Meeting the Nitrogen Needs of Processing Tomatoes through Winter Cover Cropping

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A field study was initiated in 1986 in Davis, CA, to determine the long-term effects of "winter green manures/cover crops" on N dynamics and soil structural and biological properties in a semi-arid, irrigated cropping system. Results from the first 2 y of the experiment are used to compare the productivity of several legume green manures and to determine if they can provide adequate available soil N to support yields of a subsequent crop of processing tomatoes (*Lycopersicon lycopersicum* L. Karsten var. *lycopersicum*) typical for this area. Lana woolly-pod vetch (*Vicia dasycarpa* Ten.), bell beans (*Vicia faba* L.), berseem clover (*Trifolium alexandrinum* L.), Austrian winter peas (*Pisum arvense* L.), oats (*Avena sativa* L.), and an oats and vetch mixture, planted in October and disked under in April, were compared with various levels of ammonium sulfate fertilizer. Lana vetch produced the greatest biomass of the legumes, and fixed the most N (90 lb/acre by February, and 230 lb/acre by March in 1987, as determined by the difference method). Use of green manures, relative to winter fallow, dried out the soil (0–24 in. depth) by an amount equivalent to 0.4 to 0.8 in. of water depending on the cover crop. Tomato yields for the legume cover-cropped plots were as high as those in the fertilizer-treated plots, but the response to applied N was low. Nitrate levels in the top 8 in. of soil in vetch-treated plots remained as high as in the 200 lb N/acre ammonium sulfate fertilizer plots throughout the growing season.

GREEN MANURING is defined as the process of incorporating a crop into the soil to effect some agronomic improvement, such as improving soil structure, conserving such leachable nutrients as NO_3^-, or, in the case of legume green manures, to increase soil N content (MacRae and Mehuys, 1987; Power and Schepers, 1989). Green manures can also act as cover crops, covering and protecting the soil from wind or water erosion. Prior to World War II and the beginning of intensive use of chemical fertilizers, legumes were the main input of N in agricultural soils. Since the early 1980s there has been a renewed interest in the incorporation of legumes in cropping systems, particularly as green manures, to improve soil structure and as a N source (Hoyt and Hargrove, 1986; Smith et al., 1987). Factors fueling this growing interest include the increased adoption of minimum- or no-till production systems for which winter cover crops are particularly well suited (Hoyt and Hargrove, 1986; Ebelhar et al., 1984; Hargrove, 1986), rising concerns about the environmental impacts of agricultural production (e.g., erosion and groundwater contamination by NO_3^-; Power, 1987), and fluctuating fossil fuel prices during the 1970s and 1980s which created the awareness that chemical fertilizers are manufactured from nonrenewable resources (Smith et al., 1987). In California, the increasing severity of soil structural problems, including crusting, compaction, low water infiltration capacities, salinity, and loss of soil organic matter also have contributed to the renewed interest in green manuring/cover cropping (LAWR, 1984; Williams, 1966).

Studies on green manuring have reported many site- and year-specific results on dry matter accumulation and amount of fixed N (Hoyt and Hargrove, 1986; Smith et al., 1987). Legume N is generally reported to be less efficient, i.e., less available, than fertilizer N based on recovery of applied N (Smith et al., 1987; Yaacob and Blair, 1980; Ladd and Amato, 1986). The lower efficiency of legume-N usually is attributed to higher rates of immobilization by soil microbes. Differences in N availability among legume cover crops can vary widely depending on the species grown, soil type, climate, and management practices, such as whether the cover crop is incorporated into the soil or herbicide-killed and left as a surface mulch. The factors controlling the availability of legume-N to the following crop are not well understood. Because the release of N from organic sources, such as green manures, is so closely tied to complex microbial cycling of C and N, the availability and effects of legume-N are more difficult to predict than for chemical fertilizer-N (Groffman et al., 1987).

Most recent research on green manures has focused on minimum- and no-till grain production systems. Very little has been done with vegetable production even though these tend to be relatively high-input systems. Incorporating winter green manures into processing tomato cropping systems in California may hold much potential. Processing tomatoes are one of California's most important crops, with over a quarter of a million acres harvested annually (California Crop and Livestock Reporting Service, 1989). Mild, rainy winters in many of the major tomato producing areas offer ideal conditions for green manure growth and N fixation. Several studies have indicated that tomatoes have low fertilizer recovery rates, deriving much of their N from soil pools (Miller et al., 1981; Hills et al., 1983), which could be increased by additions of organic N.

The results reported here are part of a larger study which aims to determine the long-term effects of winter green manure/cover crops in a semi-arid irrigated system on: N availability for subsequent summer crops that differ in N demand; losses of N through leaching; N use efficiency and soil structural and biological properties.

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Received 15 Dec 1989. *Corresponding author.

Published in J. Prod. Agric. 4:330–335 (1991).

The specific aims of the first 2 yr of the study were to compare the productivity of several winter legume green manures, and to determine if they could provide adequate available soil N to reduce or eliminate the need for chemical N fertilizer in processing tomato production.

MATERIALS AND METHODS

The 1.5-acre field site was located in Davis, CA, on a coarse-loamy, mixed, Thermic Mollic Xerofluvent soil with a pH of 7.7, CEC of 25.4 meq/100 g soil, and 33 ppm $NaHCO_3$-extractable P. The design was a non-factorial split-plot with four replicate blocks, in which main plot treatments were either winter green manuring or winter fallow. The green manured main plots were subdivided into six green manures, and the winter fallow main plot subdivided into six rates of ammonium sulfate fertilizer application to the summer crop. Glyphosate was applied to winter fallow plots in January 1988 for winter weed control.

Green manures, seeded in October 1986 and 1987, flailed and disked in early April 1987 and 1988, included lana woolly-pod vetch, Austrian winter peas, berseem clover, bell beans, oats, and an oat and vetch mixture (seeded 50%-50%). Green manures were sprinkle-irrigated with 1 in. of water in October 1986 but not in 1987. Ammonium sulfate was applied as a banded split application (20 lb N/acre as an April preplant with the balance sidedressed in June) at a rate of 0, 50, 100, 150, 200, and 250 lb N/acre in winter-fallowed plots only. Two fertilizer bands per bed were placed 6 in. to either side of the center and 8 in. below the surface. UC82B processing tomatoes were direct-seeded to the center of the bed approximately 3 wk after disking of the cover crops, sprinkle irrigated to a stand, and furrow irrigated through the summer. Irrigation volume was calculated to replace estimated ET losses using ET_0 data and crop coefficients (California Irrigation Management Information System, 1988).

Plant Analysis

Above-ground biomass of the green manures (crop plus weeds) were sampled in January, February, and March of 1987 using a 3-sq-ft quadrat. In 1988, two 3-sq-ft samples were taken in March only. Plant material was dried at 149° F (65° C), weighed, and the samples from the oat-vetch mixture separated into oats and vetch plus weeds. Samples were ground in a Wiley mill to pass a 0.004-in. (1 mm) screen. Total N was determined by micro-Kjeldahl digestion and analyzed for NH_4^+-N by the OPA method (Goyal et al., 1988). Nitrogen fixation for 1986-1987 was estimated by the total-N-difference method, using oats as the control. Tomato plants were sampled throughout the season for biomass and total N. Tomato yields were measured by hand-harvesting 30 ft of row in September 1987 and October 1988. Fruit samples were taken for quality analysis including size, pH, and soluble solids.

Soil Analysis

Throughout both years, soil samples were taken at depths of 0 to 8, 8 to 16, 16 to 24, and 24 to 48 in. The 0 to 8 in. depth was sampled using a 0.75-in. diameter soil probe. Twenty cores, taken from the center of the tomato beds (on 60-in. centers), were collected and bulked per plot. The deeper depths were sampled using a Giddings hydraulic corer (Ft. Collins, CO). Fifteen 2-in. diameter cores were collected and bulked per plot. All soils were stored frozen until analyzed. 1.8 oz (50 g) subsamples were extracted with 8.5 oz (250 ml) 2 M KCl, and inorganic NO_3^- and NH_4^+ were determined by the Carlson method (Carlson, 1986). Soil moisture was measured gravimetrically. Oven-dried subsamples of selected soils were analyzed for total N by the

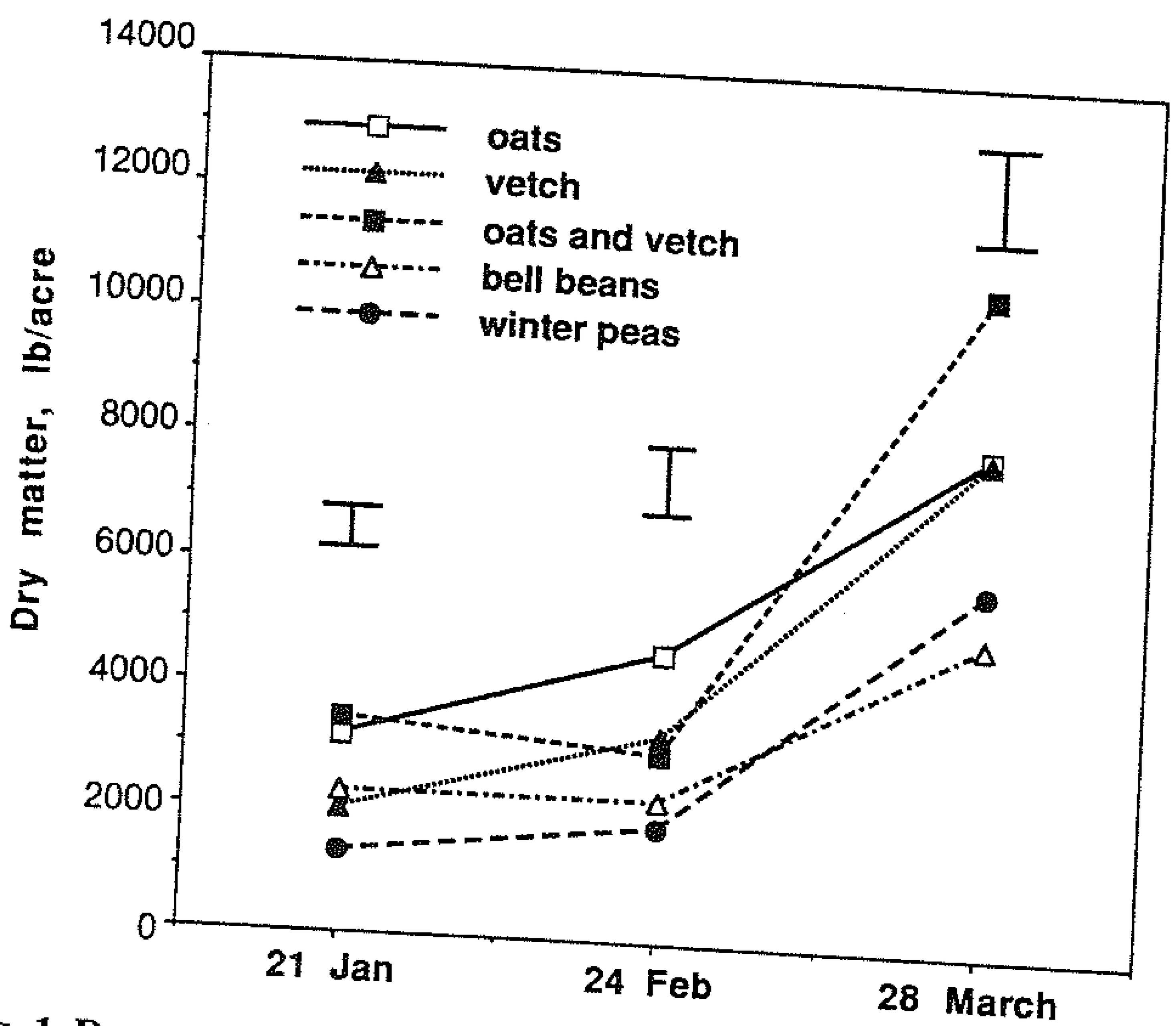

Fig. 1 Dry matter accumulation, in pounds per acre of oats, vetch, oats and vetch, bell beans, and Austrian winter peas in 1987. Each value represents the mean of four replicates, and length of bars indicate the LSD at $P = 0.05$.

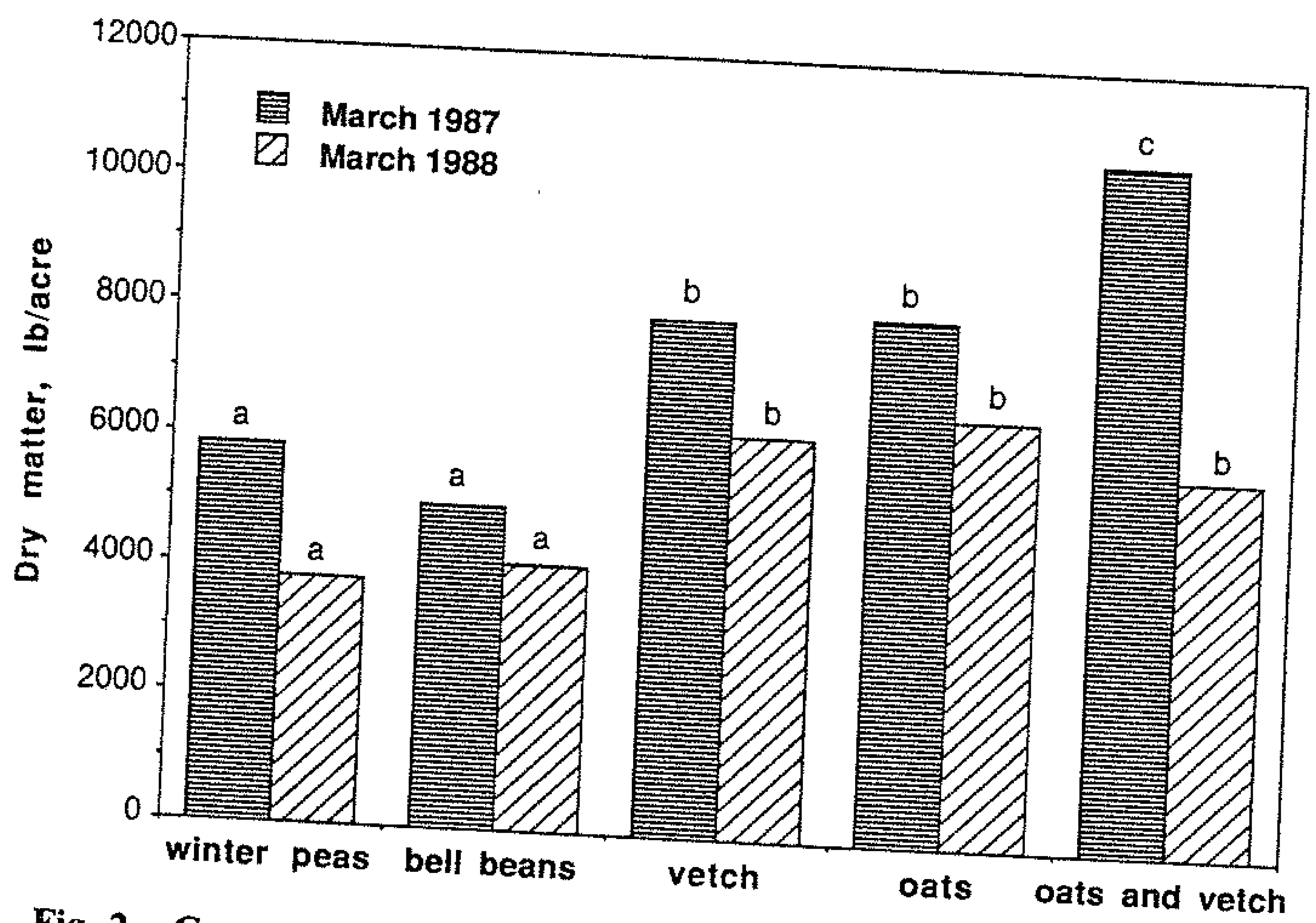

Fig. 2. Comparison of dry matter accumulation of Austrian peas, bell beans, vetch, oats, and oats and vetch, immediately prior to disking in March 1987 and March 1988. Each value represents the mean of four replicates. Letters indicate within-year mean separation by LSD at $P = 0.05$.

Kjeldahl method (Bremmer and Mulvaney, 1982). In 1988 irrigation water samples were collected and monitored for NO_3^- using a Dionex (Sunnyvale, CA) ion chromatograph.

RESULTS

Dry matter production for the winter cover crops are shown in Fig. 1 and 2. By late March, the oats and vetch mixture had produced the greatest standing biomass, 10 800 lb/acre, followed by oats at 8000 lb/acre, and vetch at 7960 lb/acre. Results for berseem are not shown because these plots were frost-damaged in late January 1987 and were mowed to permit faster regrowth. Berseem plots during both years were very weedy. Figure 2 shows dry matter production just prior to disking for March 1987 and 1988. Green manure biomass was lower in 1988, probably due to cooler, drier conditions. The greatest decrease in growth is shown in the oats and vetch mixture; both species were affected equally since the relative biomass of each (54% oats and 46% vetch) did not differ between 1987 and 1988.

Nitrogen fixation was estimated by the difference method using the oats as the non-fixing control and based upon above-ground biomass N content (Hauck and Bremner, 1976). Results are shown in Fig. 3. Estimates were not made for 1988 because, after the first year's rotation, soil N conditions differed between the legume and the oat plots. Using this method, lana woolly-pod vetch was estimated to have fixed 90 lb N/acre by 24 February and 230 lb N/acre by 28 March. Both the high biomass accumulation and the high N content of the vetch (4.2% in February and 3.6% in March) contribute to these high values for total N fixation. Austrian winter peas, at 3.5% N and moderate dry matter accumulation, fixed 150 lb N/acre by March. Bell beans produced only slightly less biomass than the peas, but lower total N fixation in the bell beans (80 lb N/acre by March) was reflected in their lower N content (2.7%).

Soil moisture profiles under the cover crops were examined in April 1988 (Fig. 4). Soil moisture was measured in the 0 to 8 in. depth just prior to disking cover crops, and in the deeper three depths immediately following disking. Green manures dried out the soil, relative to the winter fallow of the 0 and 250 lb N/acre chemical fertilizer treatments, down to a depth of 24 in. Oats depleted soil moisture to a greater degree than vetch from 0 to 8 in. The decrease in gravimetric water content down to 24 in. in the oat plots is equivalent to a loss of 0.8 in. of water for the oats, and 0.4 in. for the vetch. Water content in the 0 to 8 in. depth following disking showed no differences between treatments (data not shown).

Nitrogen uptake and fruit yields for the tomatoes in 1987 are shown in Table 1. The county average in 1987 for machine-harvested processing tomatoes was 31 tons/acre (California Crop and Livestock Reporting Service, 1989). Tomato yields in 1987 following oats were much lower than yields in the 0-N plots. This could not be explained by a difference in N availability since total N uptake by tomato was similar for both treatments when measured in July and August (Table 1). However, large amounts of undecomposed oat residue which remained near the soil surface in the oat plots made tillage and cultivation difficult, creating rougher and less well aerated beds. This was less of a problem in the oats-plus-vetch plots where the oat residue decomposed more rapidly and significantly higher tomato yields were observed than the oat plots. Yields for 1988 were very low and showed no differences across treatments due to poor stand establishment, poor growing conditions early in the season, and

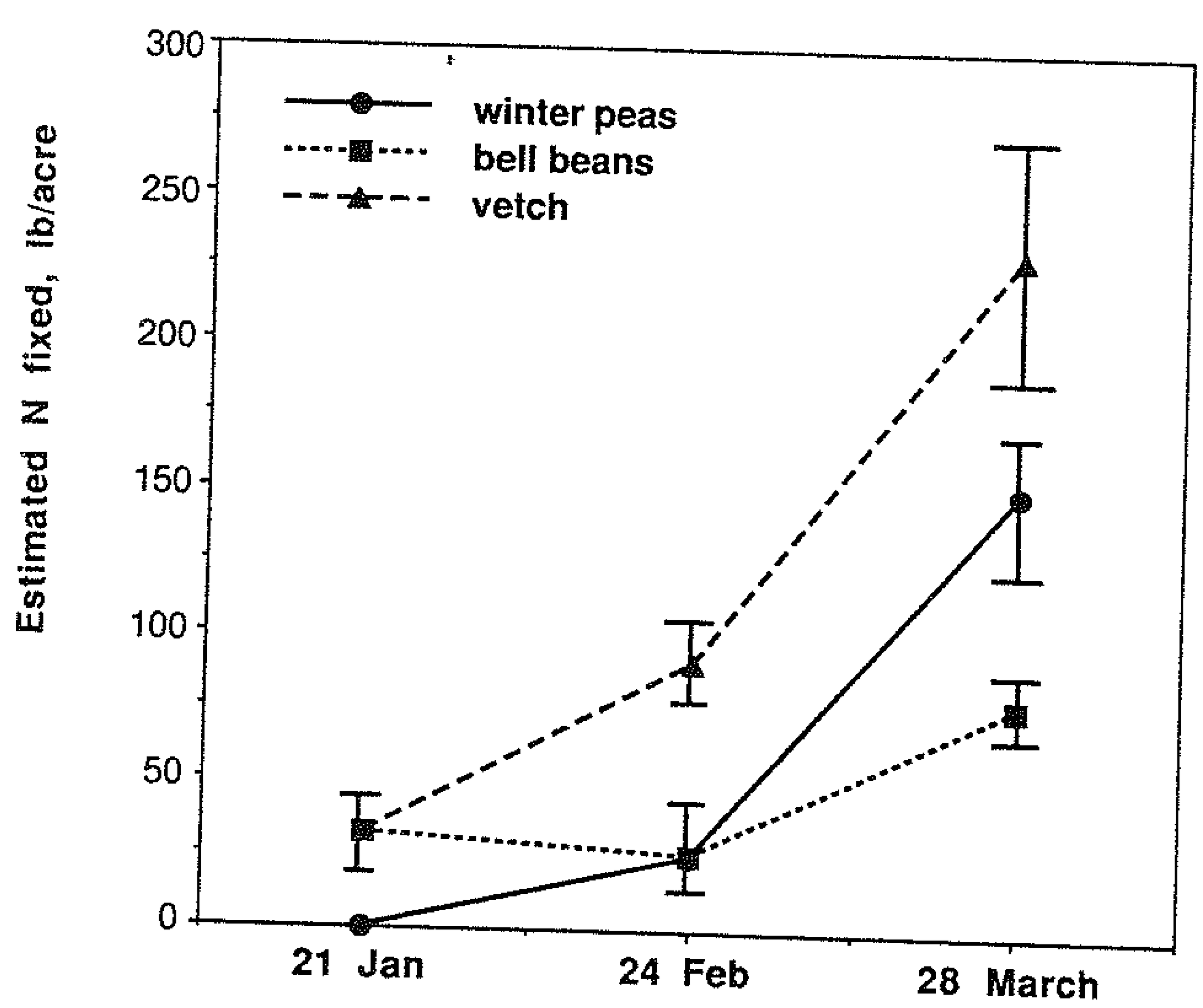

Fig. 3. Estimated N fixed by Austrian winter peas, bell beans, and vetch in pounds per acre by January, February, and March 1987. Estimates were obtained by subtracting the amount of N contained in the standing biomass of the oats from that in each legume. Length of bars indicate ± one standard error.

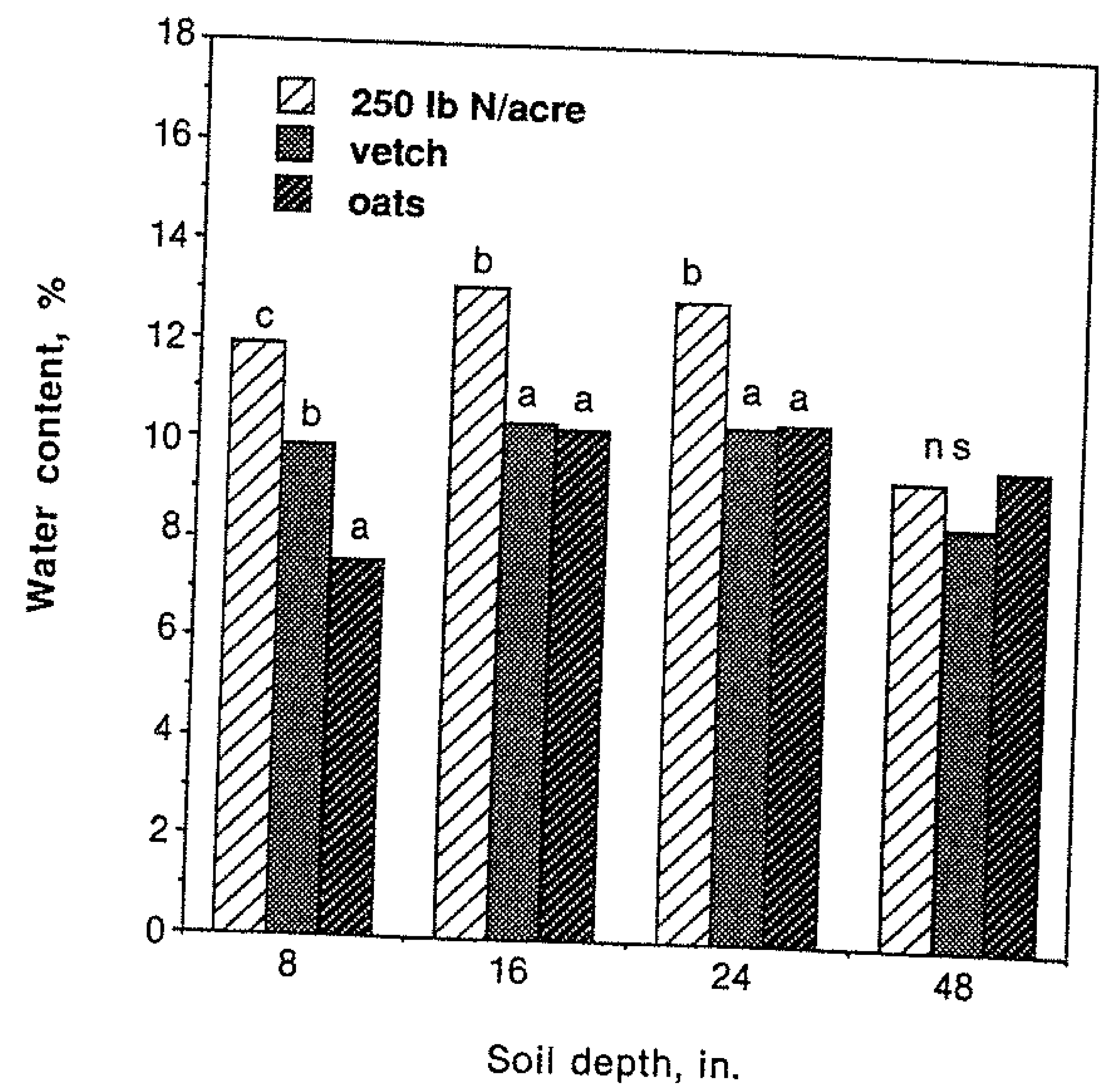

Fig. 4. Soil moisture profiles under cover crops in March 1988 for oats, vetch, and 250 lb N/acre fertilizer. The 0 to 8 in. depth was measured for gravimetric water content immediately prior to disking of cover crops, and the deeper three depths 4 d after disking. Each value represents the mean of four replicates, and letters indicate within-depth mean separation by LSD at $P = 0.05$.

Table 1. Tomato fruit yields and total plant N uptake following 1 yr of cover cropping or chemical fertilizer treatment. Values shown are means of three or four replicates.

Treatment	Yield, tons/acre September 1987	N uptake, lb/acre July 1987	N uptake, lb/acre August 1987
Cover crops:			
oats	27.6a*	73.7^{NS}	92.7ab*
oats and vetch	35.0b	87.2	74.2a
winter peas	40.7bc	94.1	98.6ab
bell beans	42.1c	97.7	103.4ab
vetch	42.4c	118.7	138.8b
berseem clover	43.3c	102.1	130.6b
Chemical fertilizer, lb N/acre:			
0	36.5†	71.8§	92.1‡
50	45.8	140.9	119.6
100	43.9	110.8	125.9
150	39.1	117.1	126.8
200	42.3	157.5	152.1
250	39.7	87.3	127.3

* Mean separation by LSD at $P = 0.05$. NS = not significant.

† Linear regression for 0 to 250 lb N/acre gave a slope not significantly different from zero. Split-line regression results: $y = 36.5 + 0.186x$ where y = yield in tons/acre, x = N applied in lb/acre for 0 to 50 lb/acre ($R^2 = 0.50$). From 50 to 250 lb N/acre, the slope was not significantly different from zero.

‡ Best-fit regression line: $y = 93.805 - 0.491x - 0.001x^2$ where y = N uptake in lb/acre, x = N applied as chemical fertilizer in lb/acre ($R^2 = 0.45$).

§ Best-fit regression line: $y = 80.83 + 0.871x - 0.005x^2$ when y = N uptake in lb/acre, x = N applied as chemical fertilizer in lb/acre ($R^2 = 0.21$).

strong weed competition. Tomato fruit quality analysis showed no treatment effects in 1987 and 1988.

Soil mineral N was determined as a measure of the availability of applied legume and chemical fertilizer N to the tomato plants. Figure 5 shows NO_3^- concentrations in the top 8 in. of soil during the tomato seasons in 1987 and 1988 and NH_4^+ concentrations in 1988 for various treatments. Ammonium levels were low through most of the 1988 season, but peaked shortly after addition of N for the vetch (late March) and the 200 lb N/acre fertilizer treatment (July sidedress). Similar peaks were not seen in 1987, presumably because plots were not sampled until 4 to 6 wk after N applications.

Nitrate levels for both years were much higher than NH_4^+ levels. Nitrate levels in the top 8 in. in the vetch plots remained as high as those in the 200 lb N/acre fertilizer treatment. Soil NO_3^- levels were similar (10–40 ppm depending on treatment) and remained constant in both years between the period 15 May to 15 September in all treatments except for the 200 lb N/acre fertilizer treatment which increased. The timing of this increase corresponds with the decrease in soil NH_4^+ concentrations approximately 30 d after the sidedress application. A similar pattern of increasing NO_3^- and decreasing NH_4^+ concentrations can be seen in the vetch plots 30 d after incorporation of the vetch residue.

Nitrate concentrations in irrigation water samples collected throughout the summer of 1988 indicated that a total of about 80 lb N/acre was applied to the tomatoes in the irrigation water. Samples were not collected in 1987. Percent total soil N measured in the spring and fall of each year did not show any significant treatment or year to year differences and averaged 0.10% N.

DISCUSSION

Our results indicate that for the conditions of this experiment, which included significant addition of N in the irrigation water, legume N was as available to the

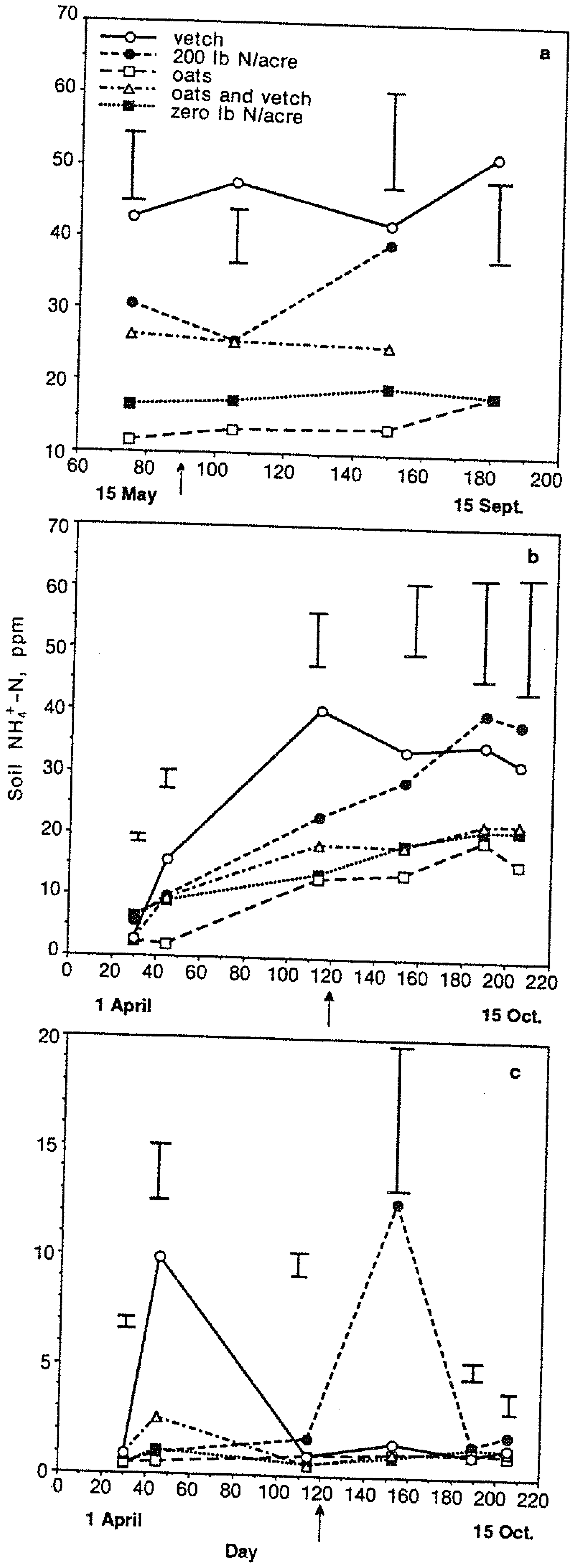

Fig. 5. Soil NO_3^- and NH_4^+ concentrations in ppm NO_3-N or NH_4-N in 0 to 8 in. depth through the tomato growing season for 0 and 200 lb N/acre fertilizer, oats, vetch, and oats and vetch. Graph a) represents soil NO_3^- concentrations, 1987; b) soil NO_3^- concentrations, 1988; c) soil NH_4^+ concentrations, 1988. Length of bars indicate the value of LSD at $P = 0.05$. Arrows indicate time of sidedress application of chemical fertilizer. Values represent means of four replicates.

following tomato crop as chemical fertilizer N, and that legume winter cover crops can provide N inputs sufficient to support 40 to 45 tons/acre yields of processing tomato. Estimates of the amount of N fixed by lana woolly-pod vetch shown here are considerably higher than those reported for similar winter cover crops (Hoyt and Hargrove, 1986; Smith et al., 1987), reflecting the excellent growing conditions during Sacramento Valley winters. Lana vetch, Austrian winter peas, and the vetch and oats mixture also appear to be well adapted for use as winter green manures planted in October. Studies conducted by Graves et al. (1987) show that planting in September rather than in October may have resulted in greatly improved berseem clover growth. Nevertheless, yields and N uptake for tomatoes following berseem in 1987 were as high as for vetch, the most productive of the legumes. The mowing and subsequent regrowth of the berseem may have added considerable belowground N even though dry matter production by March was still low.

Tomatoes are relatively inefficient users of fertilizer N; they often show low fertilizer N recovery and frequently show little response to applied N (Hills et al, 1983; Miller et al., 1981). Unlike some other crops, tomato roots do not appear to proliferate in areas of soil with higher mineral N concentrations and therefore may not absorb a substantial amount of the applied fertilizer N (Jackson and Bloom, 1990). Tomato fruit yields in this experiment showed little response to applied N, but yields for the legume cover-cropped plots were as high as those in the fertilizer-treated plots. The lack of a strong response to N in both fruit yield and plant N content indicate that N was not limiting for tomatoes in this experiment. A concurrent experiment using these same cover crop and fertilizer treatments each winter followed by corn for 2 y has shown much greater response to applied N, both from chemical fertilizer and from legumes (P.R. Miller, 1990, personal communication). Tomatoes, grown in the third year following the corn in this experiment, have also shown a strong response to N (C. Griffin, 1990, personal communication). These experiments indicate that high corn and tomato yields can be maintained by the use of winter green manures.

The concentrations of NO_3^- in the soil during the tomato season provide further evidence that vetch-N is sufficiently available to the following tomato crop. Release of the vetch-N occurs very soon after incorporation and soil NO_3^- concentrations remain high throughout the season of tomato growth. The narrow peaks in NH_4^+ levels, coupled with the high NO_3^- concentrations, indicate that net mineralization is high and that little net immobilization is occurring. The incorporated vetch decomposed quickly due in part to its high N content and viney, branched growth habit. Nitrate from the irrigation water probably contributed to the rapid mineralization of the vetch in 1988 by providing immobilizing microbes with another source of mineral N.

Cover crops and green manures may have significant effects in relation to water budgets and soil water content. In rain-fed production systems, winter legumes may deplete the soil of moisture necessary for maximum crop growth during spring and summer (Hoyt and Hargrove, 1986). In this experiment, the amount of water lost during the winter of 1987–1988 due to either vetch or oats was less than 5% of the total water applied in summer irrigation. Total precipitation from October 1987 to March 1988 amounted to 13.01 in., compared to the county average of 15.01 in. for those months from 1871 to 1977 (California Irrigation Management Information System, 1988). This indicates that water loss from cover cropping during the winter may be economically insignificant for this tomato production system, which already relies upon the availability of relatively inexpensive irrigation water. Cover cropping may also decrease the potential for soil compaction caused by heavy machinery use in the spring by lowering soil moisture content below critical levels (Flocker et al., 1958).

INTERPRETIVE SUMMARY

Incorporating winter legume green manures into existing processing tomato production, as well as perhaps other cropping systems in California, has considerable potential. Mild, moist winters favor legume growth and N fixation; cover crops can benefit soils with such structural problems as crusting, compaction, and low infiltration rates; and processing tomatoes are not a high N-demanding crop. Several problems are likely to be associated with this practice, however. Nitrogen inputs from green manures will vary from year to year, depending on winter rains, temperatures, disease, and other soil factors. Tailoring green manure N inputs therefore, to the needs of the subsequent crop is more complex than for fertilizer N. Also the management of the green manure crop may limit flexibility in the timing of tomato planting and harvesting, a critical component in the economics of processing tomato production in California. Future research should focus on: developing improved cover crop varieties (e.g., increasing N fixation and cold tolerance), developing improved methods for field determination of N inputs from green manures, adapting current cropping systems to include appropriate winter green manures (e.g., modified tillage/-planting systems which allow earlier planting of the summer crop), and developing a more detailed understanding of N dynamics and soil structure effects in cropping systems that incorporate the use of green manures.

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