Climate Controls the Fate of Anthropogenic Nitrogen Additions in Desert Ecosystems

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Problem Statement

Rapid urbanization in arid- and semi-arid regions is increasing nitrogen (N) emissions and deposition (Fenn et al. 2003; Lohse et al. 2008), yet the fate of this N is poorly constrained.

Deserts are often nutrient limited after water. However, long-term experimental N additions do not strongly affect desert shrub productivity or foliar C:N ratios. Shallow rooted desert annuals do respond positively to ammonium (NH_4^+) and nitrate (NO_3^-) additions (Hall et al., 2011) but this only accounts for roughly 5% of the total N pool. This suggests that either N is not limiting, shrubs are not able to access the N due to water limitation or substantial N is lost from the system.

Questions

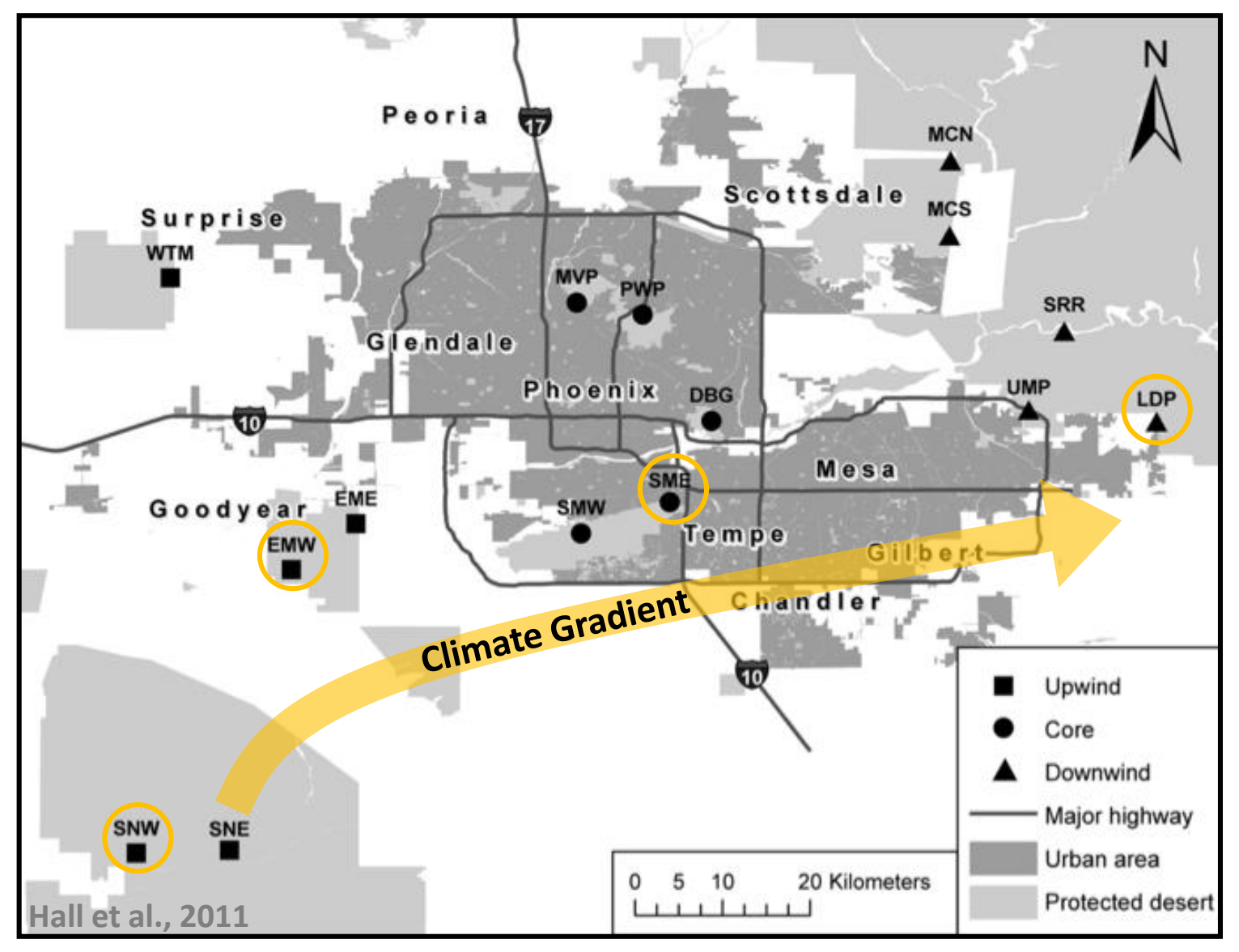
The goal of this research project is to quantify pools of soil inorganic nitrogen (iN) in soils receiving long-term N additions across a modest climosequence.

Specifically we ask:

Question 1. What is the fate of N additions? How much of the applied N is retained in the rooting zone? How is it distributed throughout the soil profile? Does this change with patch type (inter-plant vs. under-plant)? By N species (NO_3^- vs. NH_4^+)?

Question 2. How do patterns in N retention change with climate? Do modest increases in precipitation and temperature matter to N retention in deserts?

Site Description/Methods



	------ % ------				-- mm --	--------- °C ---------	
Site ID	Sand	Silt	Clay	Soil classification	MAP 5-yr	MAT 5-yr	Max T 5-yr
SNW	70.0	23.5	6.5	Typic Camborthids	113	22.8	46.6
EMW	75.3	16.3	8.4	Typic Haplargids	156	23.1	47.4
SME	68.3	21.6	10.1	Typic Haplargids	218	22.5	45.7
LDP	64.1	24.9	11.0	Typic Haplargids	231	22.1	46.6

This research project utilizes a long-term N addition experiment located in and around the Phoenix metropolitan area and CAP-LTER site in central Arizona.

Soils at 4 sites were sampled from control and N addition plots, once from under *Larrea tridentata* and once from the adjacent inter-plant patch, for NH_4^+ and NO_3^- pools to a depth of 75 cm (i.e. rooting zone) at intervals of 2-10 cm.

Q1: What is the fate of N additions?

- **Most of the applied N remains in the rooting zone (84%)**

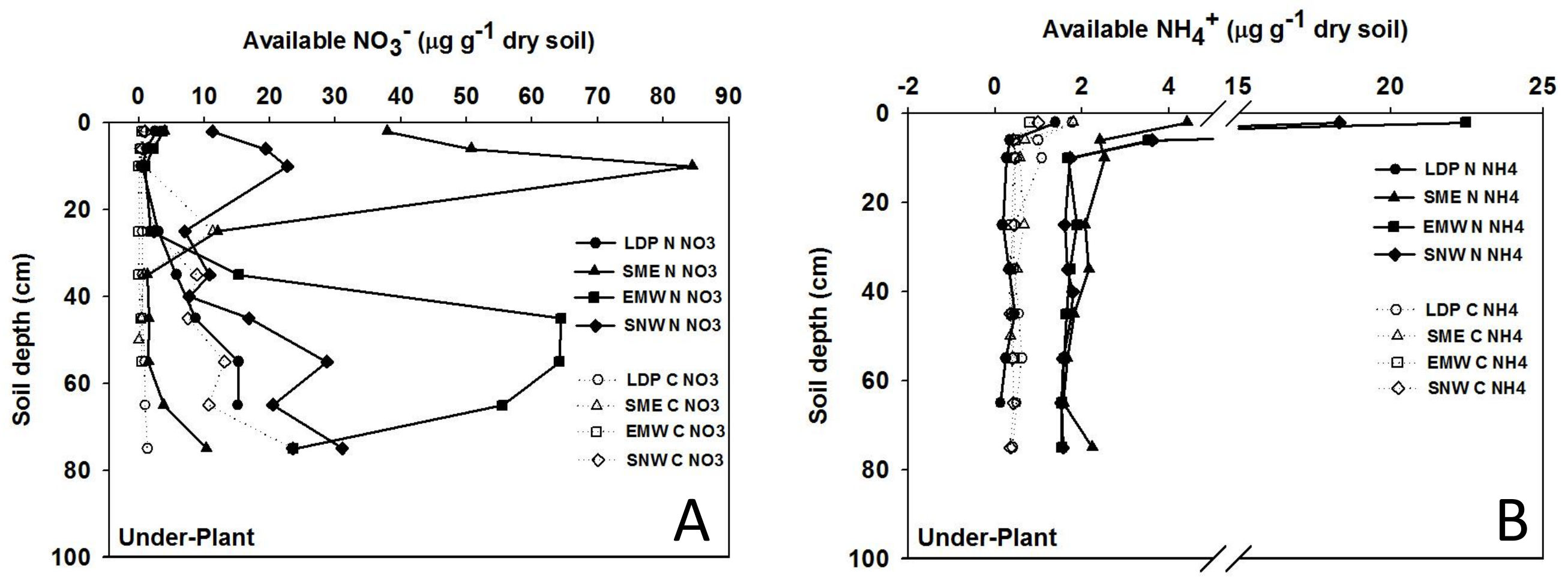


Figure 1: change in soil NO_3^- (A) and NH_4^+ (B) concentrations with depth for both control (dashed line) and fertilized (solid line) plots.

- Soil NO_3^- concentrations (Fig. 1A) remained high with soil depth, averaging 5 to 100-fold greater than NH_4^+, which declined steeply within the top 10 cm (Fig. 1B).

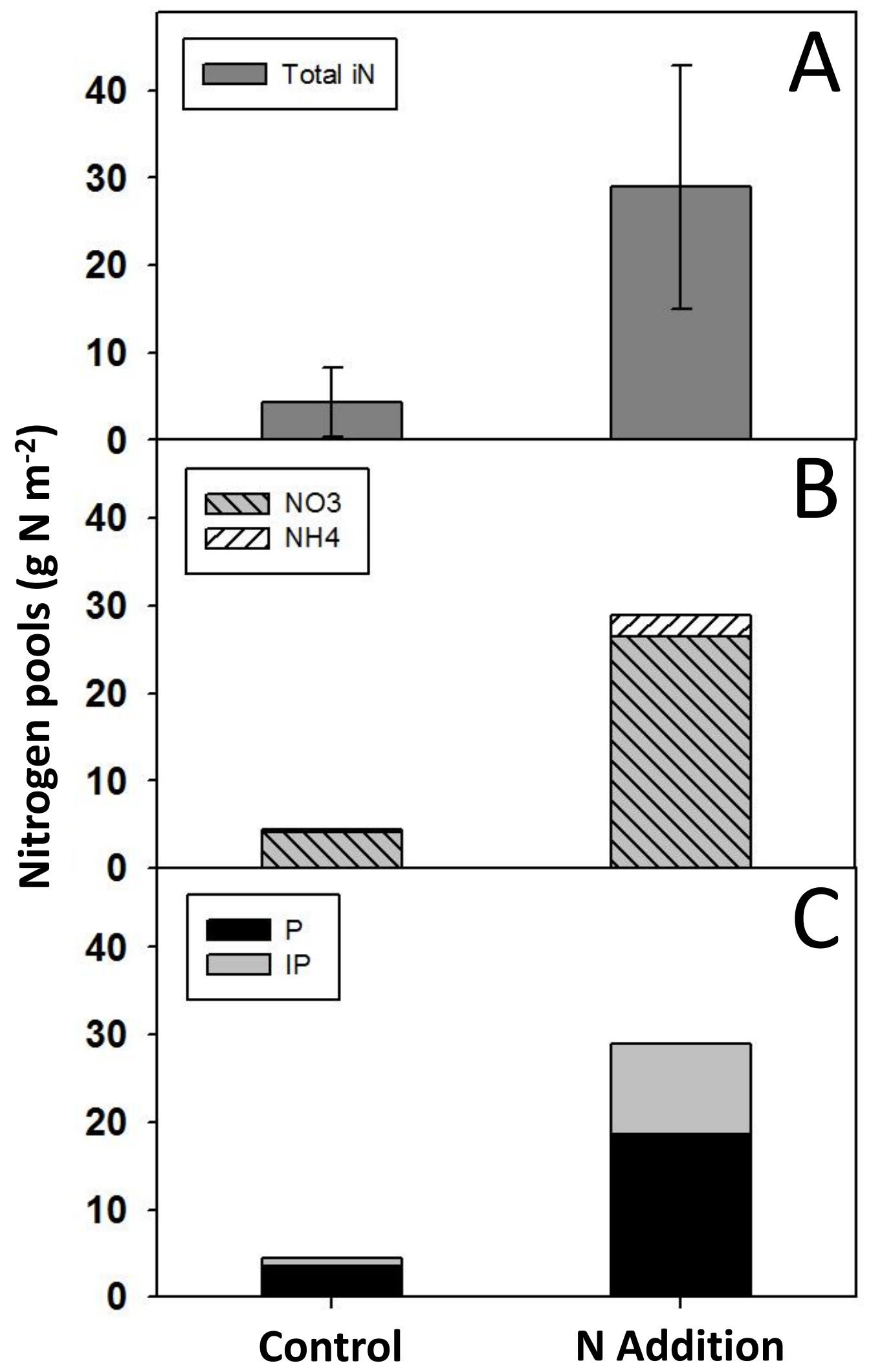


Figure 2: inorganic nitrogen (iN) pools for control and N addition plots. A) Total iN pools. B) Separate NO_3^- and NH_4^+ pools. C) Total iN pools for inter-plant (IP) and under-plant (P) patches.

- Average total stocks of iN were significantly higher than controls (4.4 vs. 28.9 g N m^{-2}, *P*=0.006) (Fig. 2A). After subtracting background iN, N addition plots contained on average 84.3±44.7% (mean±S.E.) of the total iN applied.
- Although NO_3^- and NH_4^+ were added to soils at an approximate 3:1 ratio, 91% of the remaining N applied was in the form of NO_3^- (Fig. 2B).
- Comparing under-plant vs. inter-plant patches, 65% was found under plants (Fig. 2C) despite average canopy cover of only 25.7±8.7%.

Q2: Can small climate shifts alter soil N?

- **Shifts in climate explain much of the variability in N pools**

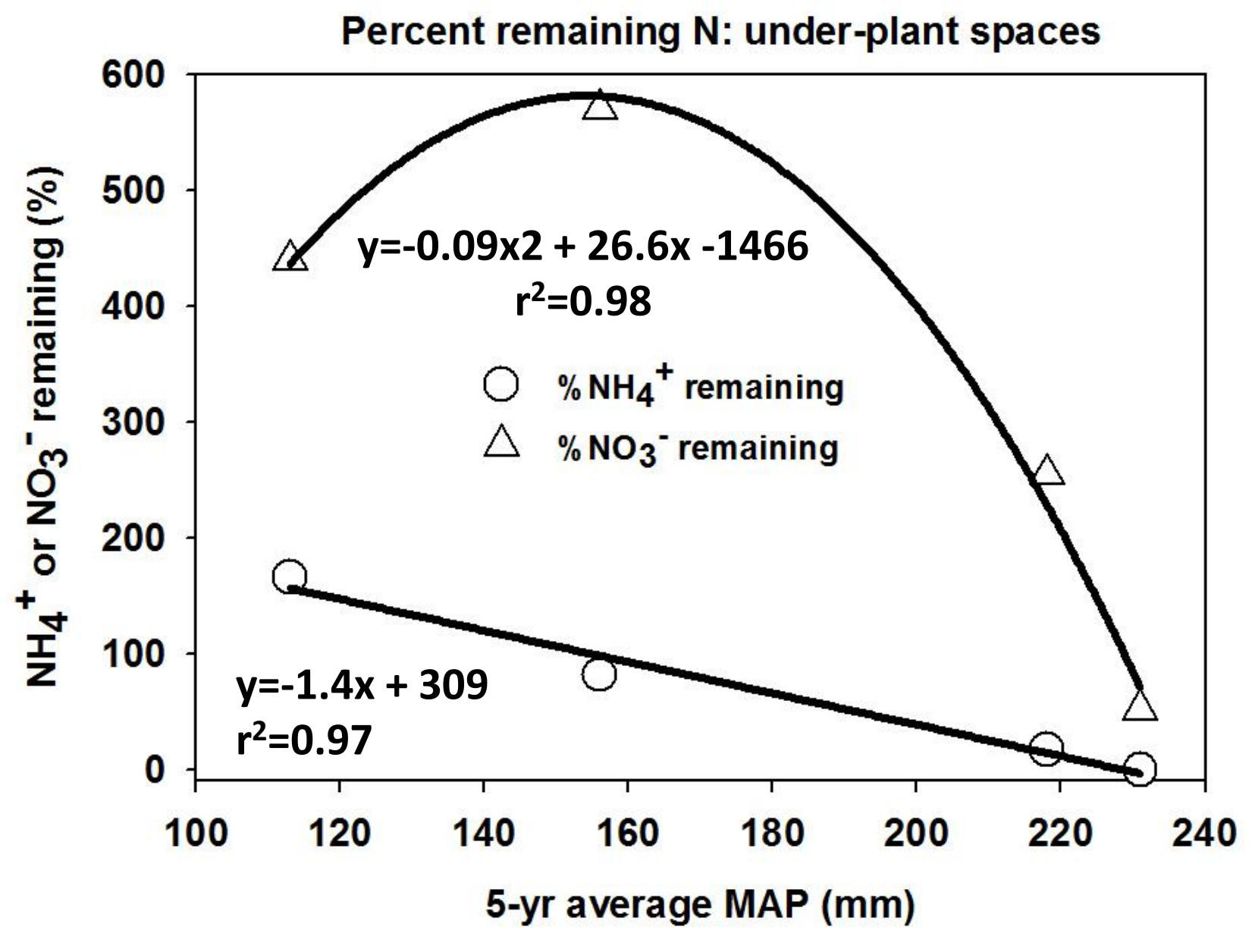
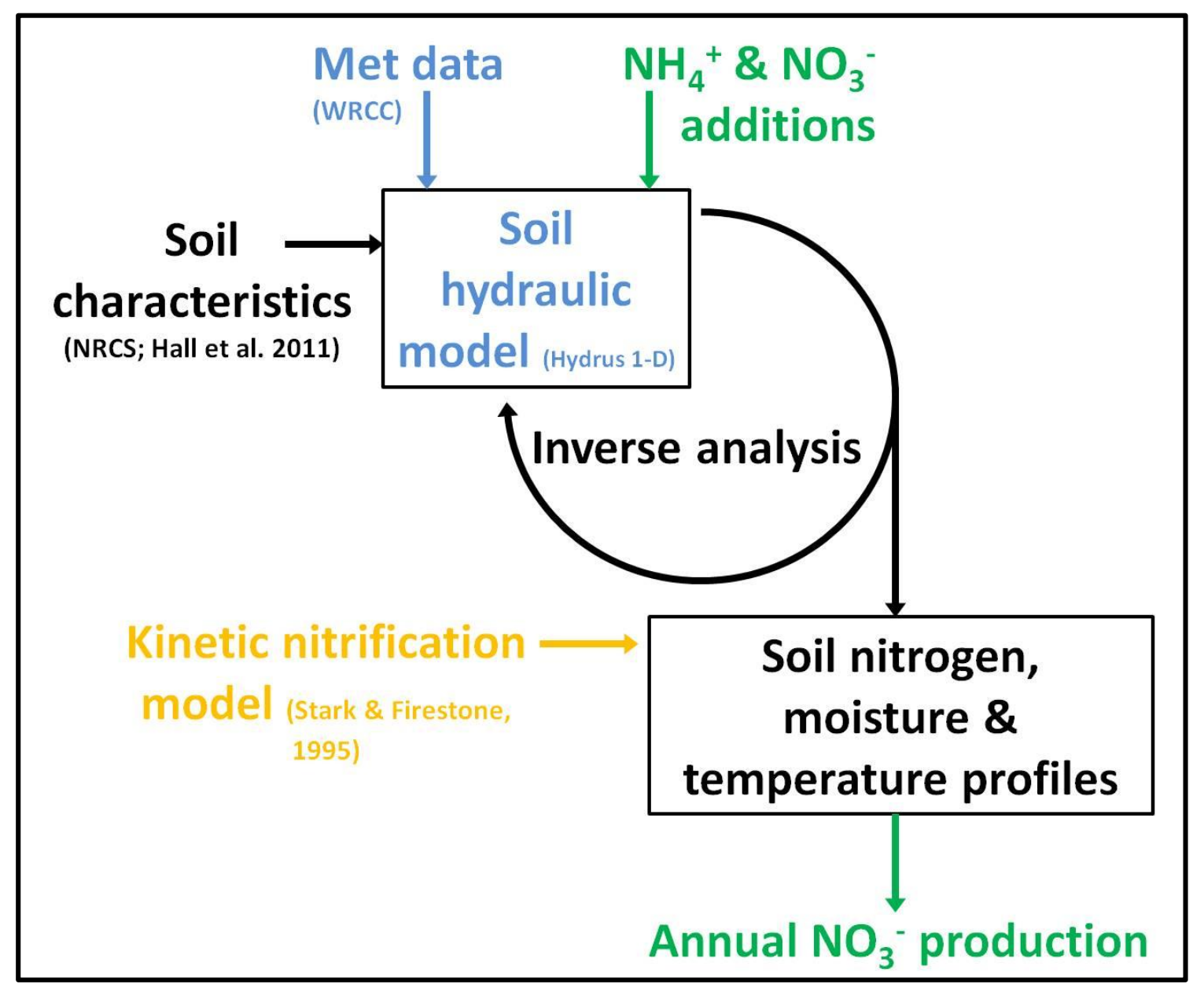


Figure 3: percent applied NO_3^- (triangles) and NH_4^+ (circles) remaining as a function of mean annual precipitation (MAP) across the climosequence.

- Storage of applied NH_4^+ under plants declined significantly with increasing precipitation (**0-166% remaining**, r^2=0.97, *P*=0.01, β=0.73).
- Storage of applied NO_3^- under plants also declined significantly with increasing precipitation (**52-570% remaining**, r^2=0.96, *P*=0.09, β=0.88).
- Inter-plant iN storage showed no relationship with MAP but average maximum daily temperature during summer trended strongly with inter-plant soil NO_3^- pools (r^2=0.80, data not shown).

What processes explain enrichment of NO_3^- relative to N additions?



Met data (WRCC)
NH_4^+ & NO_3^- additions
Soil characteristics (NRCS; Hall et al. 2011)
Soil hydraulic model (Hydrus 1-D)
Inverse analysis
Kinetic nitrification model (Stark & Firestone, 1995)
Soil nitrogen, moisture & temperature profiles
Annual NO_3^- production

Figure 4: soil hydrologic properties were estimated from soil texture and bulk density measurements using a pedo-transfer function. Parameter estimates from the NRCS database were used to constrain the model. Inverse model results were compared to NRCS values and field soil NO_3^- profiles for validation. Soil hydrologic parameters were then used to estimate soil water potential over the 5 year study. These results were incorporated into a kinetic nitrification model, which scales potential nitrification rates by soil water potential and temperature.

- We coupled a hydrologic model (Hydrus 1-D) with a simple kinetic nitrification model adapted from Stark and Firestone (1996) to estimate rates of NO_3^- production under predicted soil-water energy states (Figure 4).

		--------- g iN m^{-2} ---------		g NO_3^- m^{-2} 5yr^{-1}	--- % ---
Site	Patch	Applied NO_3^-	Measured NO_3^-	NO_3^- production	Excess explained
LDP	P	10.5	5.4	2.7	242
	IP	10.9	1.0	2.8	1356
SNW	P	2.1	9.3	11.8	149
	IP	24.8	13.1	7.6	248

Table 2: pools of applied and measured NO_3^-, NO_3^- produced due to nitrification during the 5 year experiment and percent of excess NO_3^- explained by nitrification model at the wet (LDP) and dry (SNW) N addition sites.

- The model estimates of nitrification rates in the upper 75 cm explain all the excessive NO_3^- observed (Table 2).

Conclusions

- We show that after 5 years of experimental N additions, applied N largely remain within the rooting zone (84%) of these desert soils.
- However, NH_4^+ and NO_3^- pools are strongly controlled by modest changes in MAP (70 mm) between sites.
- Our modeling results suggest that nitrification largely explains the presence of excess NO_3^- in N addition plots. In addition, our modeling suggests some of the NH_4^+ that was deposited in inter-plant spaces must have been redistributed to under-plant patches, supporting the conceptual model introduced by Hall et al. (2011).

Nitrogen loss processes sensitive to soil moisture and temperature and likely responsible for variation in N pools between sites include: fluxes of ammonia, nitric oxide and nitrous oxide (Hall et al., 2008; McCalley and Sparks, 2008). Nitrate leaching below the rooting zone at the wetter sites may also be a mechanism of N loss (Walvoord et al., 2003).

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