15
SOIL TEMPERATURE, °C
C. MAY 29, 7:00 AM
20
10
2.5
7.5
12.5
SOIL DEPTH, CM

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