Quantifying Atmospheric Nutrient Deposition to the Critical Zone on Boulder Open Space Lands

Ruth C. Heindel*, Eve-Lyn S. Hinckley

Institute for Arctic and Alpine Research, University of Colorado Boulder

*Lead PI, contact: ruth.heindel@colorado.edu

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Staff sponsor: Lauren Kolb

Executive Summary

Atmospheric deposition has the potential to impact human health, air and water quality, and biogeochemical cycling, due to the often-elevated levels of nitrogen, phosphorus, and heavy metals in wet and dry deposition. Given growing concern about increased dust generation and deposition across the southwestern United States, and with continuing land-use intensification in the Denver-Boulder metro area, it is increasingly important to quantify the fluxes of atmospheric deposition to the City of Boulder Open Space and Mountain Parks (OSMP) lands.

From April-November 2018, we quantified dust and reactive N deposition at two sites on OSMP land (Four Pines and Flagstaff Mountain). Both sites received the highest rates of particulate dust deposition during the month of May, partly due to high amounts of pollen. After pollen deposition subsided in August, rates of dust deposition to OSMP sites were still elevated (above 10 g m^{-2} yr^{-1}) relative to rates observed in the alpine of the Front Range (consistently below 10 g m^{-2} yr^{-1}). During both the spring (April – June) and summer (July – September) months, dust deposited to OSMP sites was enriched in phosphorus and the heavy metals copper, zinc, lead, and molybdenum relative to the average composition of the upper continental crust.

Levels of reactive nitrogen deposition to OSMP lands were higher in April – June than in July – September. Nitrogen deposition during the spring months exceeded 20 kg N ha^{-1} yr^{-1} at both sites and was largely in the form of ammonium, suggesting a strong contribution from eastern agricultural sources. The National Atmospheric Deposition Program (NADP) currently focuses on monitoring only wet deposition chemistry in remote locations; our results suggest that this approach results in significant underestimates of total nutrient inputs to ecosystems from atmospheric deposition. Due to the potential impacts on Front Range ecosystems, we suggest continued monitoring of total atmospheric deposition on OSMP lands.

Management Implications

- Estimates of nutrient inputs from atmospheric deposition need to be revised upward, given the current focus on remote locations and wet deposition chemistry.
- The high proportion of ammonium in total nitrogen deposition suggests that agricultural activity may be largely responsible for the continued deposition of elevated levels of reactive N to Front Range ecosystems.
- The enrichment of heavy metals (copper, zinc, lead, and molybdenum) in the dust deposited to OSMP sites suggests that anthropogenic activities contribute to dust sources.
- Given the potential water quality and ecosystem impacts of increased dust and reactive N deposition to the Colorado Front Range, we recommend the continued monitoring of wet and dry deposition chemistry to OSMP lands.

Abstract

Atmospheric deposition is an important component of biogeochemical cycling because wet and dry deposition often contain elevated levels of the limiting nutrients nitrogen (N) and phosphorus (P). In the Colorado Front Range, our current understanding of atmospheric deposition is based on observations of wet deposition chemistry at high elevations. At lower elevations, the rate, chemical composition, and source of atmospheric deposition are poorly defined. To address this gap, we quantified dust and reactive N deposition at Four Pines and near the summit of Flagstaff Mountain from April-November 2018. Dust flux peaked at both sites during the month of May, at 18.6 ± 1.7 g m^{-2} yr^{-1} (mean ± standard deviation) for Four Pines and 27.5 ± 7.2 g m^{-2} yr^{-1} for Flagstaff. Seasonal variability in dust flux was stronger at Flagstaff, due to pollen deposition during the spring months. At both sites, particulate dust chemistry was enriched in phosphorus, sulfur, copper, zinc, lead, and molybdenum relative to the average composition of the upper continental crust. Reactive N deposition was higher in April – June than in July – September and was mostly in the form of ammonium. During the spring months, Four Pines received 19.4 ± 1.9 kg N ha^{-1} yr^{-1} as ammonium and 2.9 ± 1.0 kg N ha^{-1} yr^{-1} as nitrate, while Flagstaff received 18.5 ± 2.8 kg N ha^{-1} yr^{-1} as ammonium and 2.5 ± 1.1 kg N ha^{-1} yr^{-1} as nitrate. Compared to alpine ecosystems in the Front Range, OSMP sites received higher fluxes of both dust and reactive N, potentially due to their proximity to anthropogenic activity. These results highlight the importance of atmospheric deposition as a source of nutrients and heavy metals to Boulder OSMP lands and suggest that continued monitoring may be important as land use continues to intensify in the Denver-Boulder metro area.

Keywords: atmospheric deposition, dust, nitrogen, phosphorus, biogeochemical cycling