Nitrogen Transformations, ^{15}N Assimilation and Recovery for California Almond

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Interpretive Summary

Nitrogen (N) is the primary nutrient for plant health. Since N fertilizer sources and delivery methods are numerous, we identified two primary forms for analysis of tree N uptake, soil N immobilization and N cycling rates at the tree scale. Both ammonium (NH_4^+) and nitrate (NO_3^-) fertilizer sources are subject to competition between microbial organisms and plant roots when applied to soil. Ammonium is subject to transformation into nitrate by nitrification and nitrate may be lost as gaseous by-products such as nitrous oxide (N_2O) during microbial nitrification and denitrification, and subject to leaching. In order to follow the amount of N fertilizer absorbed by the almond crop compared with native soil N and estimate nitrogen use efficiency (NUE), we used ^{15}N tracers to:

1) Quantify native N mineralized and available for uptake.
2) Quantify soil immobilization versus tree root uptake of fertilizer.
3) Estimate N_2O emissions from nitrification and denitrification.
4) Trace ^{15}N tracer into the almond tree organs to estimate NUE.

Our results indicated that NUE in the orchard studied was from 68 to 85%, and verifies our N balance approach showing high NUE.

Materials and Methods

Almond trees were identified for targeted ^{15}N enrichment during the summer of 2010 on a Milham sandy loam near Lost Hills, CA. Treatments of $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$ (10% ^{15}N a.e.) were pulse-injected through the static sprinkler micro-irrigation system. Soil and gas sampling were conducted at 0, 1 and 2 days after fertilization (DAF) after ^{15}N injection for estimation of gross nitrogen transformations, including dis-assimilatory NO_3^- reduction to ammonium DNRA), soil and root ^{15}N assimilation and $^{15}N_2O$ emissions. In 2010, 2011 and 2012 almond kernels, hulls and shells were collected and scaled along with tree yield to estimate ^{15}N crop recovery (nitrogen use efficiency, NUE). In 2012, wood cores were taken from tree roots, branches, trunk and scaffolds to estimate ^{15}N in the standing tree biomass. Leaves were also collected for ^{15}N analysis and a remote sensing approach was used to determine tree leaf biomass. All of the isotopic analyses were conducted by the UC Davis Stable Isotope Facility.

Results

Nitrogen transformations

Within 24 h after fertilization (Table 1, Day 1), gross mineralization was lower and NH_4^+ and NO_3^- assimilation by soils and roots (consumption) were greater than during Day 2. In addition, we observed over both days after fertilization that tree uptake and soil assimilation (NH_4^+ and NO_3^- consumption) of N exceeded mineralization. These results support the hypothesis that N-fertilization can stimulate both oxidation as well as consumption of N within 24 h and that the system shifts progressively toward greater soil N supply from mineralization as quickly as during the first 48 hours following fertilization (Table 1).

	Day 1		Day 2	
	g N tree^{-1} day^{-1}			
	Mean	SE	Mean	SE
N-mineralization	6.37	0.35	12.7	0.97
NH_4 consumption	65.1	6.45	28.5	0.47
N-nitrification	24.6	3.90	11.6	2.12
NO_3 consumption	37.2	5.45	18.5	4.95
	Day 1		Day 2	
	mg ^{15}N a.e. tree^{-1} day^{-1}			
	Mean	SE	Mean	SE
Soil $^{15}NH_4{}^{14}NO_3$	517	271	223	103
Soil $^{14}NH_4{}^{15}NO_3$	67.1	14.5	36.6	3.28
Roots $^{15}NH_4{}^{14}NO_3$	13.9	N/A	43.4	24.6
Roots $^{14}NH_4{}^{15}NO_3$	3.01	2.12	4.73	2.18

Table 1. Nitrogen transformation rates and soil/root assimilation of ^{15}N

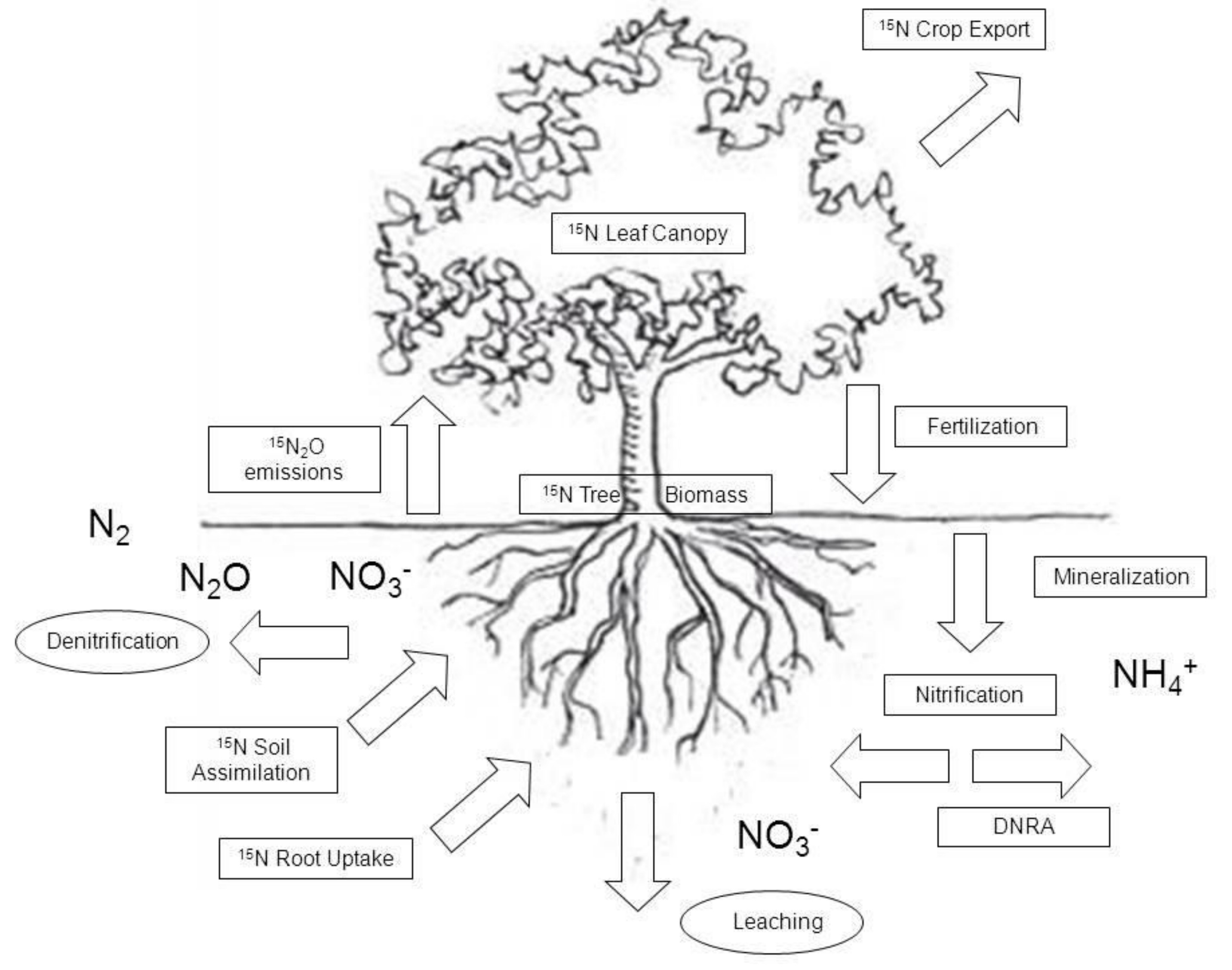

Figure 1. Nitrogen (N) transformations include mineralization of soil organic N, nitrification of ammonium (NH_4^+) into nitrate (NO_3^-). Assimilation includes abiotic (eg. cation and anion exchange capacity) and biotic processes such as microbial assimilation and tree root uptake. The major pathways for N loss are leaching, and denitrification where trace amounts of N may be lost as the greenhouse gas nitrous oxide (N_2O). Aboveground N is found in the standing tree biomass and exported in the kernel, hull and shells of the almond crop. Leaves return to the soil and along with water and fertilizer constitute the primary inputs of N to the soil nitrogen pool.

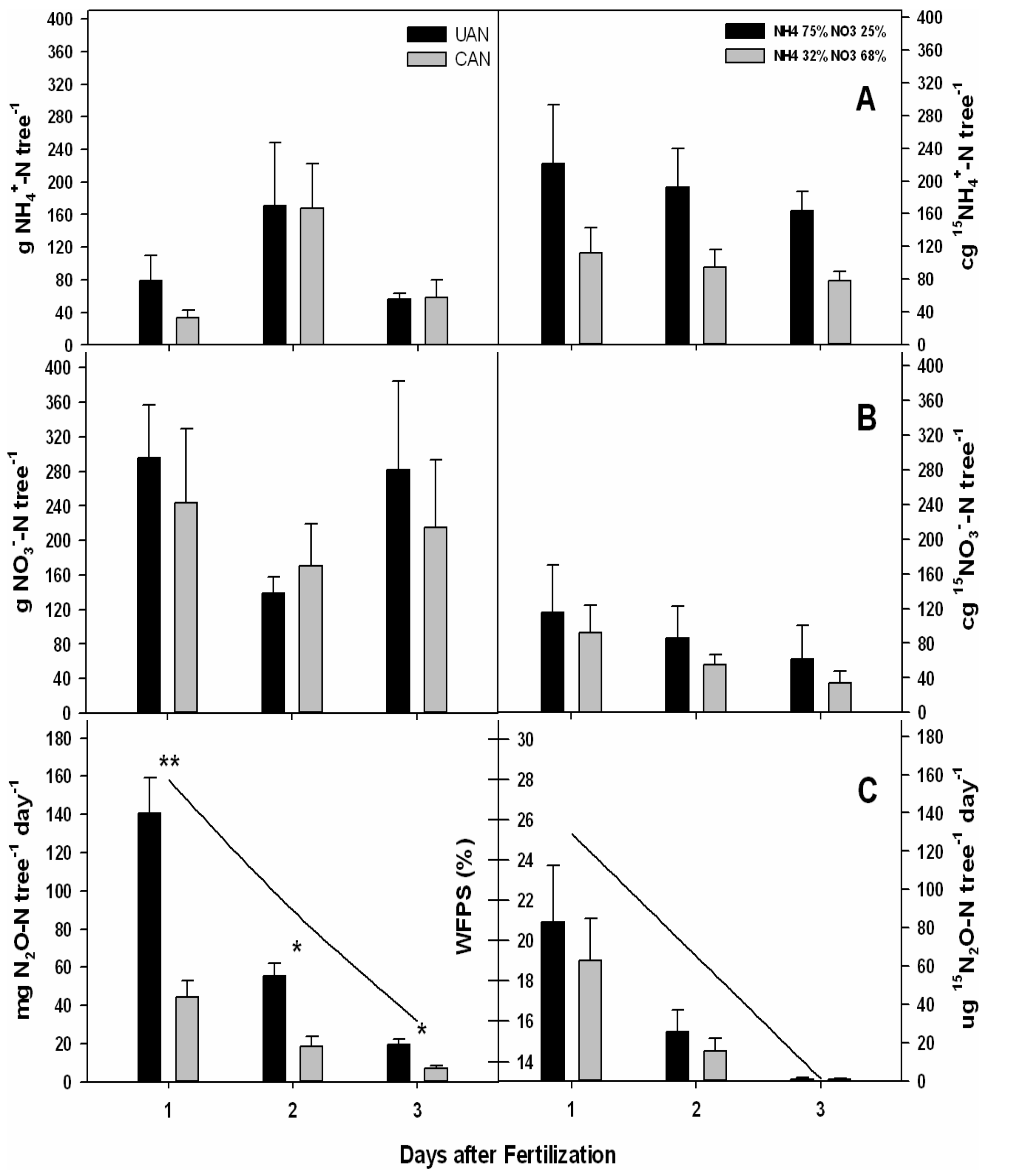

Figure 2. Soil ammonium (NH_4^+; A) and (NO_3^-; B) concentrations, nitrous oxide (N_2O; C) emissions and water-filled pore space (WFPS) from almond trees fertilized with UAN and CAN (left panel) and ^{15}N (right panel) for one, two and three days after fertilization (DAF).

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More Results

^{15}N assimilation and N_2O emissions

Soil immobilized more N on Day 1 after fertilization than Day 2, and up to an order of magnitude more N than tree roots absorbed. Tree roots were an important sink for NO_3^-. Evidence suggested that tree roots took up more NO_3^- than NH_4^+ on Day 1, but more NH_4^+ than NO_3^- overall (Figure 2). Peak $^{15}N_2O$ emissions were observed during the first 24 h (Day 1) and were greater from $^{15}NH_4NO_3$ compared to $NH_4{}^{15}NO_3$ (Figure 2). These results are consistent with results at the field scale that showed significantly greater N_2O emissions from a predominantly NH_4^+-based fertilizer of urea ammonium nitrate (UAN) compared to a majority NO_3^--based fertilizer in calcium ammonium nitrate (CAN) (Schellenberg et al. 2012).

(g ^{15}N tree^{-1})	$^{15}NH_4$ 75% - $^{15}NO_3$ 25%	$^{15}NH_4$ 32% - $^{15}NO_3$ 68%
Applied ^{15}N	5.64	5.40
2010 Crop		
Kernel	0.48 ± 0.07	0.28 ± 0.03
Hull/Shell	0.26 ± 0.09	0.14 ± 0.04
2011 Crop		
Kernel	1.14 ± 0.18	0.57 ± 0.09
Hull/Shell	0.92 ± 0.15	0.44 ± 0.07
2012 Crop		
Kernel	0.21 ± 0.01	0.10 ± 0.00
Hull/Shell	0.08 ± 0.00	0.04 ± 0.00
2012 Tree		
Leaves	0.03 ± 0.00	0.02 ± 0.00
Roots	0.38 ± 0.02	0.19 ± 0.01
Branches	0.49 ± 0.03	0.26 ± 0.02
Scaffold	0.03 ± 0.00	0.02 ± 0.00
Trunk	0.03 ± 0.00	0.02 ± 0.00
3-yr Total	4.31 ± 0.50	2.19 ± 0.25
Recovery (%)	68 - 85%	34 - 43%
‘Loss’ (%)	32 - 15%	66 - 57%

Table 2. ^{15}N recovery for almond fruits split into hull + shell and kernel, tree organs from predominantly ammonium ($^{15}NH_4$ 75% - $^{15}NO_3$ 25%) and majority nitrate ($^{15}NH_4$ 32% - $^{15}NO_3$ 68%) treatments.

Crop and tree recovery

Enrichment of ^{15}N in the almond crop was found in years 2010, 2011 and 2012 and continues to be present in the standing tree biomass (Table 2). We hypothesize that residual ^{15}N will preside in the soil after 2012 and will continue to be available for uptake and/or potential loss via leaching and/or denitrification. As a result, final estimates for a total N balance remain inconclusive. The most important finding is crop and tree recovery of ^{15}N was substantially greater for $^{15}NH_4$ compared to $^{15}NO_3$.

Conclusion

Tradeoffs exist between N recovery by trees and N loss by reactive N mobilization and N_2O emissions (in this case). Both these fates of N were greater for NH_4^+ ($^{15}NH_4^+$) which suggests the positively charged NH_4^+ ion is held in the upper soil horizons and is both more available for uptake by the tree over time but also subsequently susceptible to loss as the greenhouse gas N_2O. Lower N_2O emissions from ^{15}N enriched NO_3^- fertilizer combined with lower overall recovery of ^{15}N suggest a combination of N losses via leaching or N retention from conversion of inorganic fertilizer to dissolved organic nitrogen. These results support continued efforts of almond growers to adjust timing, placement, rate and <u>source</u> of N in order to improve nitrogen use efficiency (getting more N into the tree) and mitigate N loss.

Reference

Schellenberg DL, MM Alsina, S Muhammad, CM Stockert, MW Wolff, BL Sanden, PH Brown and DR Smart. Yield-scaled global warming potential from N_2O Emissions and CH_4 Oxidation for almond (Prunus dulcis) irrigated with nitrogen fertilizers on arid land. *Agriculture, Ecosystems and Environment Submitted for Publication in 2012*