Nitrogen Hotspots in Sierra Nevada Forest Soils

D.W. Johnson[1], W.W. Miller[1], J.D. Murphy[1], D.W. Glass[1], C.M. Stein[1], and M.M. Meadows[2]

[1]University of Nevada, Reno, Nevada

[2]University of California, Merced, California

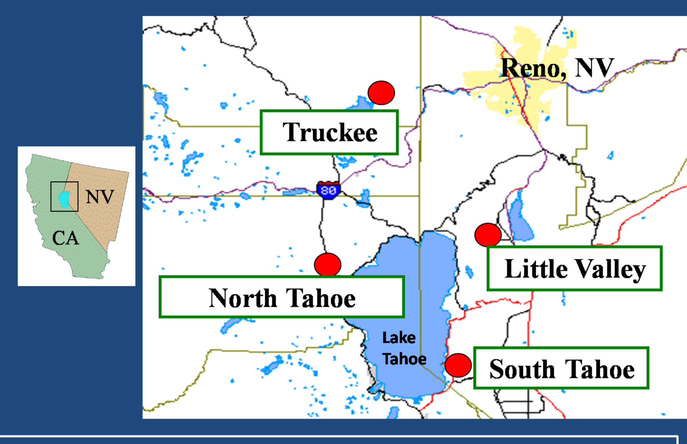
Introduction

Non-normal distributions and extreme outliers are often seen as problematic when attempting to assess treatment effects available N in forest soils. Recent papers suggest, however, that variability in available N is an important feature, allowing plant roots to migrate from one "hot spot" to another while they are hot (i.e., during "hot moments"), thereby avoiding direct competition with soil microbes for N (Schimel and Bennett, 2004). In Part 1 of this paper, we explore existing data sets from studies in forest soils of the Sierra Nevada Mountains of Nevada and California for the presence of hot spots. In Part 2, we present the initial results of a new study designed to detect hotspots in one Sierran location.

Part 1: Re-examination of existing data sets

Sites

Location	Vegetation	Soils
North Tahoe	Mixed conifer	Andic Haploxeralfs derived from basalt
South Tahoe	Mixed conifer	Typic Cryopsamments derived from granite
Truckee	*Pinus jeffreyii*	Ultic Haploxeralfs derived from andesite
Little Valley	*Pinus jeffreyii* *Ceanothus velutinus*	Typic Xeropsamments derived from granite



Question 1: Do hot spots exist in Sierran Forest Soils?

With no exception, the distribution of NH_4^+ and NO_3^- as measured by soil extraction, resin capsules, resin stakes, resin lysimeters, runoff collectors, and tension lysimeters in various study locations show positive skew and the presence of positive extreme outliers (as defined by 3 x the range from the first to the third quartile) (Table 1). Figures 1 and 2 show examples of typical patterns from the North Lake Tahoe site.

Table 1. Skewness and extreme outliers for NO_3^-, NH_4^+, and mineral N (NO_3^- NH_4^+) in soils, resin capsules, resin lysimeters, and resin stakes (PRS probes™) in various sites in the eastern Sierra Nevada Mountains.

	n	Skewness			Extreme Outliers		
		NO_3^-	NH_4^+	$NH_4^+ + NO_3^-$	NO_3^-	NH_4^+	$NH_4^+ + NO_3^-$
North Lake Tahoe							
Resin capsules	76	4.37*	4.67*	3.07*	4	8	5
Resin stakes	77	4.61*	2.88*	3.30*	2	2	3
Soils (10 cm)	99	0.90*	2.91*	2.95*	1	1	2
Soils (10 cm)†	20	1.90*	1.17*	0.60	0	0	0
Soils (70 cm)	20	0.18	0.52	0.48	0	0	0
Runoff conc.	83	3.61*	4.48*	3.16*	10	2	5
Runoff loading	83	2.80*	4.80*	3.48*	6	6	5
Little Valley							
Resin lysimeters	93	8.23*	3.16*	8.24*	5	3	5
Resin capsules	46	1.23*	4.39*	1.14*	0	3	0
Soil solution	65	5.64*	1.32*	5.57*	3	0	1
Runoff conc.	49	3.31*	5.3*	2.73*	6	3	5
Truckee							
Resin lys, Yr 1	44	5.74*	1.58*	5.64*	1	1	1
Resin lys, Yr 2	44	4.06*	1.45*	4.06*	3	0	3
Soil Solution	49	4.43*	3.38*	3.50*	2	5	1
Runoff conc.	90	3.45*	6.67*	6.40*	3	10	7
Runoff loading	90	3.49*	2.81*	2.76*	3	11	11
Gondola							
Resin lysimeters	52	6.79*	1.55*	6.78*	3	1	2
Soil solution	10	2.30*	1.05	0.63	1	0	1
Runoff conc.	87	3.11*	7.99*	5.77*	6	6	5
Runoff loading	87	2.21*	3.08*	2.22*	3	9	1

Question 2: What is the scale of the hotspots?

At the North Tahoe site, we sampled soils on two scales: 1) approximately 10 cm diameter samples, taken depth proportionally with trowels with five replicates each in 20 plots (n=100), and 2) approximately 70 cm diameter quantitative pits, one per plot (n=20) where samples were homogenized by horizon. Figure 1 and Table 1 compare samples taken at these two scales, including a randomly-selected subset of the 10 cm diameter samples, one per plot (n=20). Data from the 70 cm samples show no outliers and less skew than data from the 10 cm samples.

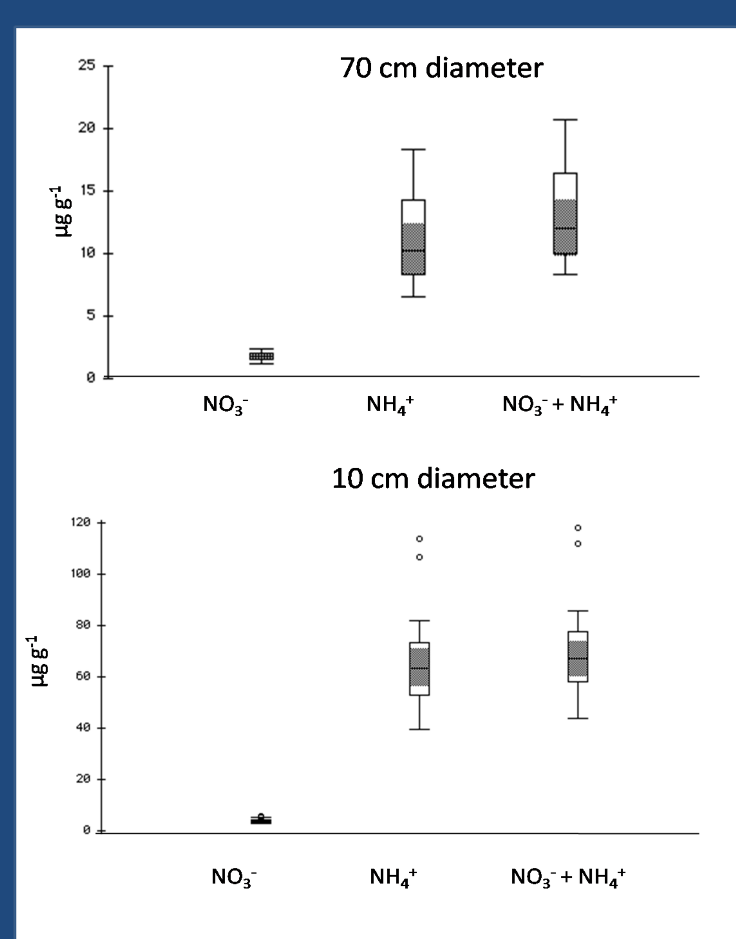


Figure 1. Box plots of NH_4^+ and NO_3^- in surface soils sampled 10 cm diameter and 70 cm diameter scales from the North Lake Tahoe Site (data from Glass, 2006). Circles represent outliers (1.5 x the range between the first and third quartiles) (n= 20 for both data sets)

Part 1: Re-examination of existing data sets (continued)

Question 3: Do hotspots exist for non-limiting nutrients?

At the North Tahoe site, we can compare distributions of NH_4^+ and NO_3^- with ortho-P, K, Ca, and Mg as measured in soils and by PRS resin stakes. The order of abundance of these nutrients in the soils is $Ca^{2+} > Mg^{2+} > K^+ >$ ortho-P $> NH_4^+ + NO_3^-$. Ortho-P shows values for skew and numbers of extreme outliers similar to those for mineral N, whereas K^+, Mg^{2+} and (especially) Ca^{2+} show much lower values (Figures 2 and 3; Table 1).

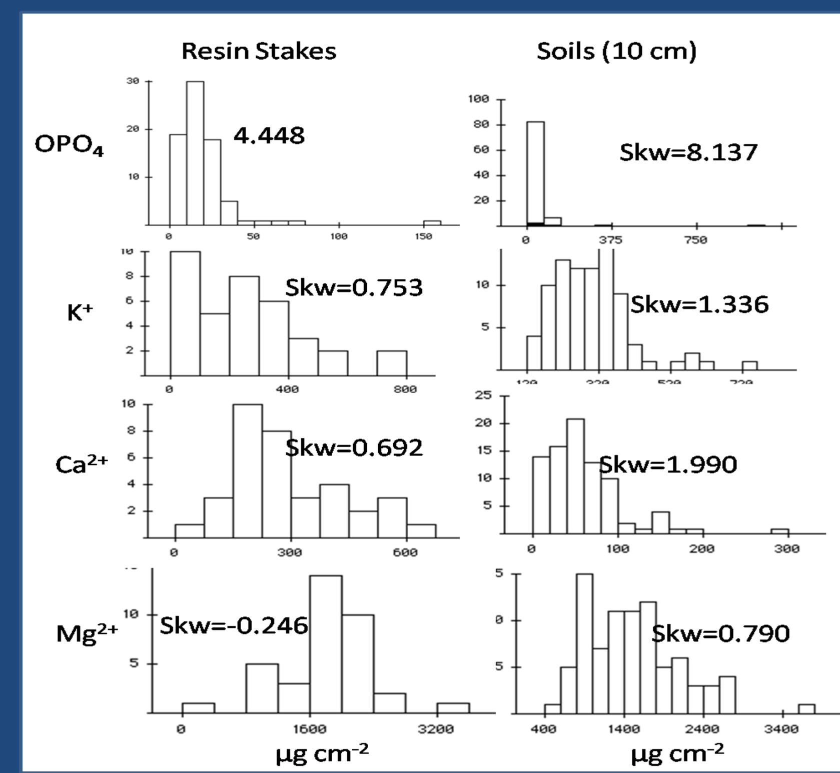


Figure 2. Histograms of ortho-P, K^+ Ca^{2+} and Mg^{2+} measured by resin stakes and surface soils sampled 10 cm diameter from the North Lake Tahoe Site (data from Glass, 2006). Skewness values are shown.

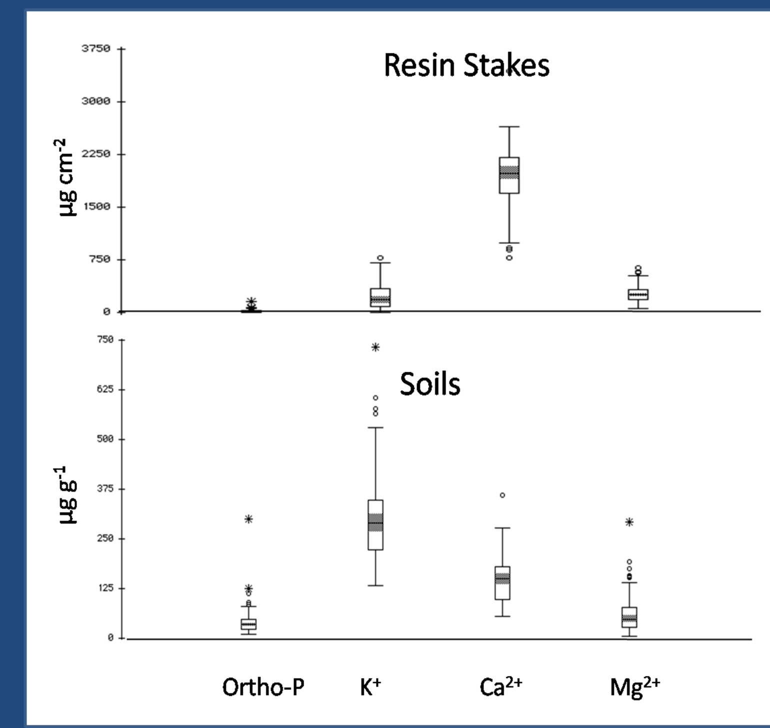


Figure 3. Box plots of ortho-P, K^+ Ca^{2+} and Mg^{2+} measured by resin stakes and surface soils (sampled 10 cm diameter) from the North Lake Tahoe Site (data from Glass, 2006). Circles represent outliers (1.5 x the range between the first and third quartiles) and starbursts represent extreme outliers (3 x the range between the first and third quartiles)

Question 4: What causes hotspots?

Perhaps the most germane and interesting question regarding hot spots is that of cause or causes. One possibility is that mineral N hot spots are simply a function of hot spots in total organic N or C:N ratio (which would then raise the question as to what causes these hot spots). Figure 4 shows plots of mineral N ($NH_4^+ + NO_3^-$) vs total C, total N and C:N ratio for the North Lake Tahoe 10 diameter soils. Mineral N is weakly but significantly but correlated with total C, total N and (less so) with C:N ratio. The correlation between mineral N and total N is logical, but the fact that C:N ratio is positively correlated with mineral N flies in the face of common textbook concepts. Total C and total N are highly correlated, as would be expected, and total C is significantly correlated with C:N ratio but total N is not. There were no significant correlations between NH_4^+, NO_3^-, and mineral N and extractable P (Bray or bicarbonate), exchangeable K^+, Ca^{2+}, or Mg^{2+}.

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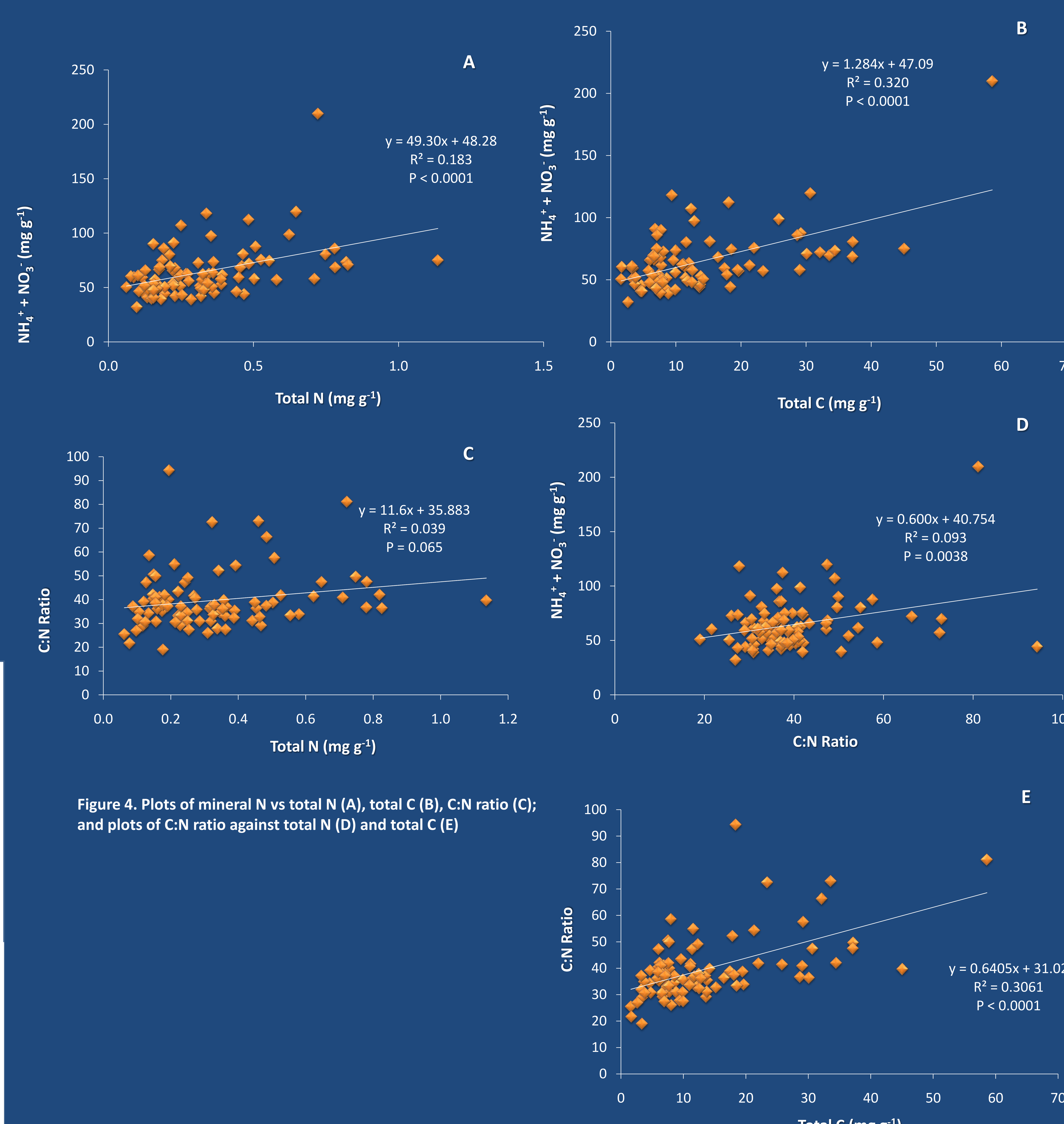


Figure 4. Plots of mineral N vs total N (A), total C (B), C:N ratio (C); and plots of C:N ratio against total N (D) and total C (E)

Question 4 (cont.): What causes hotspots?

Miller et al (2005, 2006) have noted the presence of nutrient-laden solutions flowing through the O horizons and on top of mineral soils in all of the sites sampled here. Because of the lack of plant roots in the O and upper A horizons (precluded by severe summer droughts), nutrients mineralized are not immediately taken up and cause the enrichment of O horizon interflow waters in NH_4^+, NO_3^- and ortho-P. We hypothesize that that these O horizon interflow waters cause nutrient hot spots when they enter preferential flowpaths into the mineral soil. We have no direct proof of this as yet (there is a substantial sampling problem, in that sampling such flowpaths will destroy them for further study), but we note that the distribution of NH_4^+, NO_3^- and ortho-P in runoff concentrations and loadings (total amounts per collector) show many extreme outliers and a high degree of skewness (Table 1). Figures 5 and 6 show distributions of NH_4^+, NO_3^- and ortho-P in runoff water concentrations and loading for the North Tahoe site by way of illustration.

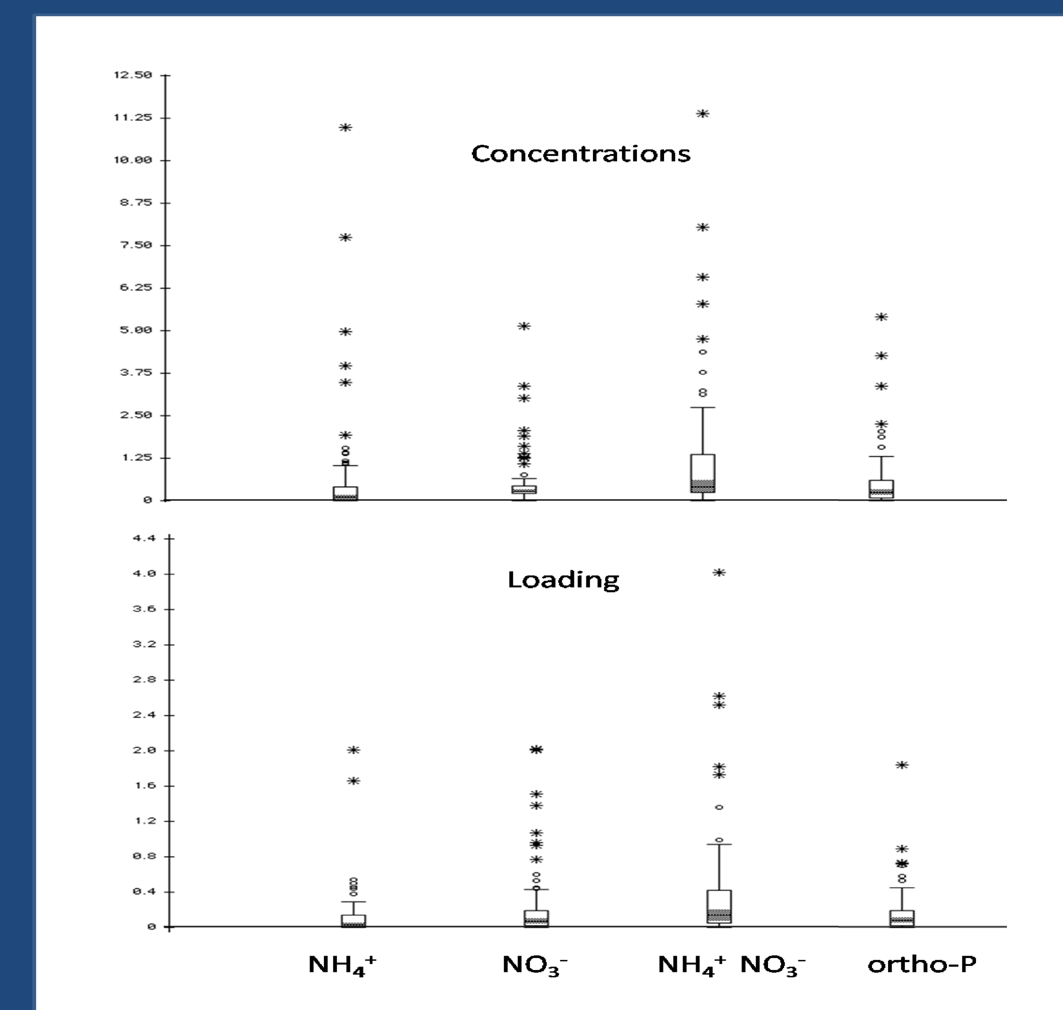


Figure 5. Box plots of NH_4^+, NO_3^- and ortho-P in O horizon interflow solution concentrations and loading at the North Tahoe Site. Circles represent outliers (1.5 x the range between the first and third quartiles) and starbursts represent extreme outliers (3 x the range between the first and third quartiles) (n= 20 for both data sets)

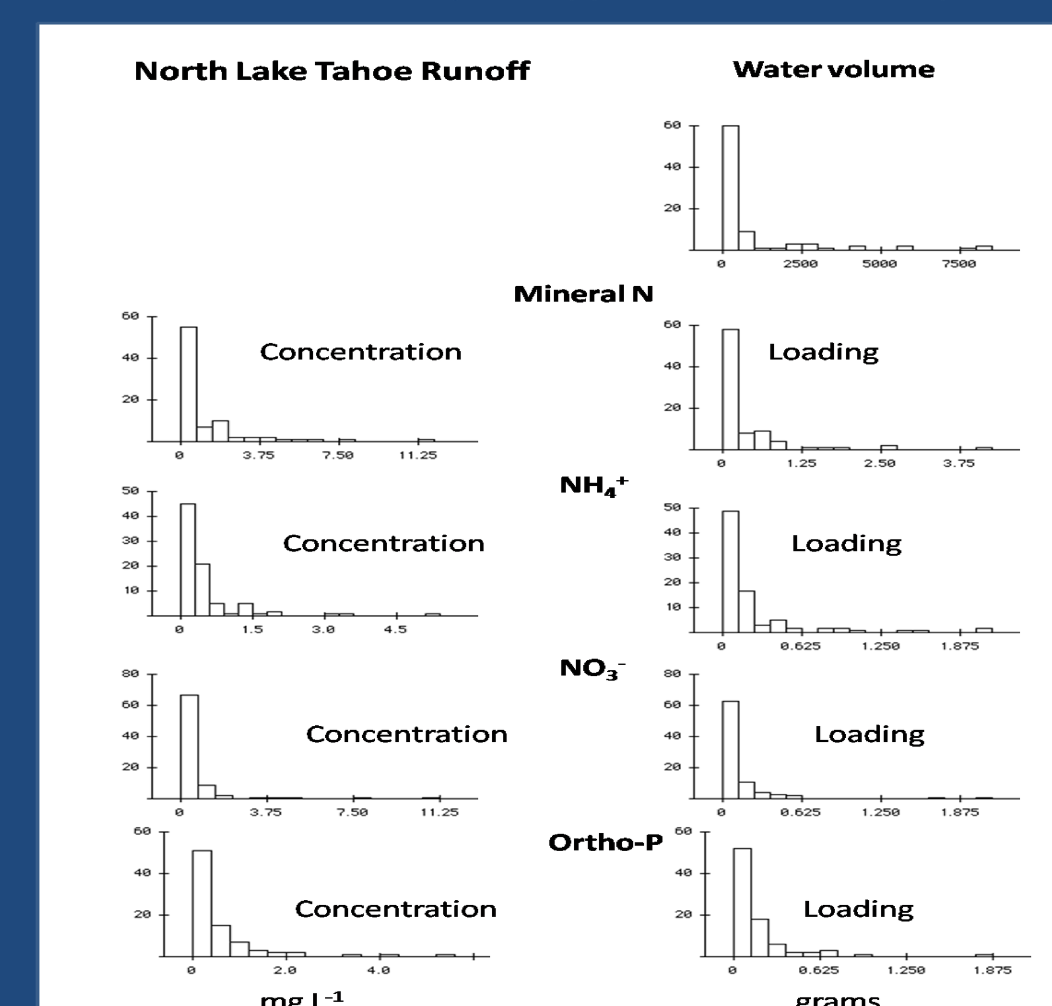


Figure 6. Histograms of NH_4^+, NO_3^- and ortho-P in O horizon interflow solution concentrations and loading at the North Tahoe Site.

Conclusions from Part 1

- Mineral N in soils, resin based collectors, and O horizon interflow solutions are always positively skewed and usually contain extreme high outliers, suggesting of the existence of N hot spots.
- The scale of these hot spots for mineral N appears to be on the order of centimeters.
- Hot spots are found for ortho-P, less often for K^+ and Mg^{2+}, but not for Ca^{2+}, the most abundant nutrient.
- Mineral N hot spots are weakly, positively correlated with total soil C , N, and (surprisingly) C:N ratio but not with any other measured nutrient.
- We hypothesize one cause of mineral N hot spots is the infiltration of nutrient-rich O horizon interflow waters.

Part 2: Investigation of nutrient hot spots in the western Sierra Nevada Mountains

Introduction

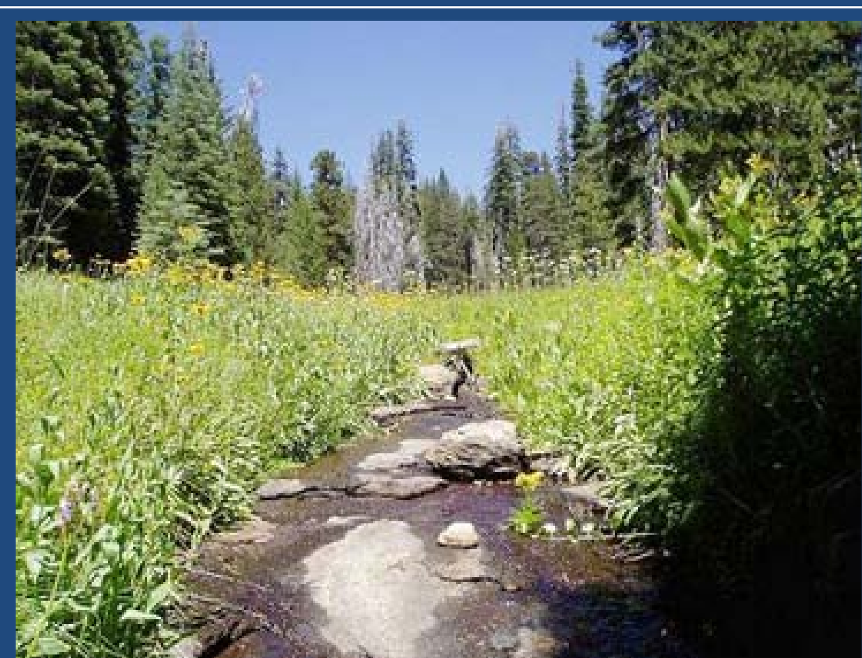
As part of the Southern Sierra Nevada Critical Zone Observatory Project, a study was initiated at the King's River Experimental Watershed (KREW) in the spring of 2008 to specifically investigate the occurance, nature, and potential causes of nutrient hotspots. For this study, a grid was laid out in two locations within which nutrients were measured by litter and soil sampling, resin techniques (PRSTM probes and Unibest® resin capsules and O horizon interflow collectors (Miller et al., 2005). In this case, the spatial distribution of collections was specifically designed to investigate the nature of hot spots. We hypothesized that:

1. Nutrient-rich O horizon interflow would occur in these ecosystems, as is common in eastern Sierran ecosystems
2. Mineral N hotspots (defined as extreme outliers) would occur in these ecosystems at a scale of centimeters, as was apparently the case from re-analyses of older data in eastern Sierran ecosystems
3. Hotspots for more abundant nutrients such as Ca would be rare or absent.

Ultimately, we would like to determine the role of O horizon interflow (assuming that it occurs) in creating mineral N hotspots. This is a difficult sampling problem in that we cannot observe points of interflow entry without destroying research plots, and thus part of our goal here is to seek indirect evidence of interflow influence.

Sites

Location	Vegetation	Soils
Upper (met station)	Sparse Mixed conifer	Ultic Haploxeralfs derived from decomposed granite
Lower (Prenart)	Dense Mixed conifer	Ultic Haploxeralfs derived from decomposed granite



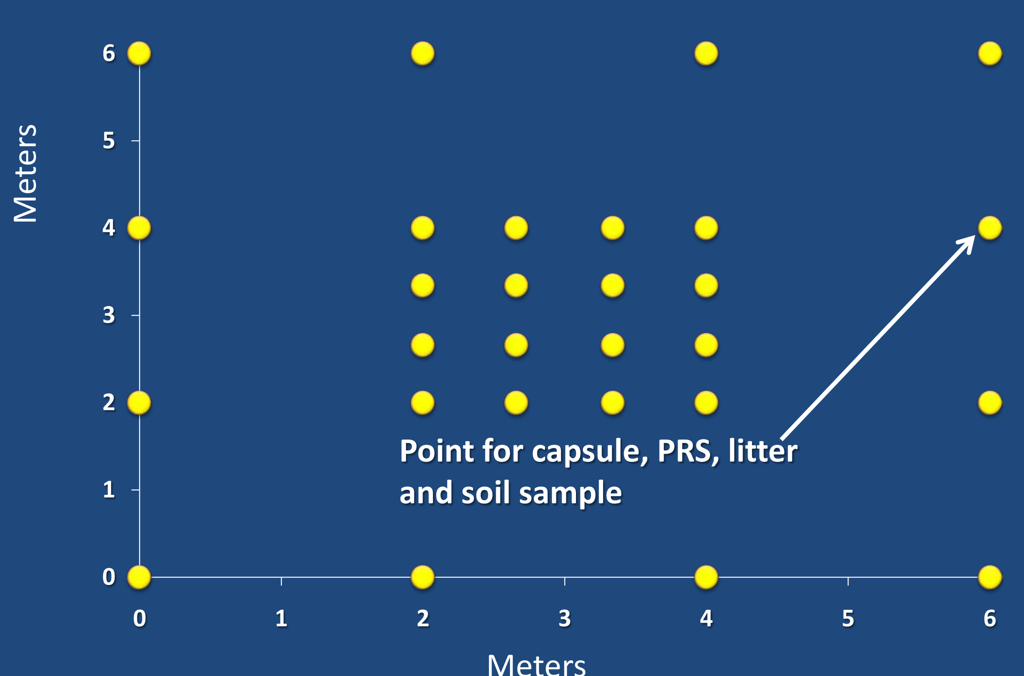


Figure 1. Layout of sampling grid established at the two KREW sites. A resin capsule and PRS probe were installed at each gridpoint and allowed to accumulate nutrients over the snow season. After snowmelt, litter and soil samples were taken at each gridpoint and extracted with water in the laboratory.

Resin collectors (left) and as installed in the field grids (right).

Installing an interflow runoff collector at the O horizon/mineral soil interface to collect O horizon interflow.

As in the eastern Sierran sites, O horizon interflow does occur and has high concentrations of mineral N. Both total water volume and concentration contributed to total amount of runoff collected (Figure 2). The collector that had the greatest total runoff (P2), perhaps creating the hottest spot, was intermediate in water volume and concentration.

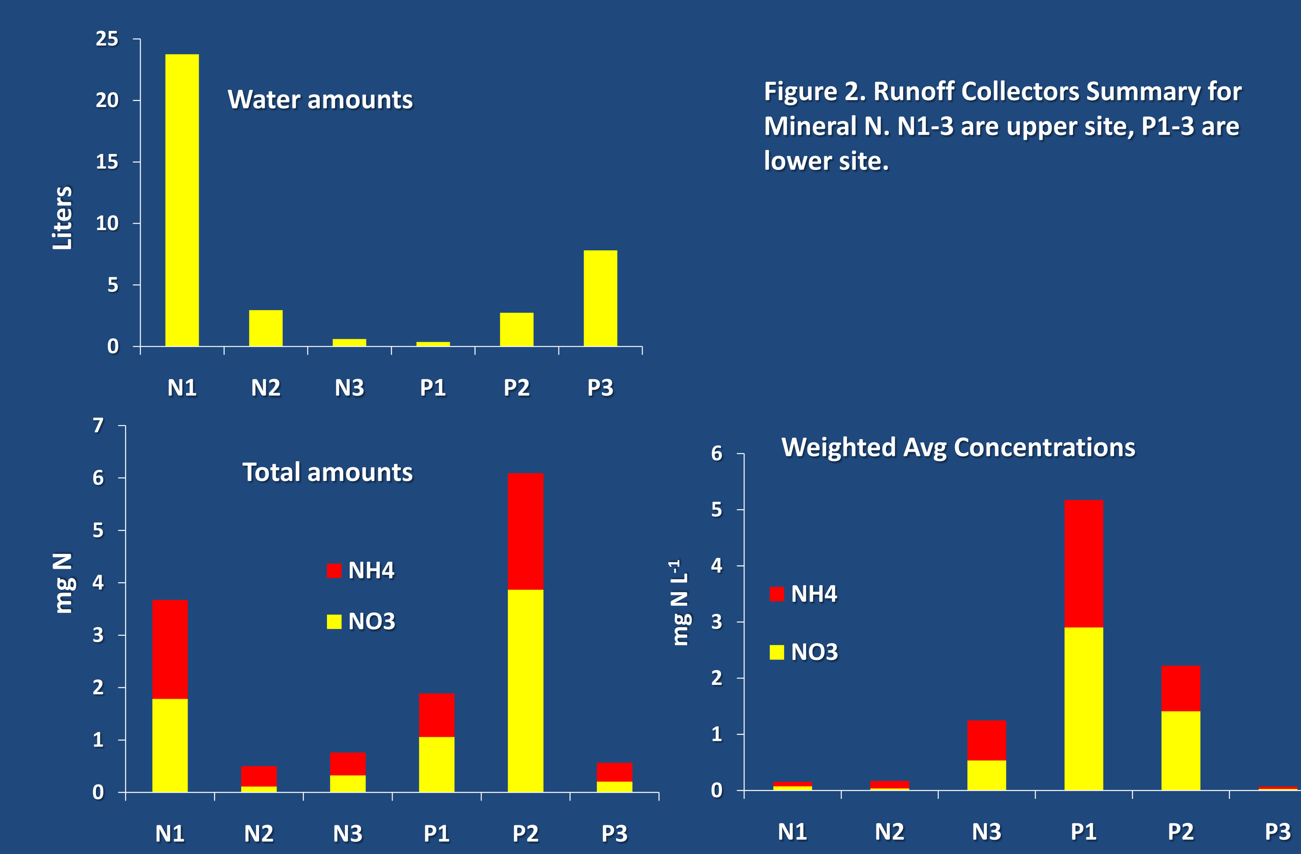


Figure 2. Runoff Collectors Summary for Mineral N. N1-3 are upper site, P1-3 are lower site.

Extreme outliers were found for mineral N as measured in soils (1 M KCl), litter leachates (water extracts of litter from each gridpoint), PRS probes, and capsules in the gridpoints of the upper plot (Plot 1). Gridpoint 4,4 proved to be an extreme outlier for all but soils, and appears to be a true mineral N hotspot. Extreme outliers also occurred in all measurements of mineral N in the lower site, none were co-located (not shown).

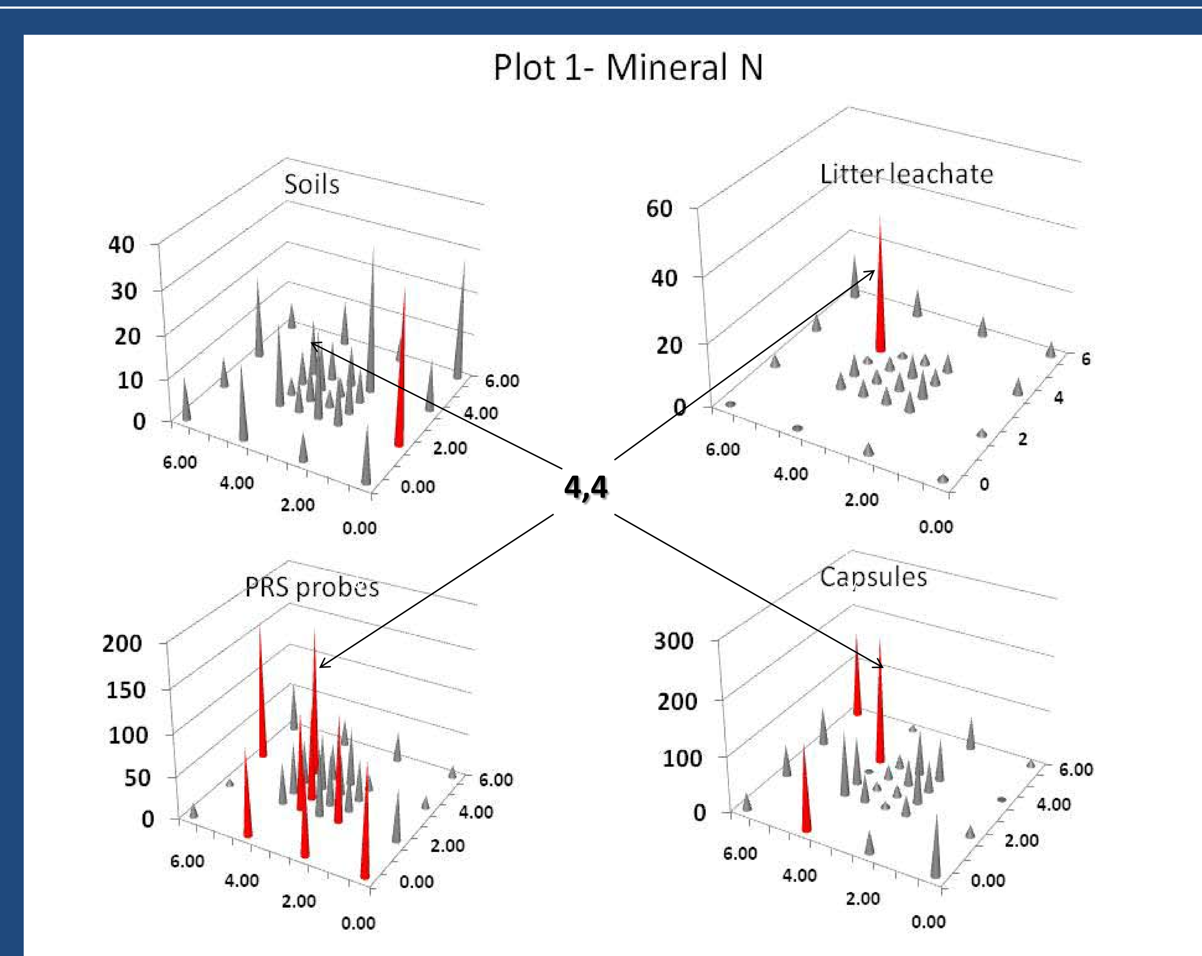


Figure 3. Mineral N in the gridpoints of the upper plot as measured in soils (1 M KCl), litter leachates (water extracts of litter from each gridpoint), PRS probes, and capsules. Red cones indicate extreme outliers.

No extreme outliers were found for Ca^{2+} as measured in litter leachates, PRS probes, or capsules in the gridpoints of the upper plot (Plot 1). (Soils data for Ca^{2+} are not available at this time.) Only one extreme outliers for Ca^{2+} was found in the lower site (in litter leachate). (not shown).

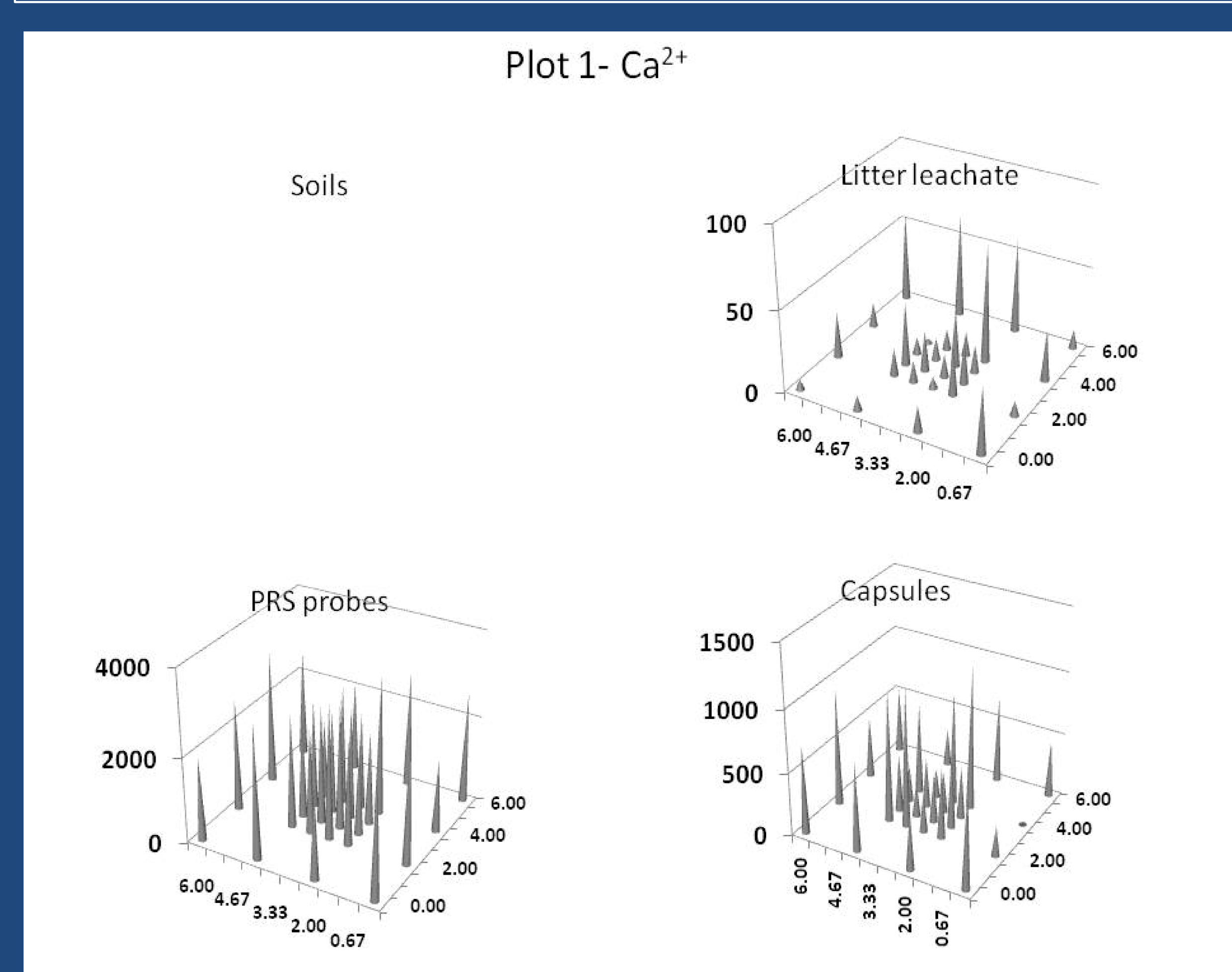


Figure 4. Calcium in the gridpoints of the upper plot as measured in litter leachates (water extracts of litter from each gridpoint), PRS probes, and capsules. Red cones indicate extreme outliers.

As in the eastern Sierran sites, there were generally much fewer outliers for more abundant nutrients than for mineral N (Table 2)

Table 2. Number of extreme outliers in the two plots

Measurement	NH_4^+	NO_3^-	Mineral N	Ortho-P	Ca^{2+}	Mg^{2+}
PRS Upper	2	0	0	0	0	1
PRS Lower	2	13	7	0	0	0
Capsules Upper	1	0	0	0	0	0
Capsules Lower	8	4	5	0	0	0
Litter Leachate Upper	2	2	1	0	0	1
Litter Leachate Lower	1	2	1	1	1	1

The only nutrients that were significantly correlated with each other were Ca^{2+} and Mg^{2+}. These two nutrients were highly correlated in capsules (Figure 5) and runoff, (Figure 6) but much less so PRS probes or litter leachates (not shown). This suggests that capsules most accurately sample runoff and, with further testing, may be able to serve as surrogates for bulky runoff collectors.

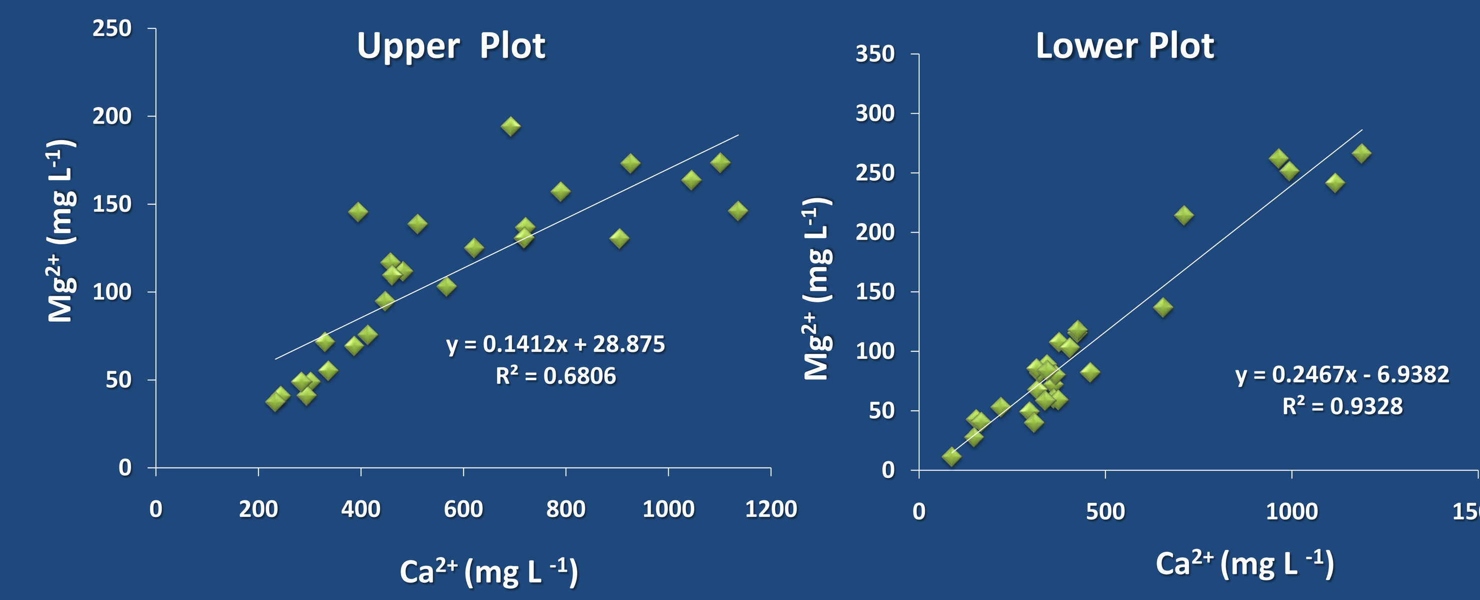


Figure 5. Ca^{2+} vs Mg^{2+} in capsules from the upper and lower plots.

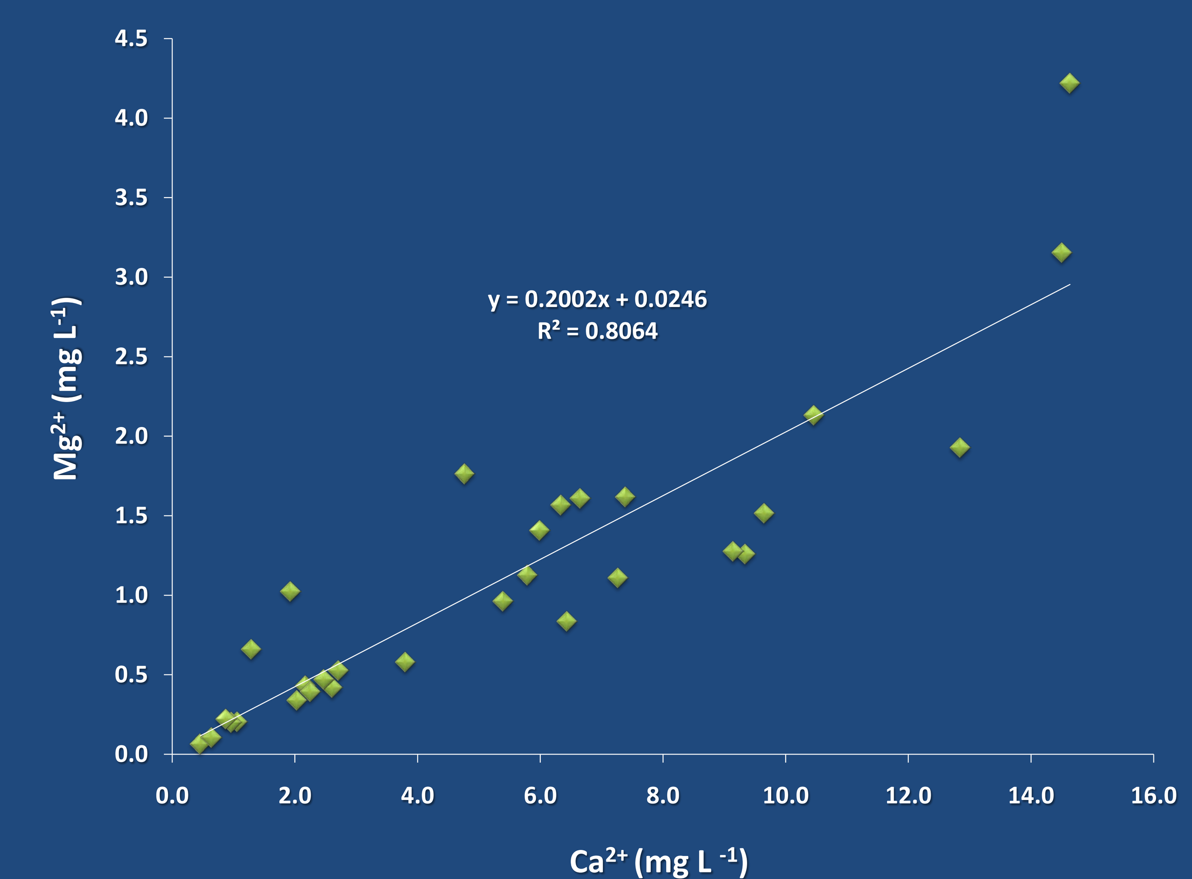


Figure 6. Ca^{2+} vs Mg^{2+} in O horizon interflow.

Conclusions from Part 2

Hypotheses:

1. Nutrient-rich O horizon interflow would occur in these ecosystems, as is common in eastern Sierran ecosystems
   True
2. Mineral N hotspots (defined as extreme outliers) would occur in these ecosystems at a scale of centimeters, as was apparently the case from re-analyses of older data in eastern Sierran ecosystems
   True
3. Hotspots for more abundant nutrients such as Ca would be rare or absent.
   True

Goal of finding indirect evidence of O horizon interflow entry:

Ca^{2+} to Mg^{2+} ratios suggest that capsules may serve as surrogates for bulkier runoff collectors. More research is needed to verify or negate this.

Acknowledgments

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