Nitrogen Cycling in California Almond from ^{15}N Sources at the Tree Scale

Daniel L. Schellenberg[1], Patrick H. Brown[2] and David R. Smart[1]

[1]University of California Davis, Department of Viticulture & Enology, One Shields Ave. Davis, CA

[2]University of California Davis, Department of Plant Sciences, One Shields Ave. Davis, CA

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 plant and soil sinks and 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 denitrification. Research has shown pathways were N_2O may be lost during nitrification as well. In order to follow the N fertilizer into the almond crop in the presence of native plant and soil N, we used ^{15}N tracer techniques to meet the following objectives:

1) Identify root uptake rates of NH_4^+ and NO_3^-
2) Quantify soil N assimilation and mineralization
3) Estimate N_2O emissions from nitrification and denitrification
4) Trace ^{15}N into the almond leaf canopy and crop

Materials and Methods

Four trees were identified for targeted ^{15}N enrichment during the summer 2010. Treatments of $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$ (10% ^{15}N a.e.) were pulse-injected from hour 0 to hour 6 through a static sprinkler system. Gas sampling was conducted at 18 and 42 hours. Soil sampling was conducted in duplicate to 0-10, 11-20, 21-30, 31-40 and 41-50 cm at 6, 18 and 42 hours. Soil was oven-dried and roots were dry-sieved into fractions separated by diameter. Soil N was extracted in 2*M* KCl and diffused into $^{15}NH_4^+$ and $^{15}NO_3^-$ fractions. Soil, roots and fruits were ground to pass through a 2mm sieve and packed into tin capsules. Samples for isotopic analysis were sent to the UC Davis Stable Isotope Facility.

Results

Root Uptake and Soil Assimilation

Root NO_3^- uptake was different by depth during the sampling period (Table 1). The highest enrichment was in the 0-10 and 11-20 cm depths. Enrichment decreased by depth to 41-50 cm. Rapid NO_3^- uptake occurred in the upper reaches of the soil profile and increased over time (Figure 1). Roots are the primary pathway to N recovery into the tree and almond crop. Initially, microbes appeared to outcompete roots for NO_3^- then saturated (Figure 2). Root uptake and soil assimilation of NH_4^+ is under analysis.

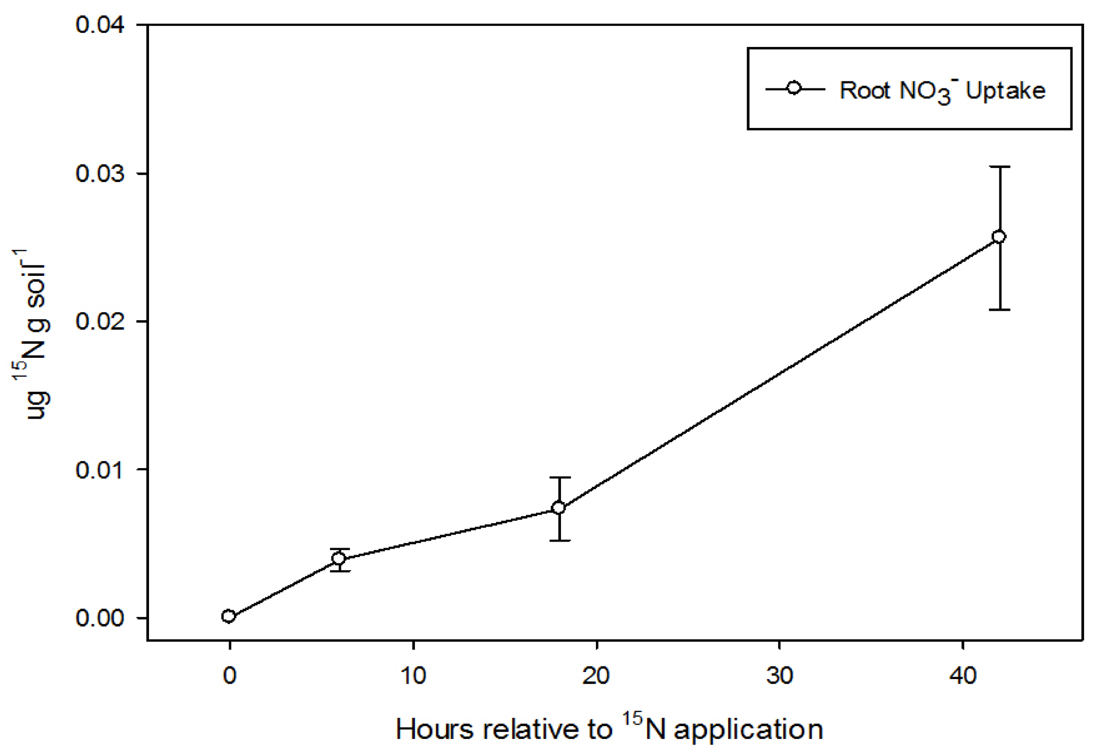
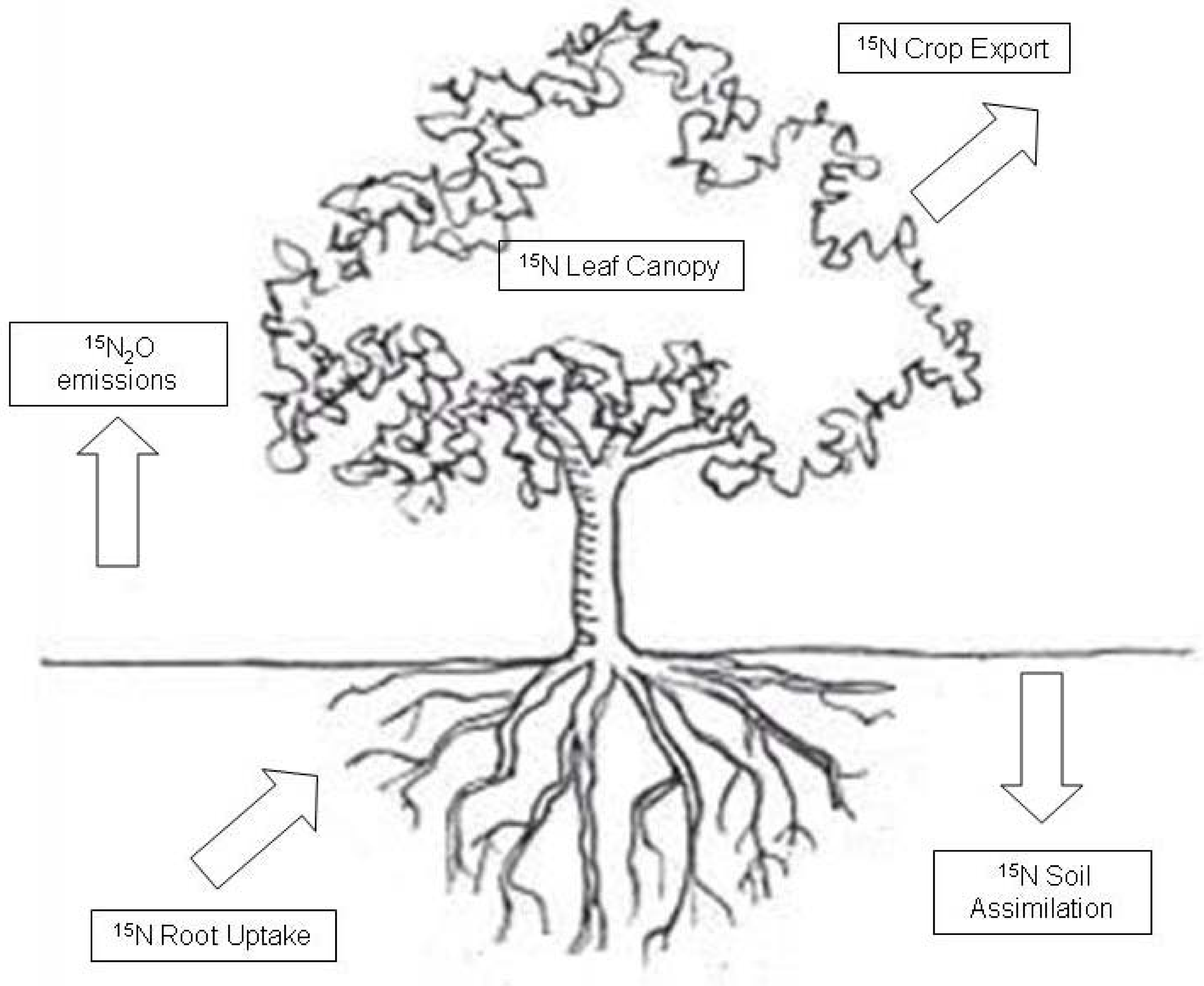


Figure 1. Root ^{15}N per gram of soil increased over the sampling period

Table 1. ^{15}N enrichment of roots (< 1.0 mm) at multiple depths from the nitrate ($^{15}NO_3^-$) treatment

Treatment	Depth (cm)	^{15}N (atom-%)
$^{15}NO_3^-$	0-10	0.455
$^{15}NO_3^-$	11-20	0.455
$^{15}NO_3^-$	21-30	0.423
$^{15}NO_3^-$	31-40	0.374
$^{15}NO_3^-$	41-50	0.370



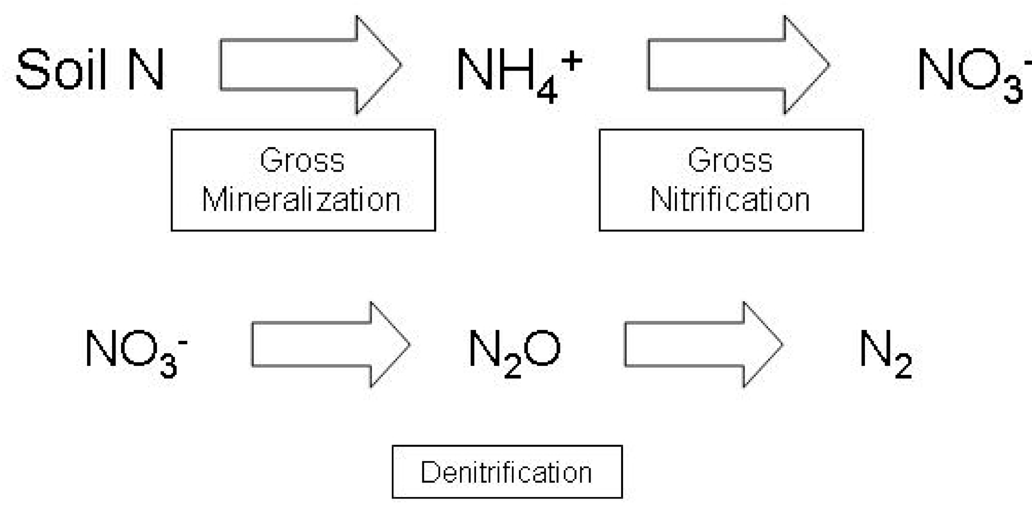


Table 2. Nitrogen cycling rates - gross mineralization (NH_4^+ from soil N), NH_4^+ consumption (root/soil assimilation plus nitrification), gross nitrification (NO_3^- from NH_4^+) and NO_3^- consumption (root/soil assimilation plus denitrification)

Soil Process	ug N g soil^{-1} day^{-1}
Gross Mineralization	1.56
NH_4^+ Consumption	3.01
Gross Nitrification	0.52
NO_3^- Consumption	1.85

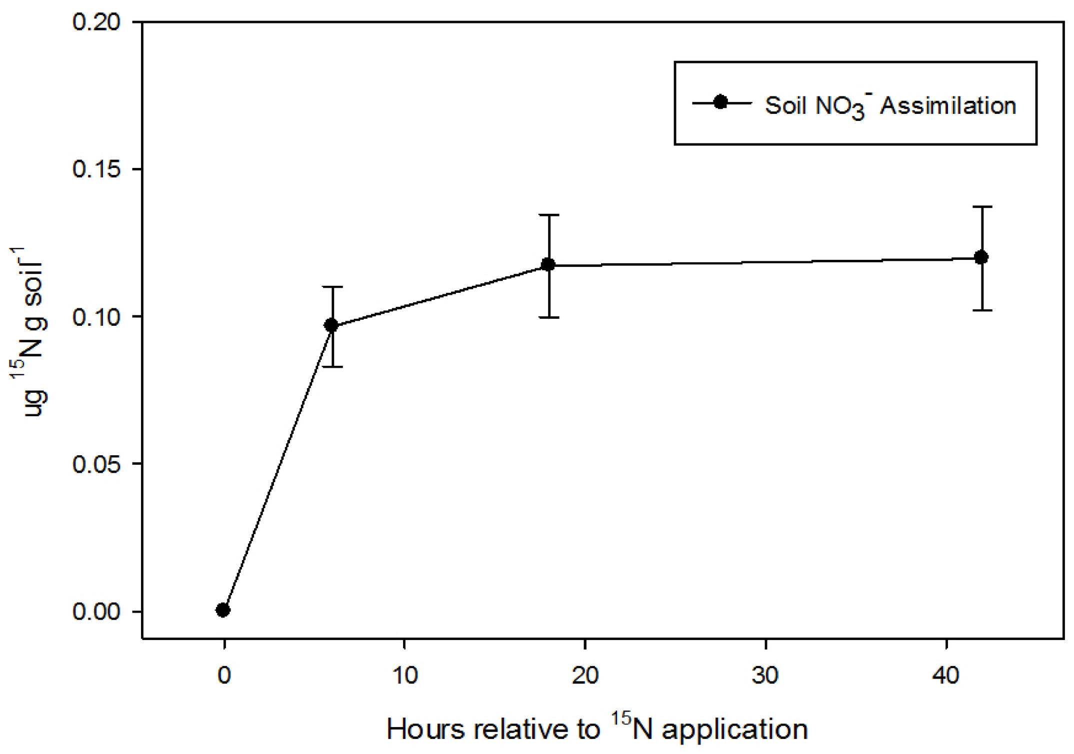


Figure 2. Soil ^{15}N per gram of soil initially increased and then saturated over the sampling period

Acknowledgements

The authors wish to offer thanks to Maria M Alsina, Christine M Stockert and Saiful Muhammad for assistance with field sampling and help with the experimental design.

We also express greater gratitude to many undergraduate research assistants including Jennifer M Jenkins, Cassy Buckingham, David Tran, Lauren N Lawless, Peggie Wong and Carolina A Almanza for many hours in the lab processing samples.

We are grateful to our funders, the USDA - Specialty Crops Research Initiative and the Almond Board of California for their support of this research.

More Results

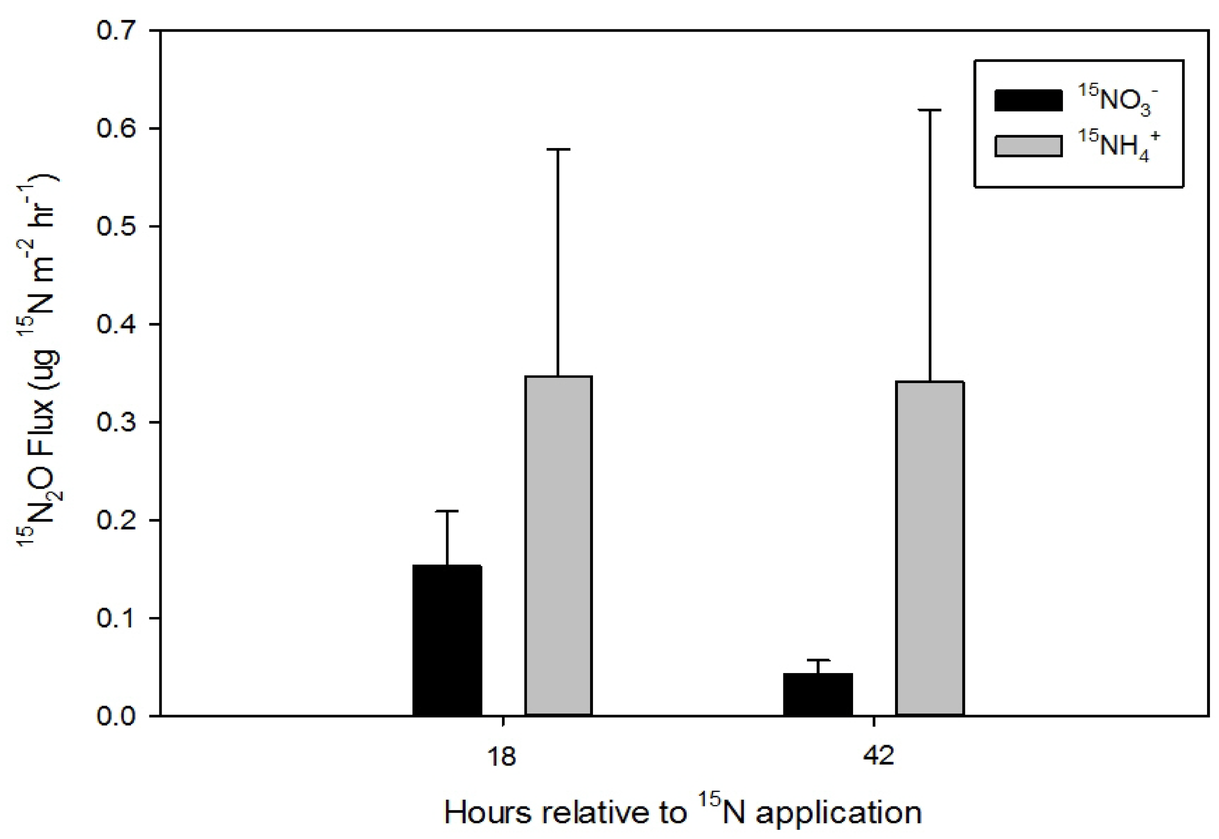


Figure 3. Temporal trends in $^{15}N_2O$ from $^{15}NH_4NO_3$ ($^{15}NH_4^+$) and $NH_4{}^{15}NO_3$ ($^{15}NO_3^-$) treatments

Nitrous Oxide Emissions

Fluxes of $^{15}N_2O$ in the $^{15}NO_3^-$ were substantially lower than the $^{15}NH_4^+$ treatment (Figure 3). This observation is consistent with higher fluxes in UAN as compared to CAN since the risk of the nitrification pathway is greater in UAN (Schellenberg et al. 2012). The amount of $^{15}NO_3^-$ in the $^{15}NH_4^+$ treatment was many times greater than the amount of $^{15}NO_3^-$ in the $^{15}NO_3^-$ treatment, which suggests the greater $^{15}N_2O$ from the $^{15}NH_4^+$ treatment was derived from denitrification coupled to nitrification. (Panek et al. 2000).

Crop Export

The isotope application injected through three fanjets and two treatments allowed for the enrichment of four almond trees in total. One tree in each treatment received a full rate and one tree in each treatment received a half rate. Despite the inability for replication distinct differences were observed.

For both the full and half rates the $^{15}NH_4^+$ treatment showed higher enrichment in ^{15}N as compared to the $^{15}NO_3^-$ treatment (Table 3). This result was consistent for both the hull + shell and kernel fractions of the almond fruit. Uptake and translocation of nitrogen in the NH_4^+ form may follow a more direct pathway to the almond fruit. However, multiple explanations may explain this treatment difference. Almond leaves are under analysis.

Table 3. ^{15}N enrichment of almond fruits split into hull + shell and kernel from ammonium ($^{15}NH_4^+$) and nitrate ($^{5}NO_3^-$) treatments at full or half fertilizer rates

Treatment	Rate	Hull + Shell	Kernel
$^{15}NH_4^+$	Full	0.436	0.443
$^{15}NH_4^+$	Half	0.414	0.421
$^{15}NO_3^-$	Full	0.381	0.387
$^{15}NO_3^-$	Half	0.374	0.376

Conclusions

- Root NO_3^- uptake increased linearly and represents a predominant sink for N fertilizer
- Soil microbes assimilated greater NO_3^- than roots after initial N application then saturated under 24 hours.
- Fluxes of $^{15}N_2O$ were greater in the $^{15}NH_4^+$ treatment and appear to be derived from denitrification coupled to nitrification
- Greater enrichment was found in the $^{15}NH_4^+$ treatment at full and half rates of fertilization, however these results are non-replicated

References

Panek, JA, PA Matson, L Ortiz-Monasterio, and P Brooks. 2000. Distinguishing nitrification and denitrification sources of N_2O in a Mexican wheat system using ^{15}N. Ecological Applications 10:506-514.

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*