Leguminous Cover Crop Residues in Orchard Soils: Nitrogen Release and Tree Uptake

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Summary

Almond production is dependent on nitrogen availability. Cover crops offer a potentially valuable source of nitrogen, especially if the cover crop plants are nitrogen fixers, such as clovers, vetches, and other legumes. Little is known about how much N derived from a cover crop is actually taken up by the almond trees, and over what period of time. In experiments with young almond trees in lysimeters, we have found that almond leaf nitrogen derived from a vetch cover crop (%Ndfv) increased rapidly over four weeks, stabilized at about 30% in existing leaves, and reached 43% in new leaves. Almond leaf nitrogen content increased from 1.6-2.3% over the first four weeks. Leaf biomass doubled in eight weeks compared with control plants grown without vetch hay. Leaf number increased 88% in treated trees and decreased 5% in controls. Soil nitrogen derived from vetch was >4% in the top 4 inches, although absolute soil nitrogen levels decreased in eight weeks. We could account for approximately 75% of nitrogen released from the vetch, about equally divided between soil and plant pools.

These results indicate that substantial nitrogen released by the cover crop was taken up by the almond trees, especially during the first four weeks, and an equal amount was stored in the soil. Tree N uptake translated into substantial leaf and tree growth. Overall, vetch can provide an appropriate source of nitrogen for young almond trees.

Materials and Methods

Lysimeters. Soil was collected from Almondeck Farm, near Hilmar in Merced County, California. Six columns of soil were collected by driving 12" diameter x 24" long PVC pipe into the soil to a depth of 22". The pipe and soil columns were lifted intact from the ground, the bottom sealed with a PVC cap, and then transported to Davis. A 1" hole was drilled at the base of the lysimeter into the side of the pipe and a 1" PVC pipe inserted as a drain.

Almond Tree Planting. Pot-grown Non-pareil almond trees on Hansen rootstock (Duarte Nursery, Hughson, CA) were planted in the centers of each of the six lysimeters on March 28, 1999. The trees were irrigated with deionized water only and allowed to settle into the lysimeters for one month before beginning the experimental treatment.

Simulated Cover Crop. We grew Lana woollypod vetch for 12 weeks in the greenhouse with three ^{15}N-labeled (10 atom % ^{15}N) Hoagland's solution irrigations per week. To simulate orchard mowing, the vetch was harvested and chopped to approximately 1" pieces. The final isotopic enrichment of the vetch tissue was 3.95 atom % ^{15}N.

Treatments. The lysimeters were arranged on a platform under a shaded canopy. At the beginning of the experiment, 300 grams of fresh, chopped vetch (180g dry weight) were placed on the soil surface of three randomly selected lysimeters. The other three lysimeters received no vetch.

Leaf Sampling. Samples were taken at T_0 on May 2, and every two weeks thereafter for 8 weeks (5 sample dates total) until June 25. Leaves that appeared after T_0 were sampled separately from those that were present on the trees at T_0. New leaves matured after week 4 in the trees given the vetch treatment, but no new leaves developed in the control trees. Ten leaves were randomly collected at each time point from each control tree, while 10 "new" leaves as well as 10 "old" leaves were collected from the treatment trees. Leaves were oven dried, ground, and analyzed on a Europa Integra mass spectrometer in the Stable Isotope Facility at UC Davis for nitrogen content and atom percent ^{15}N. Percent nitrogen in the almond leaves derived from the vetch cover crop (%Ndfv) was calculated as in Rennie and Rennie (1983).

Whole Tree Sampling. After 8 weeks, all the leaves were collected from the trees. The woody above-ground portions of the tree were removed, divided into compartments (stem, old branches, new shoots), oven dried, and sub-samples were ground for analysis. The soil was carefully washed from the roots with water and final cleaning was done with brushes and forceps. The roots were photographed, oven dried, and sub-samples were ground for analysis.

Soil Sampling. Soil cores were collected from the top 4 inches of the soil column at T_0. At eight weeks, cores were taken at three depths, 0 - 4 in., 4 - 12 in., 12 - 22 in.

Terms and Definitions. We measured the flux of nitrogen in terms of the following two categories.

> *Percent Nitrogen Derived From Vetch (%Ndfv)*. Percent Ndfv is the percentage of the total nitrogen in any one compartment (e.g., leaf, stem, soil) identifiably derived from the vetch residue placed on the lysimeter, based on its ^{15}N signature. This is a measure of the uptake and contribution of N to a given pool. The %Ndfv calculation follows Rennie and Rennie (1983).
>
> *Vetch Nitrogen Recovered (%VNR)*. The percentage of total nitrogen released from the vetch that is captured in a given plant or soil compartment. This measures efficiency of the cover crop as a fertilizer source.

Results

Almond Uptake of Nitrogen. In the first four weeks, vetch derived nitrogen (%Ndfv) in the almond leaves increased rapidly to approximately 30% and remained at that level for the remaining four weeks (Figure 1).

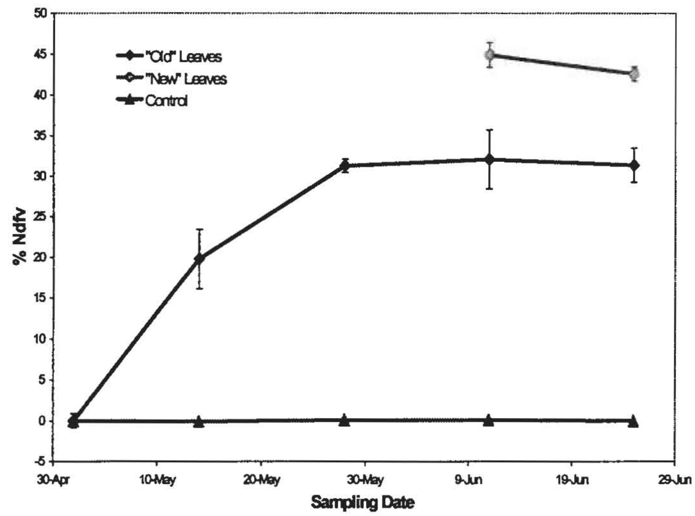

Figure 1. Almond leaf nitrogen derived from vetch (%Ndfv)

Leaf Percent Nitrogen. Leaf percent-nitrogen in the leaves present on the tree at T_0 increased by 44% (from 1.6% to 2.3%) in the treated trees over the first 4 weeks and then was reduced to a total net gain of about 25% (2.0%) by the end of eight weeks (Figure 2). Sufficient nitrogen for almond production is indicated when leaf concentrations are 2.2 - 2.5% (Weinbaum, et. al. 1996). In the present study, treatment

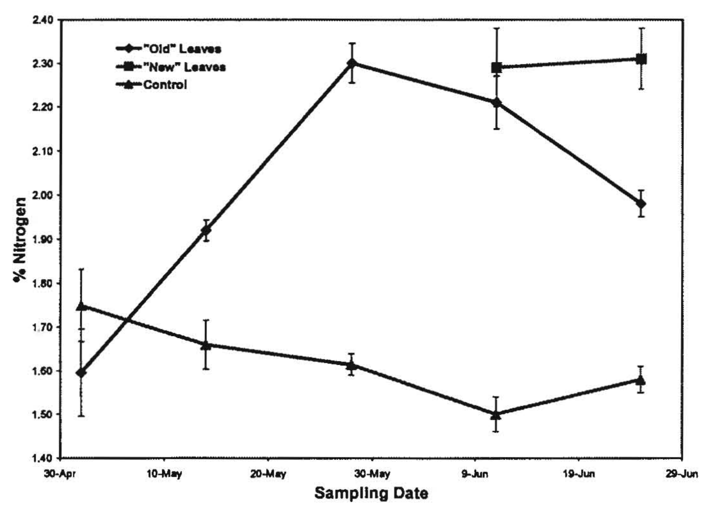

Figure 2. Almond leaf N (%)

leaf percent-nitrogen averaged 2.3% at weeks six and eight. The controls exhibited a steady decrease in leaf percent-nitrogen (10%) over the course of the eight-week experiment.

Tree Productivity. The trees given the vetch treatment initiated a second flush of growth three weeks after vetch application and continued to produce new leaves for the duration of the experiment. Average leaf number increased by 88% and biomass doubled in the vetch-treated plants. No new leaves were produced in the untreated controls and leaf number decreased 5% (Figure 3). Total new shoot growth per tree in the treated trees averaged 45 inches while the controls did not produce new shoots.

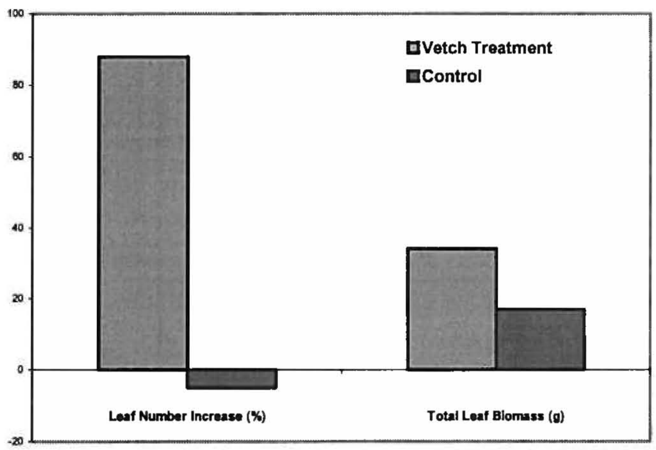

Figure 3. Almond leaf number percent increase and total biomass

Uptake of Nitrogen by the Whole Tree. The new leaf %Ndfv exhibited the highest nitrogen uptake of all plant compartments in the three trees given the vetch treatment, up to 10% of the total (Table 1). Roots exhibited the lowest vetch-nitrogen uptake yet accounted for a large proportion of vetch N recovery due to their proportionally large biomass (Table 1). Taken as a whole, the almond trees took up an average of 31% of their nitrogen from vetch after eight weeks. This represents a recovery (%VNR), by the almond tree, of 35% of the vetch-released nitrogen (plant compartment %VNR shown in Table 1). The proportion of vetch nitrogen recovered to the percentage of tree biomass in each compartment was highest in the new leaf tissue and lowest in the stem (Table 1).

Ours is the first study of cover crop nitrogen turnover and uptake by trees using ^{15}N methods. Several field and pot experiments mentioned in Müller and Sundman (1988) reported uptake in annual crops, such as maize, barley, and sugar beets, of cover crop-derived N, of 7-28% of input for field studies and 5-55% for pot studies. Similarly, Dittert et al. (1998) reported 2.5-61.7% recovery of animal waste slurry-derived nitrogen in annual agricultural crops. Our results compare favorably with these earlier reported studies.

Table 1. Average percent nitrogen derived from vetch in plant compartments, percent vetch nitrogen recovered in each compartment, and percent tree biomass in each compartment.

Plant Material	% Ndfv	%VNR	% Tree Biomass
Old Leaf	31	6	20
New Leaf	43	10	7
Stem & Branch	31	9	42
New Shoot	41	1	2
Root	26	9	29
Whole Plant	31	35	100

Whole Tree Percent Nitrogen. Whole plant percent nitrogen averaged 1.41% in treated trees while averaging only 1.08% in controls (data not shown; $P < 0.01$).

Soil Nitrogen. Soil nitrogen derived from vetch in treated lysimeters is shown in Table 2. There was no significant difference between total soil nitrogen of treated and control lysimeters at eight weeks (average values in Table 3). Percent nitrogen in the top 4 inches of soil decreased an average of 18% in controls and 22% in vetch-treated lysimeters over the course of experiment, though this was not a significant difference (data not shown).

Table 2. Soil Nitrogen derived from vetch (%Ndfv) by horizon at 8 weeks in vetch-treated trees.

	% Nitrogen Derived from Vetch
Horizon 1 (0 - 4 in.)	4.36 ± 0.38
Horizon 2 (4 - 12 in.)	3.27 ± 0.41
Horizon 3 (12 - 22 in)	1.73 ± 0.26

Nitrogen Sequestration in the Soil. The soil N pool was much more variable than were the tree pools. The vetch-derived nitrogen recovered in the soil column after 8 weeks varied from 26-51% (vetch nitrogen recovered in Table 3). The total nitrogen pool in each of the treated lysimeters varied considerably (total soil nitrogen in Table 3), though this variability was not significantly different than the controls (data not shown). Total vetch-derived nitrogen released to each lysimeter also varied (vetch N input in Table 3), but not in the same pattern as the total soil N pool. However, there was a strong correlation between total soil N and the percentage of vetch-derived N recovered in the soil ($r^2 = 0.92$). A larger experiment would be necessary in order to understand these trends.

In soils incubated at 30°C with ^{15}N-labeled soybean residue, Azam, et al. (1989) recorded rapid turnover of soybean-derived N in three contrasting soils with no plants growing in the soil. The average recovery of ^{15}N in all soil fractions was 87 ± 22% across all incubation stages (1 week to 20 weeks). Thus, our recovery of 26-51% of vetch-derived N in the soil (56-94% in soil plus plant recovery) after 8 weeks compares favorably with their results.

Table 3. Total Soil N, N released from vetch, and Vetch Nitrogen Recovered (%VNR) in soil of individual lysimeters.

	Total Soil Nitrogen at 8 weeks (g)	Vetch N input to lysimeter (g)	Vetch Nitrogen recovered in soil
Vetch Added			
Lysimeter #1	15.6	1.68	26%
Lysimeter #3	22.5	1.23	51%
Lysimeter #5	17.4	1.84	39%
Average	**18.5**	**1.58**	**38%**
Control			
Lysimeter #2	16.8	0	0
Lysimeter #4	20.1	0	0
Lysimeter #6	19.0	0	0
Average	**18.6**	0	0

Nitrogen uptake experiments in an orchard setting, using isotopically-labeled cover crops, would extend these results to mature almond trees, which would be a valuable next step. Vetch hay application as used in our experiment did not take into account root and root nodule contributions to the soil nitrogen pool and may underestimate the nitrogen supplied in an orchard setting where the cover crop is grown between the trees. It would also be useful to test cover crop mixes in addition to pure vetch, which could change the total N released and the timing of N release.

Conclusions

- Substantial nitrogen was released from the vetch residue applied to the soil surface in the treatment lysimeters.
- Thirty-five percent of the released nitrogen was taken up by the tree in eight weeks following application of the vetch residue.
- The first four weeks showed the fastest rate of uptake.
- Vetch nitrogen was partitioned into plant and soil pools approximately equally.
- On a per biomass basis, and as a total, new leaves represented the greatest uptake of vetch-derived nitrogen.
- Vetch as a source of nitrogen provided adequate nutrition for young almond trees.
- Similar nitrogen uptake experiments extended to mature cover-cropped orchard trees would be an informative and valuable next step.

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