Climate change in southwestern grasslands: Does incorporating soil water dynamics enhance our ability to understand drivers of vegetation change?

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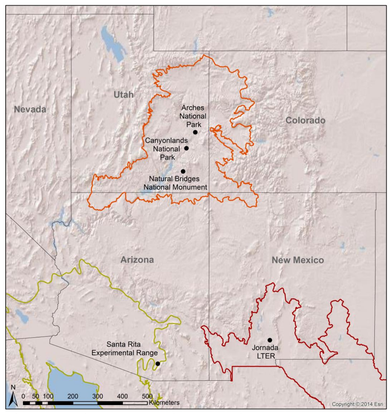
A region confronted with change



Colorado Plateau

Chihuahuan Desert

Sonoran Desert

Climate change in the Southwest

- Decrease in annual precipitation in an **already water-limited** environment
- Increase in temperature and climate variability
- May push species beyond their environmental tolerances

Plant responses to climate change can lead to:

- Loss of biodiversity, species, and habitat
- Shifts in ecosystem function
- Invasion of non-native species
- Changes in fire regimes

These responses impact the management of natural resources in the Southwest.

Understanding and predicting responses is challenging because:

- Climate is highly variable in this region, both through time and space
- Biotic interactions, such as competition, facilitation, and mutualisms, can mediate effects
- Variability in soil conditions affect water movement, availability, and storage

Integrating long-term monitoring, climate, and soil

Long-term monitoring of upland arid and semi-arid communities

- Santa Rita Experimental Range (1953—2009, 1– 4 year intervals, line– intercept transects)
- Jornada Basin Long Term Ecological Research Site (1989– 2010, every year, ocular estimate plots)
- Arches, Canyonlands, and Natural Bridges National Parks (1989-2010, every year, ocular estimate plots)

Relating climate and soil water variables to vegetation cover

- Soil water variables generated using mechanistic SOILWAT model, WorldClim bioclimatic factors used for climate
- Orthogonal soil water and climate variables identified for each site
- Perennial grasses analyzed together, using mixed models with main effect of each variable, cover in previous time step, and their interaction, plot as random effect

Ranking importance of climate and soil water variables in explaining vegetation dynamics

- Hierarchical partitioning analysis was used, which ranks the relative importance of each variable in explaining variance in grass cover, while accounting for potential correlation among explanatory variables
- Analyzed residuals from repeated measures and repeated cover

Photos: Hanson and Love, 1930. Comparison methods of quadrating. *Ecology* 11(4): 734-748, Raymond M. Turner, US Geological Survey

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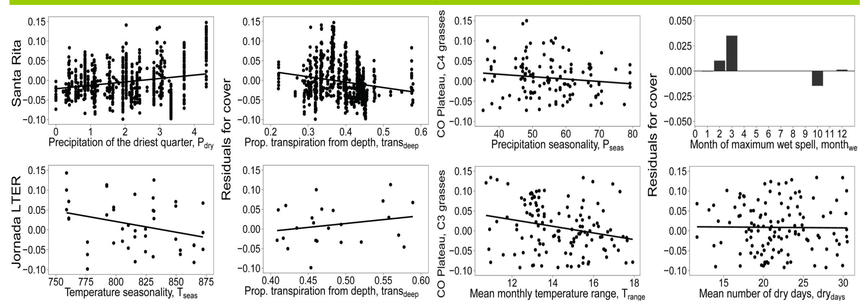
Our goals

1. **To understand what drives vegetation responses to climate change.**
2. **Use this understanding to build tools for predicting and managing responses to future change.**

Research questions

- What aspects of climate and soil water explain past grassland dynamics?
- Does incorporating soil water dynamics enhance our ability to understand responses?

Climate and soil water explain grassland dynamics



The figure above illustrates the **most important climate and soil water variables for explaining variation in grass cover** at each site. The x-axis represents the residuals from the relationship with previous cover and accounts for repeated measures.

Integrating soil water enhances understanding of plant dynamics

Santa Rita Experimental Range, C4 grasses

Variable	Independent effects (% of R^2)
Precip. of the driest quarter	33.58
Prop. transpiration from depth	17.48
Temperature seasonality	14.41
Annual number of wet spells	9.76
Mean soil dry days	9.56
Precip. of the coldest quarter	4.92
Month of maximum dry spell	3.70
Mean annual temperature	3.52
Monthly temperature range	1.85
Month of maximum wet spell	1.21
Climate total	**58.28**
Soil water total	**41.72**

Jornada LTER, C4 grasses

Variable	Independent effects (% of R^2)
Temperature seasonality	36.20
Prop. transpiration from depth	30.66
Monsoon precipitation	16.42
Prop. wet days in winter	4.87
Mean annual temperature	3.95
Annual wet spells	2.97
Month of maximum dry spell	2.91
Month of maximum wet spell	1.34
Prop. transpiration from shallow lyrs	0.67
Climate total	**56.58**
Soil water total	**43.42**

Colorado Plateau, C4 grasses

Variable	Independent effects (% of R^2)
Precip. seasonality	63.29
Mean annual precipitation	15.59
Temperature range	8.50
Temperature seasonality	6.45
Month of maximum wet spell	4.59
Month of maximum dry spell	1.57
Climate total	**93.83**
Soil water total	**6.17**

Colorado Plateau, C3 grasses

Variable	Independent effects (% of R^2)
Temperature range	37.10
Mean soil dry days	24.32
Month of maximum dry spell	16.48
Annual number of wet spells	12.84
Prop. wet days that occur in winter	4.11
Prop. shallow transpiration in summer	3.17
Month of maximum wet spell	1.49
Mean temperature of the wettest quarter	0.50
Climate total	**37.59**
Soil water total	**62.41**

Results of hierarchical partitioning analysis. The independent effects are the amount of explained variance that can be attributed to each individual variable, while accounting for multicollinearity. Sums of independent effects for climate variables and soil water variables for each site are in bold italic fonts. Climate variables are in blue, soil water variables in brown.

Acknowledgements

This project is supported by funding from the Bureau of Reclamation through the Desert and Southern Rockies Landscape Conservation Cooperatives (LCC).

Translating climate into available water

Understanding responses in arid lands requires knowing **when and where water is available.**

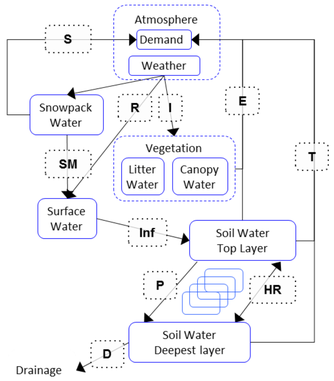
***SOILWAT inputs*:**

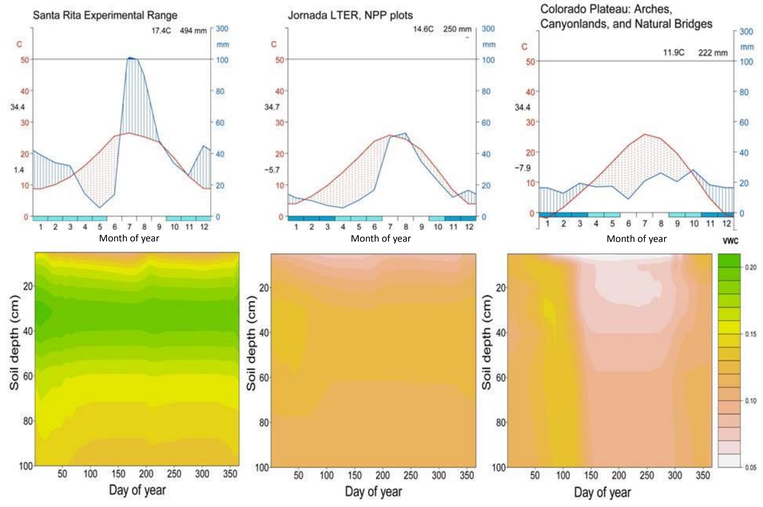
- Daily weather
  Mean & max temperature, precipitation
- Vegetation
  Live and dead biomass, litter, root profile
- Soil properties such as bulk density, texture, gravel, for each soil layer
- Ecosystem processes such as evaporation, infiltration, percolation, redistribution

***SOILWAT outputs*:**

- Daily, monthly, and annual values of each water balance component

Combined with the long-term vegetation data, this offers a **powerful way to understand responses** across systems and **identify vulnerability to change**





Climate and soil water diagrams for the three sites. Top panels are climate diagrams with average temperatures on the left axis and precipitation on the right axis. Axes are scaled to indicate dry periods (red regions) and wet periods (blue regions). Bottom panels are average volumetric water content (VWC) across soil depths through the year. Warmer colors indicate drier soils, green indicates wetter

Conclusions

Our results suggest that:

- Variability temperature and precipitation may be more important than mean conditions
- Incorporating soil water dynamics improves our ability to understand plant responses, particularly for sites that may rely more on storage of soil water.
- Functional types responded differently, with soil water being more important for C3 grasses.
- Simulations of future soil water scenarios (data not shown) suggest that conditions for perennial grasses may deteriorate in the coming decades.

Few studies incorporate this detailed understanding of soil water dynamics and doing so may aid in our ability to understand, predict, and mitigate responses to climate change.