The Effect of Cover Crops and Fertilization with Ammonium Nitrate on Corky Root of Lettuce

ARIENA H. C. VAN BRUGGEN, Assistant Professor, and PHILIP R. BROWN, Post Graduate Research Assistant, Department of Plant Pathology, University of California, Davis 95616; CAROL SHENNAN, Assistant Professor, Department of Vegetable Crops, University of California, Davis 95616; and ARTHUR S. GREATHEAD, Former Farm Advisor, University of California, Agricultural Extension, 118 Wilgart Way, Salinas, CA 93901

ABSTRACT

van Bruggen, A. H. C., Brown, P. R., Shennan, C., and Greathead, A. S. 1990. The effect of cover crops and fertilization with ammonium nitrate on corky root of lettuce. Plant Dis. 74:584-589.

Rye (*Secale cereale*) planted as a winter cover crop slightly reduced the severity of corky root early in the growing season of a subsequent lettuce crop, but at harvest the suppressive effect was observed in only one of four lettuce crops. Lettuce yields were not affected by cover crop use. Side-dressing with ammonium nitrate increased corky root severity in most plots and reduced yield in all plots. There were no significant interactions between cover crops and nitrogen fertilization with respect to lettuce yield. Nitrate concentrations tended to be lower in lettuce plants grown in the previously fallowed plots than in those grown in plots that had been cover-cropped, and higher in the plants grown in plots that received a side-dressing with ammonium nitrate. The soil moisture content at depths of 75 and 90 cm was lower in plots planted to rye than in those planted to broad bean or left fallow. The reduction in corky root after a rye cover crop might be related to a reduction in soil moisture or improvement in soil structure rather than to nitrate content in soil or lettuce tissue. The inoculum potential in soil, determined with a lettuce bioassay, was not affected by cover crop.

In the Salinas Valley of California, approximately 25,000 ha of lettuce are planted annually, with a total value of $243 million (11). Continuous cropping of lettuce has resulted in decreased soil organic matter and deteriorated soil structure over the past 20 yr (3). In that same period, the corky root disease of lettuce has become increasingly destructive (6,14). In the past, this disease was thought to be caused by toxins liberated from decomposing lettuce debris (2,8), but recently it was shown to be caused by a gram-negative bacterium (22,23) for which the name *Rhizomonas suberifaciens* has been proposed (24). Symptoms of the disease include yellow bands on the taproot and main laterals that develop into dark greenish brown and corky areas. The taproots become brittle and break off easily. Severely infected lettuce plants usually have only a few superficial, adventitious roots without a proper taproot. To sustain plant growth until maturity, heavy irrigation up to 4 days before harvest has become a common practice in recent years. This practice results in wet soils during harvesting and plowing, a deteriorated soil structure, and an increase in the severity of corky root in the next lettuce crop (7).

Accepted for publication 16 January 1990 (submitted for electronic processing).

In field experiments in the Salinas Valley, Patterson et al (15) obtained a reduction in the severity of corky root and an increase in yield using cultural practices that decreased soil compaction and improved aeration. Included among these practices were a reduction in the number of irrigations, an increase in bed height, and cover cropping with rye (*Secale cereale* L.) (7,15). In other experiments, van Bruggen et al (21) demonstrated that the severity of corky root increased with nitrogen fertilization.

Use of winter cover crops has been recommended for many years for improvement of soil conditions (20). Beneficial effects include: 1) increased organic matter and improved soil structure; 2) reduced soil erosion; 3) breaking up of man-made hardpans; 4) absorption of nutrients from deeper soil layers, which become available during decomposition of the cover crop; and 5) absorption of water from deeper soil layers, so that the subsoil can become aerated (20). At present, cover crops are used in an estimated 10% of the lettuce-growing region of the Salinas Valley. The most common cover crops are rye and broad beans (*Vicia faba* L.). Occasionally, barley (*Hordeum vulgare* L.), triticale, or vetch (*V. sativa* L.) are grown. In a single experiment in the Salinas Valley, lettuce grown in plots previously cover-cropped with rye had less corky root than lettuce grown in control plots (7).

Cover crops also affect the nutrients available to subsequent crops. However, potential interactions between cover cropping and nitrogen fertilization in relation to corky root have not been investigated. The objectives of the research described here were: 1) to determine the effects of winter cover crops (broad bean and rye) on the moisture level in the subsoil and the inoculum potential of *R. suberifaciens* in the plow layer and 2) to investigate the effects of the same winter cover crops and side-dressing with ammonium nitrate on the severity of corky root, the tissue ammonium and nitrate concentrations, and yield of subsequent lettuce crops.

MATERIALS AND METHODS

Location and experimental design. Winter cover crops were followed by two lettuce crops at the USDA Agricultural Experiment Station in Salinas in two successive years (Table 1). The field (Chualar loam; 45% clay, 35% silt, 15% sand, and 5% gravel) had been planted to various lettuce cultivars in 1983 and 1984, and corky root was quite severe in most cultivars. The same field was fallow in 1985 and planted to peppers and tomato in 1986. The experiment was initiated in the fall of 1986 when the cover crops were planted (Table 1).

The experiment had a split-plot design with six replications arranged in randomized complete blocks. Three cover crop treatments (rye, broad beans, or none) were in the main plots, and two nitrogen treatments (preplant ammonium nitrate only or preplant ammonium nitrate plus a sidedress of ammonium nitrate) were in subplots. Ammonium nitrate was selected because it is the most widely used nitrogen fertilizer in the Salinas Valley. Each plot contained seven 1.1-m-wide beds with two rows per bed (50 cm apart). The main plots and subplots were 10.7 and 5.3 m long, respectively. Paths between the main plots were 1.5 m wide.

Cultural practices. Rye (cv. Merced) and broad beans (cv. Bell Beans) were broadcast, then sprinkler-irrigated until emergence, after which irrigation was stopped. Weeds in fallow plots were controlled with paraquat according to the recommended rate (4.7 L/ha). In the spring (Table 1), the cover crops were chopped and disked under, then chisel-plowed to a depth of 25–30 cm in two directions, and disked again. Four weeks later, lettuce (cv. Salinas) was seeded, and the herbicide pronamide and, in 1988, the insecticide carbofuran (Furadan 4F) were applied according to the recommended rates. In the spring of 1987, all lettuce plots received equal amounts of ammonium nitrate (110 kg/ha of nitrogen preplant and 110 kg/ha of nitrogen as a side-dressing 1 mo after planting). In the fall of 1987 and spring of 1988, one subplot received only a preplant application (110 kg/ha of nitrogen) and the other both preplant (110 kg/ha of nitrogen) and sidedress applications (110 kg/ha of nitrogen). For the last lettuce crop, half of the subplots were not fertilized and half received only the sidedress application (110 kg/ha of nitrogen). The crops were irrigated by sprinklers throughout the season (1–2 cm water every 2–3 days until emergence, then 2 cm weekly).

Cover crop biomass and nitrogen content. Biomass was harvested from four randomly selected areas (0.1 m^2) in each plot 2 days before the cover crops were chopped and disked. The samples were dried at 70 C for 48 hr, bulked for each plot, and weighed. To determine the nitrogen content, the samples were redried overnight at 70 C, then ground in a Wiley mill with 40-mesh screen. Subsamples (0.25 g) were digested in a mixture of 2.9 ml of concentrated sulfuric acid and 2.1 ml of H_2O_2 at 100 C for 80 min (12). The temperature was increased to 150 C, catalyst ($AuSO_4$ + K_2SO_4) was added, and the temperature was raised to 380 C for 3 hr (10). Total plant nitrogen was calculated from NH_4 concentrations measured with the OPA fluorescence technique (5).

Soil moisture content during the cover crops. Soil moisture was measured with a Campbell nuclear model 503 hydroprobe (CPN Corp., Martinez, CA) 13 and 16 wk after the cover crops had been planted. One access tube was inserted in the center of each subplot of the middle four blocks (24 tubes in total). Three repeated measurements were made at each of five depths (25, 56, 75, 90, and 106 cm). Three extra tubes were inserted around the field for calibration purposes. Soil samples were taken at seven depths (at 15-cm intervals) adjacent to the calibration tubes using an auger with a volume chamber. The bulk density and the gravimetric and volumetric soil moisture contents were calculated. The neutron probes were calibrated for three depths (0–30, 35–70, and 75–120 cm) according to Karsten and van der Vyver (9).

Inoculum potential of *R. suberifaciens* in soil. In the first year, soil samples were collected to determine the inoculum potential just before and after the cover crops and just before and after the first lettuce crop. Composite soil samples, consisting of five subsamples, were taken from each plot with a trowel (18 cm deep = about 200 ml) or with a Dutch auger (20 cm deep, 7 cm diameter). An accurate soil dilution plating technique is not available for *R. suberifaciens* because of the lack of a truly selective medium and the slow growth rate of this bacterium in culture (22–24). Therefore, a most-probable-number method using a lettuce bioassay was selected to assess populations of *R. suberifaciens* in soil. First, 200 g of each sample was mixed with 300 ml of distilled water + 0.1% Tween 20, and the mixture was agitated to suspend the soil every 10 min for 2 hr. The soil extract was drained through six layers of cheesecloth, and a dilution series with four dilutions (10-fold dilutions for the first assay, 100-fold dilutions for subsequent assays) was made with distilled water. Samples of each dilution (5 ml for the first assay, 10 ml for subsequent assays) were poured at the stem bases of 2- to 3-wk-old Salinas lettuce seedlings growing in vermiculite in 5-cm pots. There were 8–10 plants per dilution. The pots were placed on individual saucers and randomized over four greenhouse benches. Uninoculated control plants (50–100) were scattered among the inoculated plants. The plants were watered daily, alternating between distilled water, 0.5-strength Hoagland's solution, and 5 mM $Ca(NO_3)_2$ + 5 mM KNO_3 solution. One month after inoculation, the plants were scored for the presence or absence of corky root symptoms.

Corky root severity and lettuce yield. Lettuce roots were scored for severity of corky root on a 0–9 scale, modified from the scale described by Brown and Michelmore (1). The modifications were made to adapt the scale to mature, field-grown plants as follows: 0 = healthy white taproot; 1 = yellow discoloration on 1–10% of the taproot; 2 = yellow to light brown discoloration on 10–25% of the taproot; 3 = light brown discoloration on 25–50% and superficial cracks on 5% of the taproot; 4 = brown discoloration on 50–75% and superficial cracks on 5–10% of the taproot; 5 = brown discoloration on 75–100% and pronounced cracks on 5–10% of the taproot; 6 = dark brown discoloration on 100% and pronounced cracks on 10–25% of the taproot, slight reduction in number of lateral roots; 7 = dark

Table 1. Planting and harvesting dates and amount of nitrogen applied to cover and lettuce crops in a field experiment at the USDA Agricultural Experiment Station at Salinas, California

Crop	Dates		Nitrogen[a] (kg/ha)
	Planting	Harvesting	
Cover (rye, broad beans)	21 Nov. 1986	7 Apr. 1987[b]	55
Lettuce	5 May 1987	15 July 1987	Preplant, 110 Thinning, 110[c]
	29 July 1987	16 Oct. 1987	Preplant, 110 Thinning, 110[c]
Cover (rye, broad beans)	1 Nov. 1987	27 Feb. 1988[b]	None
Lettuce	18 Mar. 1988	9 June 1988	Preplant, 110 Thinning, 110[c]
	3 Aug. 1988	25 Oct. 1988	Preplant, none Thinning, 110[c]

[a] From ammonium nitrate.
[b] Representative samples of aboveground biomass were harvested 2 days before cover crops were chopped and incorporated into the soil.
[c] Only in plots that received a sidedress of ammonium nitrate.

brown discoloration on 100% and pronounced cracks on 25–50% of the taproot, about 50% reduction in lateral roots; 8 = dark brown ridges and pronounced cracks on 100% of the taproot, taproot girdled at 10–15 cm below soil level, few lateral roots remaining, lower leaves mottled, and head size reduced; and 9 = taproot completely corked and girdled at 5–10 cm below soil level, no lateral roots left, plant severely stunted or dead.

At rosette stage or heading, 20 plants were systematically selected from the middle four beds in each plot; the roots were dug up and rated for disease severity. At harvest, 25 plants (fall 1987) or all plants in a 3 × 3 m square in the center of each plot were dug up, rated for disease severity, and counted, and the untrimmed heads were weighed. Five heads and 10 roots were randomly selected for dry weight measurements (dried in a forced draft oven at 80 C for 3 days).

Nitrogen analyses of lettuce tissue and soil. Dried tissue of five mature heads per plot was ground, and 100-g subsamples were used for extraction and analysis of ammonium and nitrate as described previously (21). In March, June, August, and September of 1988 (at the beginning and end of each lettuce crop [Table 1]), soil samples were taken with a Dutch auger (22 cm deep, 6 cm diameter) from the center of the bed at four locations equidistant from the edges and center of each plot. The four samples were mixed and frozen until use. The samples were analyzed for ammonium-N and nitrate-N as described previously (21).

Data analysis. Data from the bioassay on inoculum potential of *R. suberifaciens* in soil were analyzed as contingency tables (number of plants with corky root symptoms in each combination of cover crop treatment and soil dilution) with chi-square tests. In addition, the most probable number (MPN) was determined for each plot using the computer program of Pfender et al (16). MPNs were analyzed in an analysis of variance, after log transformation.

Continuous data for biomass, nitrogen content, soil moisture, and lettuce yield were analyzed using an analysis of variance with the appropriate split-plot design. All residual values were tested for normality. Discrete data for the severity of corky root were analyzed as contingency tables with chi-square tests (MINITAB, Statistics Department, The Pennsylvania State University, University Park).

RESULTS

Cover crop biomass and nitrogen content. The biomass of both cover crops was higher during 1986–1987 when nitrogen fertilizer was applied than during 1987–1988 when it was not (Table 2). In both years, rye produced significantly ($P = 0.001$) more biomass than broad bean (91% more in 1987 and 53% more in 1988). The percentage of total nitrogen was the same for both cover crops, but the total amount of nitrogen incorporated into the soil from the residue was significantly ($P = 0.001$) higher in the plots with rye (91% higher in 1987 and 46% higher in 1988). Side-dressing the lettuce crops with ammonium nitrate did not significantly increase the biomass or percentage of nitrogen of subsequent cover crops.

Soil moisture content during the cover crops. The soil moisture contents were similar for the two sampling dates, and the data were combined. The soil moisture content at the 75- and 90-cm depths was about 29% lower in the cover-

Table 2. Dry biomass (shoots only) and total nitrogen content of rye and broad beans used as winter cover crops and projected nitrogen incorporated into the soil

Cover crop	Planting date	N[a]	Biomass (t/ha)	Plant nitrogen (%)	Incorporated nitrogen (kg/ha)
Rye	21 Nov. 1986	...[b]	15.3 ± 2.9[c]	1.8 ± 0.2[c]	275
Broad bean		...	8.0 ± 1.4	1.8 ± 0.3	144
Rye	1 Nov. 1987	+	10.0 ± 1.5	2.3 ± 0.3	230
		−	10.2 ± 2.0	2.2 ± 0.3	224
Broad bean		+	6.8 ± 1.0	2.2 ± 0.2	150
		−	6.4 ± 1.7	2.5 ± 0.2	160

[a] Side-dressing of previous lettuce crop with ammonium nitrate.
[b] Not applicable.
[c] Means of six replications ± standard deviations.

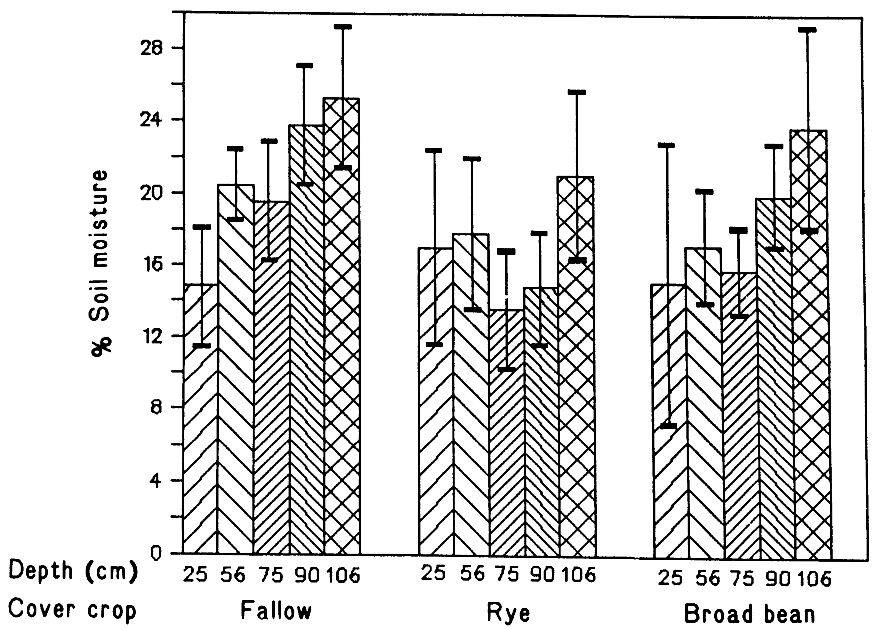

Fig. 1. Volumetric soil moisture content (%) at five depths under bare soil (fallow), rye, and broad bean 13 and 16 wk after cover crops were planted (data for both dates combined). Vertical bars denote standard deviations.

Table 3. Effect of previous cover crops on the number of plants in seven disease severity classes for corky root disease in two successive lettuce crops grown in the same plots[a]

Lettuce season	Previous cover crop	Disease score[b] 2–4	5	6	7	8	Chi-square[c]
Spring 1987[d]	None	11	30	35	40	4	
	Rye	22	26	24	34	14	18.4*
	Broad bean	16	31	27	27	19	
Fall 1987[e]	None	3	2	16	38	1	
	Rye	13	7	14	25	1	18.5*
	Broad bean	4	3	10	42	1	

[a] All lettuce plots were side-dressed with ammonium nitrate (110 kg/ha of nitrogen).
[b] A 0–9 scoring scale for severity of corky root, based on percentage of taproot area yellow or corked.
[c] Cover crop effect; * = significant at $P = 0.05$.
[d] Disease scored 8 wk after planting.
[e] Disease scored 5 wk after planting.

cropped plots than in the fallow plots ($P = 0.0001$) (Fig. 1). However, depth interacted with cover crop ($P = 0.0001$). At 90 cm, the percent moisture was about 30% lower under rye than under broad bean ($P = 0.05$). Thus, both cover crops reduced the moisture content of the soil, but rye dried the soil to a greater depth (90 cm) than did broad beans.

Inoculum potential of *R. suberifaciens* in soil. The inoculum potential was similar in all plots before treatments were applied (0.2 infective units per gram of soil) and was not affected by cover crop treatment. Before the first lettuce crop was planted, the inoculum potential was 2.6 infective units per gram of soil; after harvest, the potential was 0.8 units. The estimates of infective units before and after the lettuce crop are not comparable, however, because the bioassays conducted to determine the inoculum potential were performed in different seasons.

Corky root severity and lettuce yield. In 1987, 8 and 5 wk after the first and second lettuce crops, respectively, were planted, the severity of the disease was slightly, but significantly, lower in the rye treatment than in the broad bean or fallow treatments (Table 3). The mean scores were 5.8 for both lettuce crops after rye, 6.0 for the spring crop after fallow or broad bean, and 6.5 for the fall crop after fallow or broad bean. At harvest, there were no significant cover crop effects on disease severity, except for the fall of 1988 (Table 4), when disease severity was lower in the cover crop treatments than in the fallow treatment ($P = 0.005$) and also lower in the rye treatment than in the broad bean treatment ($P = 0.05$). In the fall of 1987, there was a significant interaction between the nitrogen fertilization and cover crop treatments. Without cover crop, the additional nitrogen application had no effect, but after the cover crop treatments, nitrogen side-dressing increased the disease ($P = 0.005$). In the spring of 1988, corky root severity was significantly increased by nitrogen side-dressing, but in the fall of that year, disease severity was not affected by nitrogen side-dressing.

Lettuce stand (number of plants per square meter) was lower in both cover-crop treatments than in the fallow treatment in the spring of 1987 (4.9 vs. 5.6 plants per square meter) and in the rye treatment in the spring of 1988 (6.1 plants after rye vs. 7.3 and 7.6 plants per square meter in the broad bean and fallow plots, respectively). Plant stand was not determined in the fall of 1987, but in the fall of 1988 the number of lettuce plants was not affected by previous cover crop treatments.

The cover crop treatments did not affect the yield (head fresh weight) of subsequent lettuce crops, whereas the nitrogen sidedresses led to significant reduction in head fresh weight (Table 5). This was associated with an increase in corky root severity in the fall of 1987 (in plots that had been cover-cropped) and spring of 1988 (Table 4). Head and root dry weights of all lettuce crops were not affected by either cover crop or nitrogen treatments.

Nitrogen content of soil and lettuce tissue. In March of 1988, after the first lettuce crop was planted, the mean concentrations of NO_3-N in the soil were 11 ± 15, 27 ± 11, and 29 ± 14 ppm for the rye, fallow, and broad bean treatments, respectively. The differences were not significant, however. After harvest of this crop, the NO_3-N concentrations did not differ significantly for any of the treatments, whereas the NH_4-N concentration was higher ($P = 0.02$) in the plots that had received a sidedress with ammonium nitrate, but only in those plots that had not been cover-cropped (5.2 ± 0.6 and 4.4 ± 0.7 ppm with and without sidedress, respectively). In August and September, during the second lettuce crop, the concentrations of NH_4-N and NO_3-N in soil were not affected by previous cover crop treatments but were higher after side-dressing with ammonium nitrate than without side-dressing ($P = 0.04$ for NH_4-N and $P = 0.01$ for NO_3-N). The mean values were 5.0 ± 1.3

Table 4. Effect of cover crops and ammonium nitrate side-dressing on the number of plants in six severity classes of corky root disease of lettuce at harvest in the spring and fall of 1987 and 1988

Lettuce season	Previous cover crop	N[a]	Disease score[b] 3–4	5	6	7	8	Chi-square[c] CC × N	CC	N
Spring 1987	None	+	7	40	126	51	8			
	Rye	+	5	42	89	36	5		**8.3**	
	Broad bean	+	3	51	84	34	5			
Fall 1987	None	+	3	107	38	2	0			
		−	0	101	47	2	0			
	Rye	+	1	80	63	6	0			
		−	7	85	50	8	0	16.5**	22.9**	4.6
	Broad bean	+	0	98	44	7	1			
		−	4	110	32	3	1			
Spring 1988	None	+	0	274	116	2	0			
		−	10	345	50	0	0			
	Rye	+	9	251	98	0	0	4.7	2.8	83.9**
		−	4	262	58	0	0			
	Broad bean	+	4	259	126	0	0			
		−	12	326	51	0	0			
Fall 1988	None	+	1	104	115	5	0			
		−	0	103	127	13	0			
	Rye	+	3	135	82	2	0	4.0	30.0**	3.2
		−	4	135	95	4	0			
	Broad bean	+	3	127	107	9	0			
		−	5	106	113	5	0			

[a]Side-dressing with ammonium nitrate (110 kg/ha).
[b]A 0–9 scoring scale for severity of corky root, based on percentage of taproot area yellow or corked.
[c]CC = cover crop effect, N = nitrogen effect, CC × N = interaction between cover crop and nitrogen treatments; ** = significant at $P = 0.01$.

Table 5. Effect of cover crops and a sidedress with ammonium nitrate on head fresh weight (g) of two lettuce crops in 1987 and 1988

Cover crop	N[a]	1987 Spring crop	1987 Fall crop	1988 Spring crop	1988 Fall crop
None	+	506 ± 64[b]	241 ± 56[b]	572 ± 68[b]	476 ± 152[b]
	−		274 ± 58	627 ± 42	553 ± 64
Rye	+	484 ± 123	210 ± 117	622 ± 91	469 ± 72
	−		309 ± 154	664 ± 105	553 ± 60
Broad bean	+	500 ± 98	246 ± 68	577 ± 93	563 ± 98
	−		281 ± 65	609 ± 109	559 ± 90
***F* values**[c]					
CC		0.12	0.01	1.27	0.65
N		···	8.14**[d]	5.02*	4.33*
CC × N		···	1.23	0.12	1.03

[a]Side-dressing with ammonium nitrate (100 kg/ha).
[b]Means of six replications ± standard deviations; Bartlett's test for homogenicity of variances showed that the variances were not significantly different.
[c]CC = cover crop effect, N = nitrogen effect, CC × N = interaction between cover crop and nitrogen treatments.
[d]* = Significant at $P = 0.05$, ** = significant at $P = 0.01$.

and 8.1 ± 4.4 ppm NH_4-N and 52.9 ± 24.3 and 82.0 ± 31.1 ppm NO_3-N, without and with side-dressing, respectively.

With respect to concentrations of NH_4-N and NO_3-N in lettuce tissues, there were no significant interactions between cover crop and nitrogen fertilization treatments. The plot-to-plot variability was fairly high, and side-dressing with ammonium nitrate increased the NO_3-N concentrations only slightly (on average, 8.5%). This difference was not significant, however. In the fall of 1988, the mean NH_4-N concentrations were 286 ± 80 and 251 ± 67 ppm with and without side-dressing, respectively ($P = 0.08$). Cover cropping with rye or broad bean increased the NO_3-N concentration in lettuce tissue slightly in both spring crops, but the effect was significant only in 1988 ($P = 0.06$). There were no significant differences between rye and broad beans in this respect. The mean NO_3-N concentrations were 0.36 ± 0.06%, 0.44 ± 0.05%, and 0.45 ± 0.07% for lettuce grown in plots that had been fallow, grown to rye, or grown to broad bean, respectively.

DISCUSSION

In a grower's field with compaction problems, Grogan et al (7) demonstrated that use of a rye cover crop led to a reduction in corky root and an increase in lettuce yield. In the experiments discussed in this paper, rye planted as a winter cover crop led to a reduction in corky root severity in only one of four subsequent lettuce crops, but this reduction was not associated with an increase in yield. The broad bean cover crops affected neither corky root severity nor the yield of subsequent lettuce crops. The soil used for these experiments may have been less compacted than that used by Grogan et al (7).

Both cover crops depleted soil moisture at intermediate depths (75 and 90 cm) relative to fallow plots, but broad beans to a lesser extent than rye. Thus, a reduction in corky root in one lettuce crop following rye may have resulted from a reduction in soil moisture or improved soil structure. Grogan et al (7) observed that the reduction in corky root after a rye cover crop seemed to be related to a reduction in soil bulk density. From a cover crop study on mine-soil, Swiader and Morse (19) concluded that incorporation of green manures (fescue or rye plus soybean) improved yields of various vegetable crops because of improved soil physical properties and soil moisture status rather than nutritional factors.

In previous experiments, we demonstrated that corky root was increased when lettuce was side-dressed with nitrogen fertilizers (21). In the tests reported here, however, the significant reduction in corky root following a rye cover crop (fall 1988) was not accompanied by a reduction in nitrogen concentration in soil or lettuce tissue. In the spring of 1988, on the other hand, the nitrate concentration in lettuce tissue was significantly higher in plots that had been planted to the cover crops, but the severity of corky root did not increase. Thus, the reduction in corky root after a rye cover crop does not seem to be mediated by nitrogen availability or uptake.

Ammonium nitrate sidedresses decreased yield of all lettuce crops in this study and increased corky root in some of the lettuce crops. This was in agreement with results from other experiments at Davis and Salinas (21). The fact that a decrease in yield was not always correlated with an increase in corky root indicates that at least a portion of the reduction in yield may have been due to ammonia toxicity (21). Nevertheless, *R. suberifaciens* was isolated from lettuce plants with symptoms of the corky root disease. The nitrogen concentrations in lettuce tissue and soil were relatively high but were similar to those encountered in some growers' fields (21). The irrigation water used in the current experiments contained relatively high concentrations of nitrate (90 and 80 ppm in 1987 and 1988, respectively), but this too is not uncommon in the Salinas Valley (4). A combination of symptoms of infectious corky root (caused by *R. suberifaciens*) and noninfectious corky root (caused by ammonia toxicity) has been observed in a grower's field in the Salinas Valley (21).

In both spring seasons, the lettuce stand was reduced in plots that had been planted to rye the previous winter and, in the spring of 1987, also in plots that had been planted to broad bean. Wireworms (*Limonius* sp.) were observed in both spring crops (despite application of an insecticide in the second year), and they were probably the main cause of the stand reduction. Wireworms can cause problems after various other cover crops, especially when such crops are turned under relatively late in the spring (18). Wireworms were also a problem in the second lettuce crop (fall 1987) and were probably responsible for the poor stand and low yields of that crop. Besides wireworms, damping-off by *Pythium* spp. and *Rhizoctonia solani* and general toxicity from decomposing debris can cause problems after cover cropping, particularly when insufficient time is allowed for decomposition of the plant material (17,13). In our experiments, lettuce was sown at least 1 mo after the cover crops were turned under. Under optimal conditions for decomposition, this waiting period was shown to be sufficient time for dissipation of the toxic effect of decomposing broad bean and, to a lesser extent, of rye (13).

In conclusion, cover cropping with broad bean did not control corky root and cover cropping with rye reduced lettuce corky root only slightly. In areas with severely compacted soil, however, rye cover cropping may be beneficial.

ACKNOWLEDGMENTS

We thank Hubert van Rijckevorsel and Gerard de Boer of the Cooperative Extension DANR Diagnostic Laboratory at U.C. Davis for the nitrogen analyses and Rebecca Bozarth, Carl Bogdanoff, and Michelle Wander for their assistance in the field and laboratory. This research was partially funded by the California Iceberg Lettuce Research Program and the University of California Statewide IPM Project.

LITERATURE CITED

1. Brown, P. R., and Michelmore, R. W. 1988. The genetics of corky root resistance in lettuce. Phytopathology 78:1145-1150.
2. Busch, L. V., and Barron, G. L. 1963. Root rot of head lettuce in Ontario. Can. J. Plant Sci. 43:166-173.
3. Dillard, H. R., and Grogan, R. G. 1985. Influence of green manure crops and lettuce on sclerotial populations of *Sclerotinia minor*. Plant Dis. 69:579-582.
4. Friedrich, A., and Zicarrelli, J. 1987. Update on water quality in Monterey County. Monterey County's Progress in Public Health (March), Department of Health, Salinas, CA.
5. Goyal, S. S., Rains, D. W., and Huffaker, R. C. 1988. Determination of ammonium ion by fluorometry or spectrophotometry after on-line derivatization with O-phthalaldehyde. Anal. Chem. 60:175-179.
6. Grogan, R. G., Kimble, K. A., Engler, D. E., Patterson, C. L., Waters, C. M., Roberts, H., and Delp, B. 1981. Development of procedures for optimal control of fungal, bacterial, and physiological diseases of lettuce. Pages 21-42 in: Annual Report 1980-1981, Iceberg Lettuce Research Program, Salinas, CA.
7. Grogan, R. G., Patterson, C. L., Waters, C. M., Kimble, K. A., Roberts, H., Delp, B., and Engler, D. 1982. Development of procedures for optimal control of fungal, bacterial, and physiological diseases of lettuce. Pages 25-35 in: Annual Report 1981-1982, Iceberg Lettuce Research Program, Salinas, CA.
8. Hartnett, J. P., and Lorbeer, J. W. 1971. The production of a noninfectious lettuce root rot under controlled environmental and soil conditions. Phytopathology 61:1153-1158.
9. Karsten, J. H. M., and van der Vyver, C. J. 1982. The form of the calibration curve of a neutron moisture meter near the soil surface. Commun. Soil Sci. Plant Anal. 13:191-196.
10. Novozamsky, I., Houba, V. J. G., van Eck, R., and van Vark, W. 1983. A novel digestion technique for multi-element plant analysis. Commun. Soil Sci. Plant Anal. 14:239-248.
11. Nutter, R. W. 1986. Annual crop report for Monterey County, 1985. Agricultural Commissioner's Office, Salinas, CA. 18 pp.
12. Parkinson, J. A., and Allen, S. E. 1975. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Commun. Soil Sci. Plant Anal. 6:1-11.
13. Patrick, Z. A., Toussoun, T. A., and Snyder, W. C. 1963. Phytotoxic substances in arable soils associated with decomposition of plant residues. Phytopathology 53:152-161.
14. Patterson, C. L., Grogan, R. G., and Campbell, R. N. 1986. Economically important diseases of lettuce. Plant Dis. 70:982-987.
15. Patterson, C. L., Waters, C. M., and Grogan, R. G. 1981. Factors affecting corky root of lettuce in California. (Abstr.) Phytopathology 71:898.
16. Pfender, W. F., Rouse, D. I., and Hagedorn, D. J. 1981. A "most probable number" method for estimating inoculum density of *Aphanomyces euteiches* in naturally infested soil. Phytopathology 71:1169-1172.
17. Phillips, D. J., Watson, A. G., Weinhold, A. R., and Snyder, W. C. 1971. Damage of lettuce

seedlings related to crop residue decomposition. Plant Dis. Rep. 55:837-841.
18. Stone, M. W. 1951. Effect of winter cover crops on wireworm injury to the dry lima bean crop. U.S. Dep. Agric. Tech. Bull. 1039. 20 pp.
19. Swiader, J. M., and Morse, R. D. 1984. Influence of organic amendments on solution phosphorous requirements for vegetables in minesoil. J. Am. Soc. Hortic. Sci. 109:150-155.
20. Thompson, H. C., and Kelly, W. C. 1957. Vegetable Crops. McGraw-Hill Book Co., New York. 611 pp.
21. van Bruggen, A. H. C., Brown, P. R., and Greathead, A. 1990. Distinction between infectious and non-infectious corky root of lettuce in relation to nitrogen fertilizer. J. Am. Soc. Hortic. Sci. In press.
22. van Bruggen, A. H. C., Brown, P. R., and Jochimsen, K. N. 1989. Corky root of lettuce caused by strains of a gram-negative bacterium from muck soils of Florida, New York, and Wisconsin. Appl. Environ. Microbiol. 55:2635-2640.
23. van Bruggen, A. H. C., Grogan, R. G., Bogdanoff, C. P., and Waters, C. M. 1988. Corky root of lettuce in California caused by a gram-negative bacterium. Phytopathology 78:1139-1145.
24. van Bruggen, A. H. C., Jochimsen, K. N., and Brown, P. R. 1990. *Rhizomonas suberifaciens* gen. nov., sp. nov., the causal agent of corky root of lettuce. Int. J. Syst. Bacteriol. 40:175-188.