2006-2011 Mission
Kearney Foundation of Soil Science: Understanding and Managing Soil-Ecosystem Functions Across Spatial and Temporal Scales
Progress Report: 2007026, 1/1/2008-12/31/2008

Fog Drip Drives Summertime Soil Respiration in California's Coastal Conifer Forests

Mariah Carbone[1], Christopher Still[*1], Todd Dawson[*2], Joshua Schimel[*1], Claudia Boot[1], Sean Schaeffer[1], Anthony Ambrose[2], Park Williams[1]

Project Objectives

The objective of this study is to understand how fog water inputs influence biogeochemical cycling and ecosystem function in coastal California forests. Specifically, we are investigating whether additional fog-derived moisture (1) stimulates summer photosynthesis and growth of Bishop pine trees; and (2) influences soil carbon cycling processes, including root respiration, microbial decomposition and biomass dynamics, and soil nutrient availability.

Approach and Procedures

We are working at two sites on Santa Cruz Island that differ in summertime fog water inputs, cloud cover, and soil moisture (SAUC - higher, UPEM - lower). Vegetation at each site includes Bishop pine (*Pinus muricata*) (hereafter canopy/forest, where fog drip occurs) and nearby grass and shrub cover (open, no fog drip). Environmental sensors were installed in 2003 and 2005 at these sites, and include a meteorological station, a fog-collector, and soil moisture and temperature sensors (Fischer and Still 2007). Additionally, pine basal growth and mid-day xylem water potential have been regularly monitored. We are combining these observations with new measurements of plant activity, soil nutrient and microbial dynamics, soil respiration (SR), soil CO_2 production, and the partitioning of SR into plant and microbial sources.

At each site in June 2008, automated sapflow systems were installed at the base of five pine trees (Burgess et al. 2001). Automated SR chamber systems (Carbone 2008) were deployed in the canopy/forest (five chambers, paired with the sapflow probesets) and open (three chambers) vegetation cover. Additionally, one soil pore space CO_2 profile was installed in the canopy/forest soil (four probes at different depths) (Tang et al. 2003). To complement these automated measurements, monthly litter and soil (10 cm) cores have been analyzed for gravimetric water content, extractable organic C and N, biomass flush C and N, inorganic nitrogen (NH_4^+, NO_3^-), and amino acid C and N in both canopy/forest and open cover (Gaudinski et al. 2000). At several temporal scales (monthly, fog event, and diel) over the summer, the radiocarbon (^{14}C) content of respired CO_2 was determined from the SR chambers, and separate laboratory incubations of roots and SOM (Carbone 2008). An isotope mass balance approach was then applied to determine the plant and microbial sources contributing to SR (Dawson 1998).

[1] University of California, Santa Barbara
[2] University of California, Berkeley
*Principal Investigator

Results

Soil respiration and ^{14}C source partitioning: At both sites, summer SR under the pine canopy was driven by frequent moisture pulses from fog drip and the seasonal increase in air temperature (*fig. 1*, only SAUC shown). By DOY 280, fog water inputs, as measured by the fog collector, stopped and canopy SR declined dramatically with surface soil volumetric water content (VWC) until the first rains on DOY 305-309. Canopy surface VWC was supplemented by fog-water inputs, but overall decreased over the summer. In contrast, SR from the open vegetation cover (meters away, no fog drip) declined slowly over the summer and fall until the first rain event. On DOY 170, 203, and 243, respired CO_2 was collected for ^{14}C analyses. The ^{14}C signature of canopy SR declined from DOY 170-243, indicating that root respiration was responsible for the rise in canopy SR over the summer measurement period (*fig. 2*). Changes in SR source contributions were also observed on shorter temporal scales with moisture pulses from fog events. On DOY 166, day one of a fog event, canopy SR increased (*fig. 3*) and reflected greater contribution from microbial decomposition (*fig. 4*). By day four of the fog event, canopy SR was still elevated (*fig. 3*), yet ^{14}C partitioning showed a more balanced contribution from plant and microbial respiration sources (*fig. 4*).

Bishop pine sapflow: Maximum sap velocity (SV) at both sites declined throughout the summer as vapor pressure deficit (VPD) increased and soil VWC decreased (*fig. 5*). Trees at SAUC had much higher SV than trees at UPEM throughout the season. Higher SV at SAUC appear to be sustained by higher soil VWC and generally lower VPD compared to UPEM. Frequent fog events resulted in only small and temporary increases in SV and did not prevent a gradual decline throughout the summer at both sites. Soil VWC and SV at both sites slightly increased during the first small rain event on DOY 305-309 but declined without further moisture inputs until DOY 330, when a larger set of rain events substantially increased soil VWC and maximum SV.

Soil nutrient and microbial dynamics: Forest soils at both sites had double the water content as those in the open cover, in agreement with surface soil VWC sensors at the sites. While no distinct patterns have yet emerged for extractable organic and biomass flush C and N, the inorganic N dynamics show decreasing nitrate (NO_3^-) concentrations and ammonium (NH_4^+) accumulation over the summer (*fig. 6*). Amino acid C was measured to determine if microbes were accumulating compatible solutes, such as glutamate, to survive in the dry summer. We expected to see a larger proportion of glutamate in the open vs. forest soil, because it receives no fog-drip. However, as a proportion of microbial biomass flush C, the highest value was observed in the SAUC forest soil (average 4.6%) while all others were around 1% (*table 1*).

Discussion

Previous studies have demonstrated the hydrological importance of fog-water inputs to California's coastal conifer forests (Dawson 1998; Burgess and Dawson 2004). However, fog water impacts on C cycling have been addressed only indirectly from its effects on plant transpiration and water relations. **Our observations are the first to link**

summertime fog-water inputs with whole ecosystem function and biogeochemical cycling, focusing on soil processes.

Our initial summer results demonstrate that fog-drip strongly influences SR rates and sources over multiple temporal scales, enhancing both plant and microbial activity in the absence of rain. Between the sites, large differences have emerged in soil moisture availability and its impact on pine SV rates and SR patterns. Interestingly, no prominent patterns in soil nutrient and microbial indices have been observed between the sites. It remains unclear to what degree the soil moisture disparity is the result of differences in fog/rain inputs, evapo-transpirational losses, and/or soil type, and will be the focus of further measurements and data analyses.

In the next year, we will continue to concentrate our efforts on Santa Cruz Island. We hope to be able to quantitatively assess the importance of summertime fog versus that of wintertime rain to the seasonal dynamics of biogeochemical processes. This will include the ongoing automated measurements, and targeted soil and ^{14}C sampling to capture seasonal patterns through the end of the summer fog season. We plan to conduct simulation modeling to predict seasonal variations in canopy photosynthesis to aid interpretation. We will also conduct a series of SOM laboratory incubations, simulating fog-drip and rain moisture controls on microbial dynamics, decomposition, and the age of respired C.

This work is significant to the Kearney Mission in that (1) we are observing processes across multiple spatial and temporal scales, (2) our experimental approach is providing mechanistic information needed to support biogeochemical model development, and (3) our results have implications for science-based management of California's unique coastal ecosystems, and how they may be affected by a changing climate.

References

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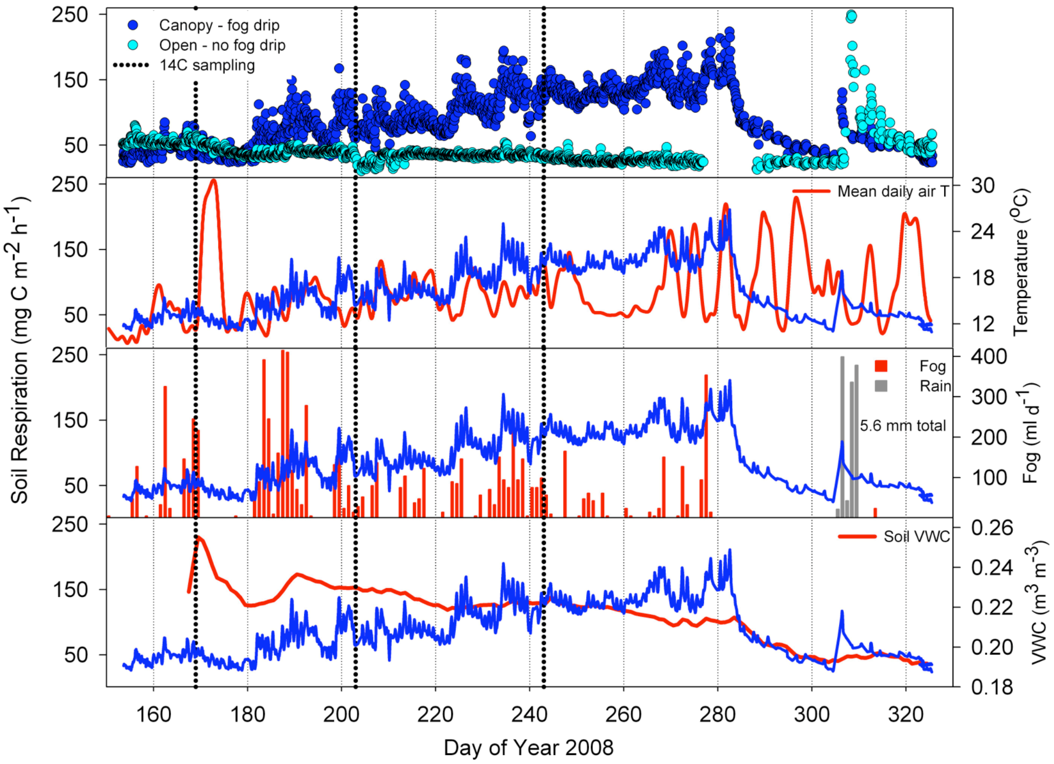

Figure 1: Panel 1: SAUC SR under the Bishop pine canopy (dark blue, all panels) and open vegetation cover (light blue). Panel 2: mean daily air temperature (red) and canopy SR. Panel 3: fog (red) and rain (grey) water inputs and canopy SR. Panel 4: surface mineral soil volumetric water content (red) under canopy vs. canopy SR. Black dotted lines indicate ^{14}C and soil sampling for Figures 2-4.

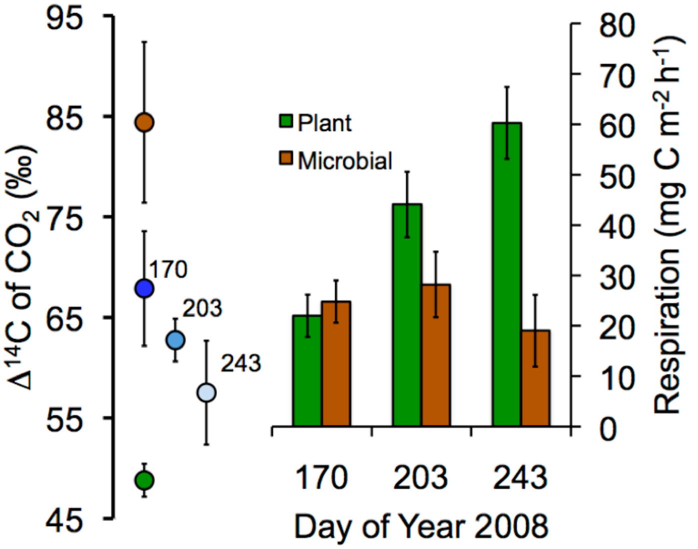

Figure 2: Left axis: Radiocarbon signature of respired CO_2 for root (green) and SOM (brown) incubations, and SAUC canopy SR from DOY 170, 203, and 243 (blue shades). Right axis: SR partitioning into plant (green) and microbial (brown) sources from DOY 170, 203, and 243.

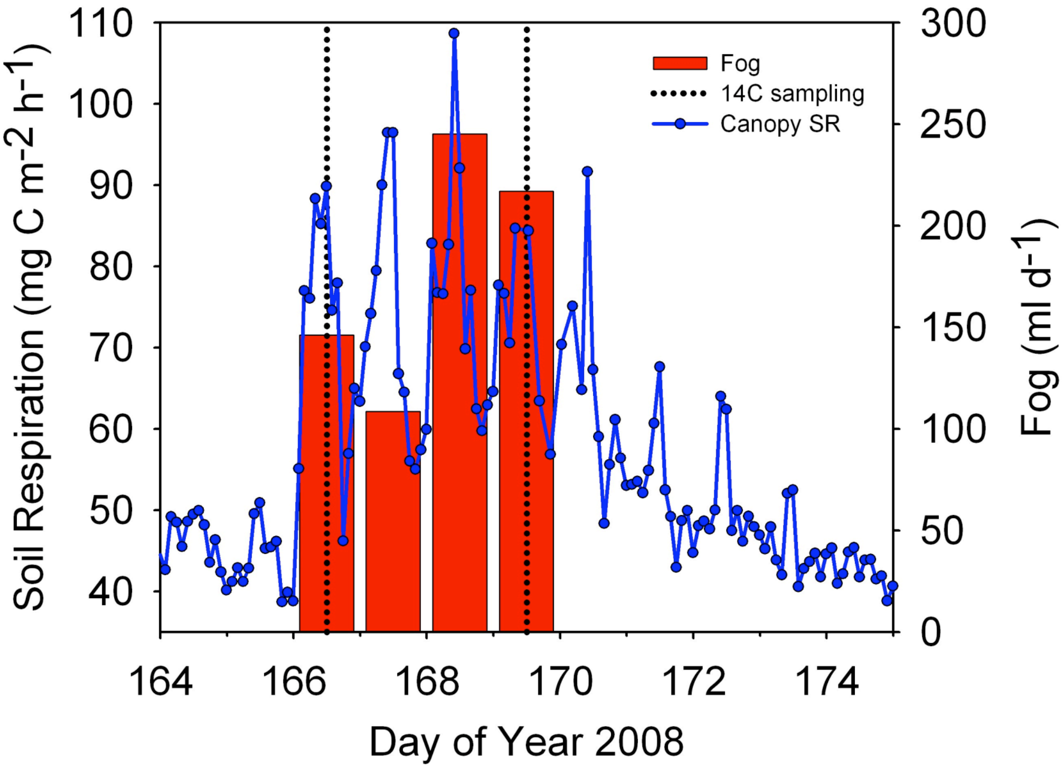

Figure 3: SAUC canopy SR (blue) and fog water inputs (red) during a fog event. Black dotted lines indicated when 14C was sampled.

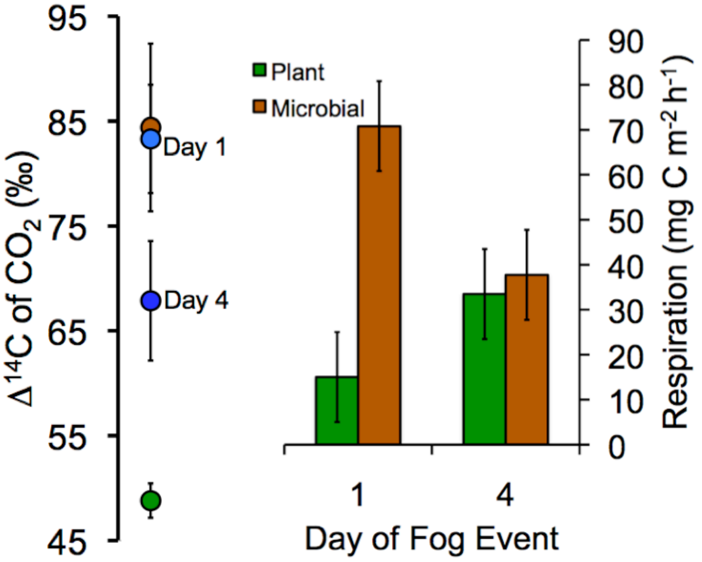

Figure 4: Left axis: Radiocarbon signature of respired CO_2 for root (green) and SOM (brown) incubations, and SAUC canopy SR from day 1 and 4 of fog event between DOY 166-169 (blue). Right axis: SR partitioning into plant (green) and microbial (brown) sources from day 1 and 4 of this fog event.

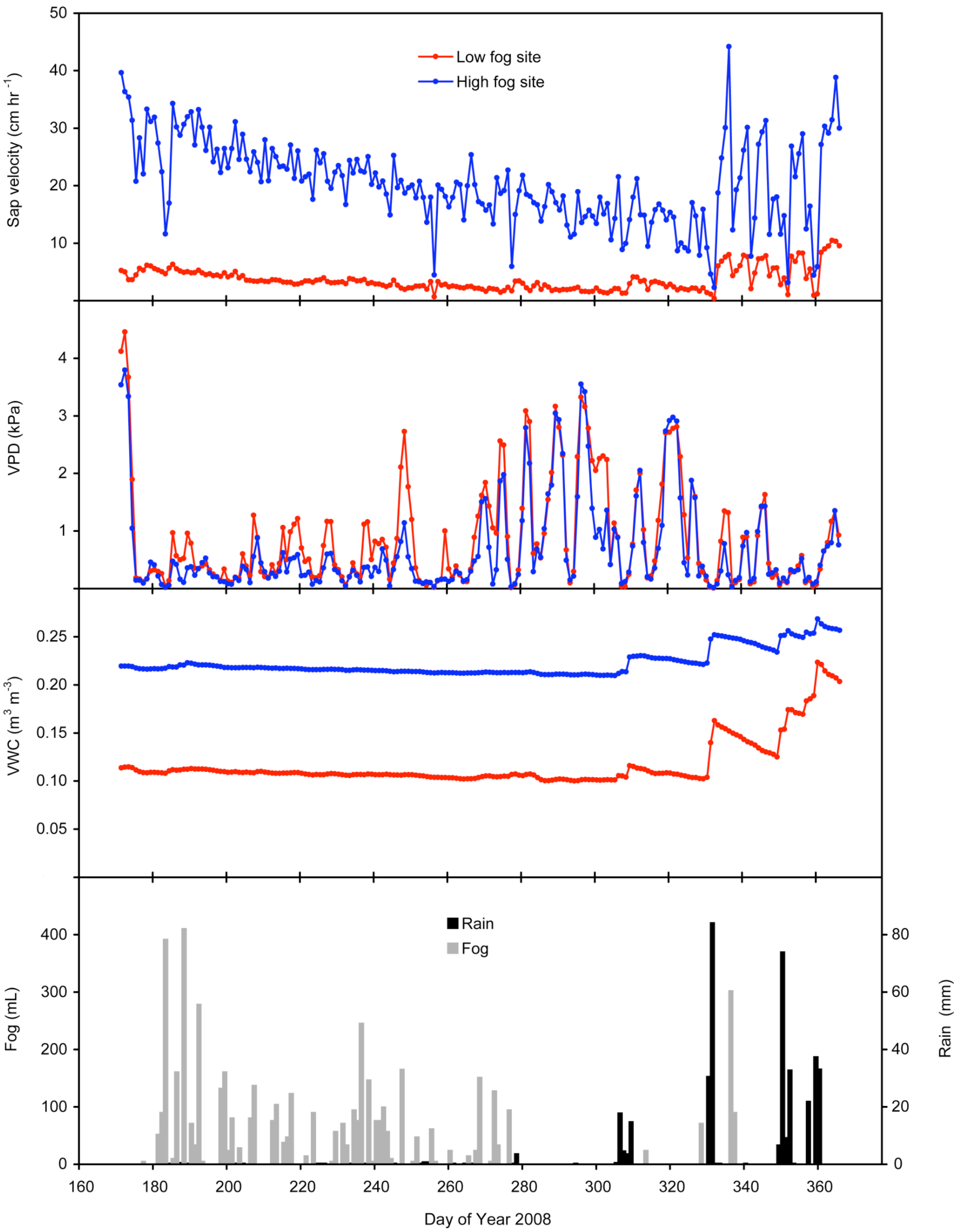

Figure 5: Seasonal trend of mean daily maximum sap velocity at SAUC (blue) and UPEM (red) in relation to climate drivers, VPD, VWC, and fog and rain inputs from June through December 2008 (DOY 171-366).

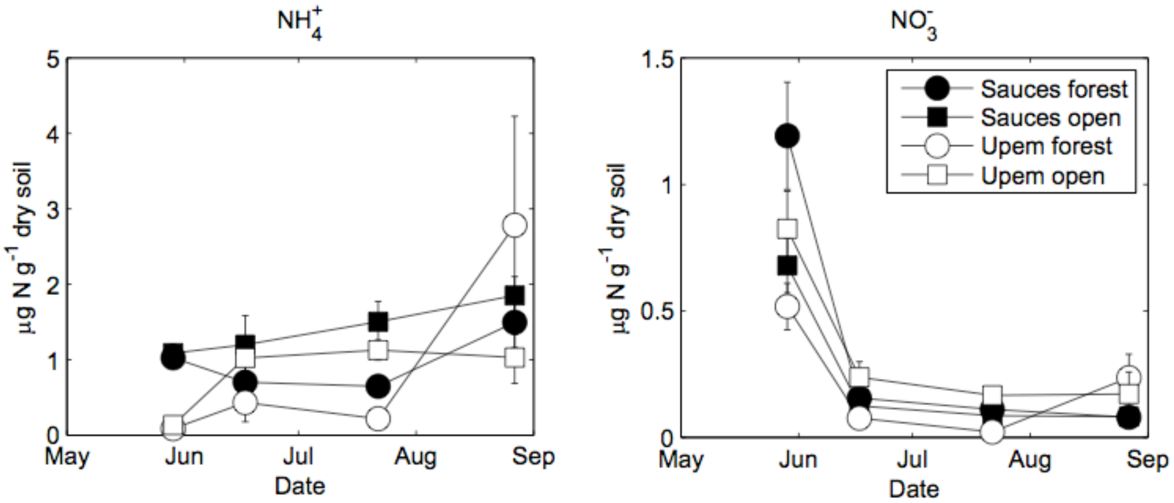

Figure 6: Surface soil concentrations of NH_4^+ (left panel) and NO_3^- (right panel). SAUC forest (closed circles) and open (closed squares) cover, and UPEM forest (open circles) and open (open squares) cover.

Table 1. *Soil concentrations of glutamate (glu-C), soil microbial biomass flush carbon (MB-C) (µg C g^{-1} dry soil), and proportion of glutamate C per microbial biomass flush C (glu/MB).*

Date, DOY **Forest**	SAUC glu-C	SAUC MB-C	SAUC glu/MB	UPEM glu-C	UPEM MB-C	UPEM glu/MB
6/17/08, 168	4.12	77	.054	2.49	175	.014
7/22/08, 203	6.36	131	.044	2.23	228	.010
8/27/08, 239	5.64	142	.039	2.71	273	.010
Open						
6/17/08, 168	1.12	149	.008	1.29	118	.011
7/22/08, 203	1.21	188	.006	1.92	130	.015
8/27/08, 239	0.34	39	.009	0.47	90	.005

This research was funded by the Kearney Foundation of Soil Science: Understanding and Managing Soil-Ecosystem Functions Across Spatial and Temporal Scales, 2006-2011 Mission (http://kearney.ucdavis.edu). The Kearney Foundation is an endowed research program created to encourage and support research in the fields of soil, plant nutrition, and water science within the Division of Agriculture and Natural Resources of the University of California.