Winter Cover Crops and Nitrogen Management in Sweet Corn and Broccoli Rotations

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Abstract. Cover crops hold potential to improve soil quality, to recover residual fertilizer N in the soil after a summer crop that otherwise might leach to the groundwater, and to be a source of N for subsequently planted vegetable crops. The objective of this 5-year study was to determine the N uptake by winter cover crops and its effect on summer vegetable productivity. Winter cover crops [red clover (*Trifolium pratense* L.), cereal rye (*Secale cereale* L. var. Wheeler), a cereal rye/Austrian winter pea (*Pisum sativum* L.) mix, or a winter fallow control] were in a rotation with alternate years of sweet corn (*Zea mays* L. cv. Jubilee) and broccoli (*Brassica oleracea* L. Botrytis Group cv. Gem). The subplots were N rate (zero, intermediate, and as recommended for vegetable crop). Summer relay plantings of red clover or cereal rye were also used to gain early establishment of the cover crop. Cereal rye cover crops recovered residual fertilizer N at an average of 40 kg-ha⁻¹ following the recommended N rates, but after 5 years of cropping, there was no evidence that the N conserved by the cereal rye cover crop would permit a reduction in inorganic N inputs to maintain yields. Intermediate rates of N applied to summer crops in combination with winter cover crops containing legumes produced vegetable yields similar to those with recommended rates of N in combination with winter fallow or cereal rye cover crops. There was a consistent trend ($P < 0.12$) for cereal rye cover crops to cause a small decrease in broccoli yields as compared to winter fallow.

The first written accounts of cover crops for soil improvement are from the Chou dynasty in China over 3,000 years ago, and agricultural literature has consistently mentioned the benefits of green manure cover crops. North American agricultural doctrine of the nineteenth and early twentieth century equated financially successful farming with the use of green manures because of their ability to protect fields from erosion and to absorb minerals that would otherwise be leached from the soil (Harlan, 1899; Pieters, 1927).

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Cover crops have been used for thousands of years to preserve and enhance soil fertility (Pieters, 1927). As use of inorganic N fertilizers increased during the past 60 years, cover cropping declined. Crop yields have risen during this time, but so have soil erosion rates and nitrate concentrations in groundwater (Keeney and Follett, 1991; NRC, 1989). Close monitoring of agricultural soils has revealed evidence of nitrate leaching when crop N use is insufficient to deplete available soil N (Staver and Brinsfield, 1990).

Groundwater pollution by nitrates has been identified as a problem in parts of Oregon's productive Willamette Valley. Oregon vegetable growers may apply inorganic N at more than 250 kg-ha⁻¹ in a season on sweet corn or broccoli. Wet winters in western Oregon provide optimum conditions for residual soil nitrate to be leached into the groundwater.

Interest in the dynamics of N in agricultural systems has increased in recent years (Keeney and Follett, 1991). Many studies have shown that N can be conserved in agricultural systems by various management strategies such as green manure cover cropping (Ditsch

and Alley, 1991; Ebelhar et al., 1984; Hargrove, 1986; Hesterman et al., 1986).

A potential method for reducing nitrate leaching from agricultural soils is to replace some of the applied inorganic N with green manure cover crops, because N from decomposing plant material becomes available over a longer time span than most inorganic N. Green manure residues can supply most or all of crop N needs if mineralization coincides with crop N requirements (Fauci and Dick, 1994; Touchton et al., 1982). Griffen and Hesterman (1991) found that the N content of legumes grown as green manures ranged from 33 to 238 kg-ha⁻¹, and the average N fertilizer replacement value of these legumes was about 100 kg-ha⁻¹. One study showed a recovery of between 89% and 102% of N derived from decomposing ¹⁵N-labeled cover crop plant materials buried in mesh bags, and that uptake of the mineralized plant N by barley (*Hordeum vulgare* L.) was correlated to cover crop decomposition (Muller and Sundman, 1988). If mineralization of organic N does not correspond to plant N growth requirements, yields will be depressed in the absence of other available N sources. Griffen and Hesterman (1991) did not find a significant yield response of potatoes (*Solanum tuberosum* L.) to plowed-down legumes, and attributed this to lack of synchrony between N mineralization and availability for potato N growth demands.

There is little information on agronomic and environmental performance of cover crops in vegetable-based systems located in a Mediterranean climate, as is found in western Oregon (Copeland, 1965). This climate is characterized by hot dry summers followed by cool wet winters, when conditions are conducive to leaching of soil N. The objectives of this study were to investigate the contribution of winter cover crops to the N nutrition of a subsequent crop of either sweet corn or broccoli over five growing seasons, and the ability of winter cover crops to accumulate N after the vegetable harvest.

Materials and Methods

The study area was located at the Oregon State Univ. North Willamette Research and Extension Center near Aurora, Ore. The soil was a Willamette silt loam (mixed mesic Pachic Ultic Argixeroll). This study, initiated in 1989, is a randomized split-plot complete block with four replications of six winter cover crop treatments and three N rate subplots within each main plot (Table 1). Main plots were 18 × 9 m and were divided into three equal subplot areas of 54 m², except for the spring-seeded red clover winter cover crop treatment, which had one-half plowed in the late fall and the other half plowed the following spring before summer crop planting; the half-plots of clover were then further divided into two subplots of 40.5 m² and received either zero N or the recommended N rate on subsequent vegetable crops.

Cover crops. Winter cover crop treatments were 'Wheeler' cereal rye, cereal rye/Austrian winter pea mix, 'Kenland' red clover, and

Table 1. Pesticide input and timeline of plantings in cover crop–vegetable rotation plots.

Pesticide input	Crop grown ^a									
	1989	1990		1991		1992		1993		1994
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Recommended	Fallow	Corn	Fallow	Broccoli	Wheat	Fallow	Broccoli	Broccoli	Fallow	Corn
Recommended	RedCl	RedCl	RedCl	Broccoli	RedCl	RedCl	RedCl	Broccoli	RedCl	Corn
Reduced	CR	Corn	CR	Broccoli	CR	Corn	RelCR	Broccoli	RelCR	Corn
Reduced	CR/P	Corn	CR/P	Broccoli	CR/P	Corn	RelCl	Broccoli	RelCl	Corn
Recommended	CR	Corn	CR	Broccoli	CR	Corn	CR	Broccoli	CR	Corn
Recommended	CR/P	Corn	CR/P	Broccoli	CR/P	Corn	CR/P	Broccoli	CR/P	Corn

^aRedCl = red clover, CR = cereal rye, RelCR = relay cereal rye, CR/P = cereal rye/pea, RelCl = relay clover.

winter fallow (Table 1). Cover crops were planted in mid-September of each year. From 1989 to 1992, there were two sets of cover crop rotations in which each treatment had the same winter crops (cereal rye or cereal rye/pea mix as described above), but summer crops received either reduced (weeds were controlled with cultivation) or recommended prophylactic pesticide applications (Oregon State Univ. Extension Service). Both treatments comprised 18 × 9-m plots with the same N rate subplots described above and as further described under “Summer crops” below. Since there were no statistical differences due to the herbicide treatments on either summer crops or cover crop productivity measurements, data from these treatments were pooled for statistical analysis and presentation of the data. In Summer 1992, the treatment plots receiving no pesticide inputs were converted to a system that had a summer relay establishment of either ‘Wheeler’ cereal rye (implemented in plots that previously had a September planting of cereal rye) or ‘Kenland’ red clover (implemented in plots that previously had cereal rye/pea mix) into the standing vegetable crop (Table 1).

Cereal rye was drilled at 75 kg·ha⁻¹ in the fall-seeded plots and broadcast at 85 kg·ha⁻¹ in summer relay plots. In the cereal rye/pea mix, the cereal rye rate was 40 kg·ha⁻¹ and for Austrian pea it was 112 kg·ha⁻¹. Fall-seeded red clover plots in rotation with summer crops were drilled at 20 kg·ha⁻¹ in 1990 and 1992, harvested for seed in late July, and then allowed to regrow as a ratoon winter cover crop for both years of broccoli. Red clover in summer relay plots was broadcast at 25 kg·ha⁻¹. Higher seeding rates were used for relay broadcast seeding to ensure adequate stand establishment.

In late March of each year, we randomly cut 1.0 m² biomass samples at ground level from each subplot of the treatment. In plots planted to a cereal rye/pea mix, the pea plants were counted, weighed and analyzed separately from the cereal rye biomass. Subsamples weighing ≈0.5 kg were taken from well-mixed field samples for dry matter and total N analyses. In April of each year, cover crops were mowed, disked, and incorporated with a mold-board plow. Seedbed preparation consisted of disking and rotovating.

Summer crops. The experiment consisted of alternate years of sweet corn (1990, 1992, and 1994) and broccoli (1991 and 1993) fertilized at three rates of N (urea-N at 0, 56, or 224 kg·ha⁻¹ for sweet corn and 0, 140, or 280 kg·ha⁻¹ for broccoli). In 1992, winter fallow plots (pseudo fallow) were in wheat instead of sweet corn, which was included in the fallow treatment to more closely follow conventional crop rotations in the Willamette Valley, where summer vegetable crops normally are followed by winter fallow once every 3–5 years winter wheat is planted. The N treatment subplots remained at the same relative rates (zero, low, or recommended) from year to year; for example, the N application of 56 kg·ha⁻¹ subplot for sweet corn in 1992 and 1994 also received N at 140 kg·ha⁻¹ for broccoli in 1991 and 1993. The intermediate rates were specifically chosen for each crop to ensure a suboptimal N rate. Previous research has shown that N at >56 or >140 kg·ha⁻¹ for sweet corn and broccoli, respectively, does not consistently result in lower yields than the recommended rates (unpublished).

During the 1991 and 1992 growing seasons, half the vegetable plots with winter cover crops received either recommended [atrazine, 2-chloro-4-ethylamino-6-isopropylamino-s-

triazine, at 2.24 kg·ha⁻¹ and alachlor, 2-chloro-N-(2,6-diethylphenyl)-N-(methylthio)-1,3,5-triazine-2,4-diamine at 3.36 kg·ha⁻¹ for sweet corn, and trifluran, N,N-di-*n*-propyl-2,6-dinitro-4-trifluoromethylthianiline, at 0.84 kg·ha⁻¹ for broccoli] or reduced (EPTC, S-ethylpropylthiocarbamate, at 2.24 kg·ha⁻¹ for corn, no herbicide for broccoli and no insecticides) pesticide treatments. In the summers of 1992 and 1993, plots that had received reduced herbicide inputs were interseeded with either red clover or cereal rye into standing sweet corn or broccoli as described under “Cover crops.” Sweet corn and broccoli were direct-seeded in 51-cm paired rows spaced 102 cm apart. Sweet corn was seeded to a stand of ≈62,000 plants/ha. Broccoli stands were thinned to an in-row spacing of 30 cm, ≈4 weeks after emergence. All plots received a banded P application of 90 kg·ha⁻¹ as triple superphosphate at planting and, within a week, a surface-banded application of one-half the respective N rate for each subplot. The other half of the urea N was banded between rows in mid-July.

In addition to any herbicide applications, all vegetable plots were mechanically cultivated and then hand-weeded, if necessary. Plots were irrigated twice weekly by overhead sprinklers (3 cm·week⁻¹) for 5 weeks and subsequently by drip lines with emitters at 23 cm intervals and a flow rate of 1.9 min⁻¹ per 30.5 m for 4 h·week⁻¹.

Unhusked ears of sweet corn were harvested (in mid-August from 4.6-m lengths of two inner rows of each subplot) and weighed. Broccoli heads were twice harvested (mid-August and late August) from 4.6 m lengths of two inner rows in each subplot and weighed.

Laboratory analyses and statistics. Cover crop subsamples were dried in forced air at 60

Table 2. Summary of analyses of variance showing the sources of effects on total cover crop N content and broccoli and sweet corn yields for 1990 through 1994.

Source of variation	Cover crop N content		Broccoli head yield		Sweet corn ear yield	
	df	MS	df	MS	df	MS
Year (Y)	3	18287***	1	49485636***	2	1145794844***
Block (R)	3	572 ^{ns}	3	8848327***	3	16653263 ^{ns}
Cover crop (C)	3	8808***	4	12771920**	4	107870994***
Y × C	5	1608*	2	1045833 ^{ns}	3	37371124 ^{ns}
Error A	33	459	20	2655776	27	16895447
N rate (N)	2	15479***	2	113352036***	2	905938310***
N × C	6	556 ^{ns}	8	4860037**	8	3907658 ^{ns}
N × Y	6	2063***	2	10796853**	4	7084282 ^{ns}
N × C × Y	10	366 ^{ns}	4	1067801 ^{ns}	6	4168392 ^{ns}
Error B	72	305	46	1604438	60	10380787
Residual error	47	427	27	921900	48	12316583
Total	19		119		167	

^{ns}, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 3. Aerial N content of winter cover crops for 1991 through 1994. N rates on previous vegetable crops were 56 or 140 kg·ha⁻¹ for intermediate and 224 or 280 kg·ha⁻¹ for recommended treatments.

Winter cover crop	N quantity (kg·ha ⁻¹)		
	Zero	Intermediate	Recommended
<i>1991</i>			
Clover	61 abA ^z	---	32 bA
Cereal rye	45 bB	65 aB	138 aA
Cereal rye/pea	74 aB	85 aB	124 aA
<i>1992</i>			
Cereal rye	22 bB	31 bAB	49 bA
Cereal rye/pea	57 aB	69 aB	85 aA
<i>1993</i>			
Clover	117 aA	---	90 aA
Relay clover	73 bA	61 aA	73 abA
Relay cereal rye	33 cB	35 bB	60 abA
Cereal rye	20 cB	24 bA	45 bA
Cereal rye/pea	44 bcB	59 aAB	87 aA
<i>1994</i>			
Relay clover	38 aA	35 abA	41 bA
Relay cereal rye	9 cB	16 cB	42 bA
Cereal rye	17 bcB	40 abAB	49 abA
Cereal rye/pea	45 aB	58 aAB	66 aA

^zWithin each year, lower case letters compare cover crops at a specific N rate (columns) and upper case letters compare N rates for each cover crop (rows). Aerial cover crop N content means comparisons are within a year, and those with the same letter in a column or row do not differ significantly with regard to N rate or cover crop, respectively, by Fisher's Protected LSD at $P \leq 0.05$.

°C for 3 to 5 d. Dried subsamples were weighed, ground first in a Wiley mill to a coarse texture, and then ground to (100 mesh) size in a Cyclotec mill. Cover crop plant samples were analyzed for total N by the Kjeldahl procedure (Bremner and Mulvaney, 1982).

Data were tested by analysis of variance with a general linear model (SAS, 1985) as a randomized complete split-plot block design over years with winter cover crop treatment as main plots and N rate as subplots. This analysis is unbalanced because the reduced-pesticide, fall-planted cover crop treatment

was converted to relay-planted cover crops in 1992. Mean comparisons of sweet corn and broccoli yields at the three N rates and various winter cover crop treatments as well as total N content of cover crops at the three N rates were accomplished using Fisher's Protected LSD (SAS, 1985). The spring-seeded red clover seed crop/vegetable rotation treatments were not included in the statistical analysis because these plots were fertilized at two rates of N rather than three. Statistical analysis (Table 2) includes the main-plot cover crop rotations that were studied for 5 years (winter fallow,

fall-planted cereal rye, and fall-planted cereal rye/pea mix) and separate ANOVA was performed for relay established cover crops since these were only tested 2 years.

Results and Discussion

Winter cover crops and N rate had highly significant effects on broccoli and sweet corn yield. Sweet corn yields were unaffected by interactions, but broccoli head yields were significantly affected by the interactions, N rate by cover crop and N rate by year (Table 2). Cover crop N content also had significant interactions of year by cover crop and N rate by year (Table 2). Consequently, data have only been pooled for main effects when there were no significant interactions ($P < 0.05$).

Cover crops. N uptake was significantly affected by all main effects of time (year), cover crop, and N rate (Table 2). The cover crop aerial N content by year interaction was significant, which indicates that yearly weather conditions had a differential effect on cover crop N recovery. Fall precipitation and soil temperature have a great effect on the establishment and early growth of winter cover crops. Weather data for the North Willamette Research and Extension Center during September and October showed large variability over the five years, with precipitation ranging from 36 mm in 1993 to 206 mm in 1994. Our qualitative observations of cover crop growth showed that a dry fall and/or excessive rainfall and/or a cold spell ($<0^\circ\text{C}$ for several days) in November/December severely reduced cover crop growth. However, when we attempted to correlate weather data with cover crop growth and N uptake, we had nonsignificant correlation coefficients, which likely is related to the confounding and interacting effects of temperature and moisture conditions each year.

These results indicate that it is important to design cover crop systems that provide consistent winter growth regardless of weather conditions. Adequate early growth and consistency of growth patterns are needed to reliably recover residual fertilizer N during the time of maximum rainfall and nitrate leaching potential and to develop realistic fertilizer recommendations for subsequent summer crops. These observations led to the development of the relay cover crop treatments. Qualitative visual observations showed that relay cereal rye and clover grew best during the late summer and early fall in those areas of the plots that received drip irrigation. This fact suggests that, for the typical dry summer of a Mediterranean climate, irrigation is needed for relay cover crop establishment. All vegetables in Western Oregon are grown under irrigation, which would facilitate relay cover crop establishment under farmers' conditions. However, relay establishment of cover crops resulted in N uptake similar to that with fall-established cover crops (Table 3).

The N content of the cereal rye cover crop increased with increasing fertilizer N applied to the previous vegetable crop (Table 3). An estimate of residual fertilizer N taken up by the cereal rye cover crops was obtained by the

Table 4. Aerial N content of the cereal rye/Austrian winter pea cover crops, 1991 through 1994. N rates (kg·ha⁻¹) were intermediate—56 and 140 (1992 and 1994); or recommended—224 and 280 (1991 and 1993) for N applied to summer crops.

N rate applied to previous crop	Pea plants (no./m ²)	N content (kg·ha ⁻¹)		
		Pea plants	Cereal rye plants	Cereal rye/pea cover crop
Zero	71 a ^z	19 a	40 b	59 b
Intermediate	69 a	20 a	51 b	71 b
Recommended	57 b	16 b	79 a	96 a
<i>P</i>	0.16	0.25	<0.05	<0.05

^zMean separation within columns at the specified probability (P) by Fisher's protected LSD.

Table 5. Mean broccoli head yields as affected by N rate and winter cover crop for 1991 and 1993.

Winter cover crop	Broccoli head yield (Mg·ha ⁻¹)		
	N rate (kg·ha ⁻¹)		
	0	140	280
<i>1991</i>			
Fallow	3.9 a ^C	6.3 abB	8.4 aA
Cereal rye	3.6 aC	5.1 bB	7.4 aA
Cereal rye/pea	4.2 aB	7.1 aA	8.1 aA
<i>1993</i>			
Fallow	4.2 bB	9.3 abA	8.9 aA
Cereal rye	4.6 abB	7.8 aA	8.4 aA
Cereal rye/pea	6.6 aB	10.2 aA	8.3 aAB
Relay cereal rye	3.6 bB	7.8 bA	7.4 aA
Relay clover	7.8 aB	8.4 abA	8.3 aB

^zWithin each year, lower case letters show comparisons among cover crops at a specific N rate (columns) and upper case letters show comparisons among N rates for each cover crop (rows). Means comparisons for each year are separate and those with the same letter in a column or row do not differ significantly with regard to N rate or cover crop, respectively, by Fisher's Protected LSD at $P \leq 0.05$.

Fig. 1. Yield of sweet corn ears at three N rates and five winter cover crop treatments for the 1994 growing season. The bars for fallow treatments shown do not include data from 1992 since there were no fallow plots for sweet corn that year (wheat was grown in the conventional winter-fallow system). Mean separation by Fisher's Protected LSD at $P \leq 0.05$.

difference between that grown on soil that had been fertilized and N uptake of cereal rye grown on unfertilized soil. This difference (which does not include N recovered in roots), averaged over years, was 51 and 30 kg-ha⁻¹ for fall-planted cereal rye and relay cereal rye cover crops, respectively, at the highest N rates (Table 3).

Winter cover crops with a legume component had a higher N content at plowdown for all N rates than did a cereal rye cover crop. At zero N, legume cover crops contained about twice the N as the cereal rye cover crop (Table 3). The N content of legumes in the winter cover crop did not increase with increasing N rate applied to the previous vegetable crop for either the clover (Table 3) or the Austrian winter pea component of the cereal rye and pea mix (Table 4). Interestingly, the N content of the cereal rye component of the cereal rye/pea mix averaged 28%, 18%, and 12% more N at the zero, intermediate, and high N rates, respectively, than did the N content of cereal rye cover crop grown alone (Tables 3 and 4). This higher rate of N accumulation by cereal rye in the presence of the legume suggests fixed N from the legume is transferred to the cereal rye either in-season or from the accumulated N incorporated into the soil from previous years.

The number of pea plants in a cereal rye/pea mix tended ($P < 0.16$) to decrease with increased N applied to the summer crops (Table 4). This decrease may be due to a greater competitive advantage of cereal rye under high N conditions or a suppressive effect of residual N on legume growth, suggesting that to maintain active growth of Austrian pea and take advantage of N₂ fixation, intermediate N rates applied to the summer crop is preferable.

Red clover grown for seed and left as a

winter cover crop in 1990 and 1992, and analyzed in 1991 and 1993, had a mean N content of 89 kg-ha⁻¹ with zero N and 61 kg-ha⁻¹ with the recommended N rate for the 2 years (data not shown). Relay red clover, unlike fall-planted Austrian pea, was unaffected by application of N fertilizer applied to the previous summer vegetable crop (Table 3).

Vegetable crops. At all N rates, cereal rye cover crops resulted in a slightly reduced, but not statistically significant, broccoli yield com-

pared to the fallow treatments (Table 5). This trend also occurred with sweet corn in 1994 (Fig. 1). Averaged over all years and N rates, the relative yield of the vegetable crops from cereal rye cover crop plots compared to fallow plots is 81.3%. Similarly negative field corn responses to a cereal rye cover crop have been reported by McCracken et al. (1989), Mitchell and Teel (1977), and Raimbault et al. (1991). Lettuce (*Lactuca sativa* L.) yield and available soil N decreased following an incorporated mature cereal rye cover crop as compared to fallow (Wyland et al., 1995). Cover crops such as cereal rye, with a greater C to N ratio than legumes, may result in net microbial N immobilization and deplete the soil of available N for subsequent crop use. Such immobilization may explain the trend in our data, but phytotoxic compounds released by the decomposing cereal rye residue may also be an explanation (Raimbault et al., 1991).

Sweet corn yields with N at 56 kg-ha⁻¹ following a cereal rye/pea mix or relay clover were equivalent to yields with N at 224 kg-ha⁻¹ following fallowing and/or a cereal rye cover crop (Figs. 1 and 2). In 1994, sweet corn yields at all N rates were highest following relay clover. Unfertilized sweet corn following relay clover produced a yield equivalent to that of corn following cereal rye and N fertilized at 224 kg-ha⁻¹ (Fig. 1). Previous studies using legume green manure crops have shown similar results. Decker et al. (1987) reported no N fertilizer response in field corn above a rate of 80 kg-ha⁻¹ following fall-seeded legume winter cover crops. And field corn yields increased significantly compared to a control after 3 years of a nonharvested alfalfa (*Medicago sativa* L.) crop that contained N at 170 kg-ha⁻¹·year⁻¹ (Sheaffer et al., 1991).

Broccoli yields in the cereal rye/pea plots

Fig. 2. Yield of sweet corn ears at three N rates and for three winter cover crop treatments averaged over three growing seasons (1990, 1992, and 1994). The bars for fallow treatments shown do not include data from 1992 since there were no fallow plots for sweet corn that year (wheat was grown in the conventional winter-fallow system). Mean separation by Fisher's Protected LSD, $P \leq 0.05$.

at 140 or 280 kg-ha⁻¹ in 1991 were equivalent but with cereal rye or winter fallow, broccoli yield increased significantly at all N rates (Table 5). In 1993, however, broccoli yields with N at 140 or 280 kg-ha⁻¹ did not differ significantly for all winter cover crop treatments (Table 5). This result contrasts with a study without cover crops that showed a higher broccoli yield with N applied at 250 than at 125 kg-ha⁻¹ (Kowalenko and Hall, 1987). At the intermediate rate in 1991, and the zero and intermediate rates in 1993, legume cover crops had a positive effect on broccoli yields (Table 5), and the highest fresh mass yield was obtained with N at 140 kg-ha⁻¹ after the pea/cereal rye mix cover crop (Table 5). For both years, broccoli grown with no fertilizer N after a legume-containing winter cover crop had an average yield of 6.5 Mg-ha⁻¹, while a cereal rye or fallow treatment resulted in a mean yield of 4.1 Mg-ha⁻¹ with no fertilizer N. In 1993, broccoli grown without N after a relay clover cover crop had a yield equivalent to that obtained at the recommended N rate (Table 5), and yields following all winter cover crops, except cereal rye, reached their maximum yields in this experiment with N at 140 kg-ha⁻¹.

Conclusions

In theory, cereal winter cover crops that annually conserve fertilizer N and then are repeatedly incorporated into the soil should reduce the amount of N that needs to be applied to the summer crop. After 5 cropping years, our results showed that cereal rye did not have this effect on fertilizer requirements because yields of vegetables were similar between fallow and cereal rye plots at zero or intermediate N rates. In contrast, Ditsch and Alley (1991), who had N recovery rates [11 to 81 kg-ha⁻¹ for wheat (*Triticum aestivum* L. em Thell) and cereal rye cover crops] similar to ours, found that these cereal cover crops could make a significant N contribution to field corn. More time may be needed under Pacific Northwest soil and climatic conditions before N can accumulate to levels where recycled cover crop N is available to summer crops in cereal rye cover-cropped soils. Alternatively the cereal rye may have an allelopathic effect on subsequent vegetable crops. Results from our study suggest that a legume is needed in a

cover crop mix or alone for farmers to reduce N application below the recommended rate for subsequent vegetable crops.

Legume winter cover crops contributed significant amounts of N to increase sweet corn and broccoli yields. Sweet corn following a legume-containing cover crop and fertilized at one-quarter the recommended N rate, produced ear yields equivalent to those of sweet corn at the recommended N rate with winter fallow or a cereal rye cover crop. Similarly, 1991 broccoli yields after a legume winter cover crop and with one-half the recommended N rate were not significantly different from yields following winter fallow or cereal rye winter cover crops at the recommended N rate. Cereal rye was able to capture residual soil N that would otherwise have been leached, but its negative effect on subsequent sweet corn and broccoli yields suggests that a different non-leguminous species winter cover crop should be used to recover residual fertilizer N.

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