Spatial Variability of Soil Moisture Content in California Sagebrush Terrain

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Abstract

The ongoing drought in the Southern California region has led to a number of environmental issues. The drought has not only prompted an increase in the number and intensity of wildfires but has also added additional stress upon native plant species, which are already burdened by habitat loss and invasive species (Fellows 2012). Water conservation has become a leading priority for individuals, businesses, and municipalities in the California region. One of the major water conservation techniques that has been used is the increased usage of Southern California native vegetation. Understanding the factors that influence soil moisture content is essential for managing water conservation efforts, because soil moisture is a primary factor in successful plant growth. This study will use statistical regression analyses to determine which environmental factors indicate higher soil moisture content in the native plant *Artemisia california*, commonly referred to as California Sagebrush. The factors that will be considered consist of air temperature, humidity, precipitation, and aspect of the hill (north or south facing). The variables listed will all be studied over time beginning at the peak of the rainy season and continuing into the dry season. Data collection will take place at six research sites with three varying elevations on Wildflower Hill at the Theodore Payne Foundation for Wildflowers and Native Plants, situated in La Tuna Canyon. The results of this study aim to aid in conservation efforts by determining if the environmental variables studied have a relationship with the spatial variability of soil moisture content in *Artemisia californica* terrain. The findings can be utilized by individuals, native plant nurseries, and municipalities seeking to use minimal irrigation on native plants.

1. Introduction

1.1. Background and significance

Understanding the spatial variability of soil moisture content is an important area of study for individuals, native plant nurseries, and municipalities looking to minimize their consumption of water resources. California has experienced serious drought over the last twenty years (Mann & Gleick 2015). Soil moisture is one of the most important factors that determines plants ability to grow (Liu and Luo 2011). Soil moisture variability is determined by various elements, including climatological factors, topography, vegetation cover, soil properties, and hydrological processes (Famiglietti et al. 1998; Entin et al. 2000; Gomez-Plaza et al. 2001; Brocca et al. 2007, Hu et al. 2017). While there has been research regarding various environmental factors that influence soil moisture content, there is less extensive research on the significance of air temperature, relative humidity, and precipitation. This study aims to assist in conservation efforts by delineating which measurable factors, including, air temperature, humidity, precipitation, elevation, and aspect of the hill (north or south facing) influence soil moisture content in *Artemisia californica* range.

1.2. Research question and hypothesis

Do air temperature, humidity, precipitation, elevation, and aspect of the hill (north or south facing) have a relationship with soil moisture content in *Artemisia californica* range? This study hypothesizes that the environmental variables studied will display a statistical relationship with soil moisture content within *Artemisia californica* range. It further hypothesizes that air temperature will have the greatest correlation with soil moisture content, specifically, as temperature increases soil moisture content will decrease due to evapotranspiration.

2. Literature review

Examining the spatial variability of soil moisture content in drought sensitive regions is essential to decrease the consumption of water resources. The spatial variability of soil moisture content is influenced by various factors including drought, and numerous other environmental factors such as air temperature, humidity, precipitation, elevation, and aspect of the hill. The remainder of this section provides a brief overview of the mechanisms impacting soil moisture content and its variability across the landscape.

2.1. Drought

California has been plagued by drought over the course of the last two decades. Ten of the past fourteen years experienced below average rainfall, and the most intense droughts on record were documented in 2012, 2013, and 2014. The drought is due to a lack of rain as well as stress placed upon the environment for human consumption (Mann & Gleick 2015). Municipalities across California have employed water conservation tactics due to drought, increasing costs of water, rapid rise in development, and increasing demand for water (Spinti et al., 2004).

In 2009, California passed water conservation legislation that called for almost all of the urban water districts to reduce their water consumption 20% by 2020. In 2015, Governor Jerry Brown passed further legislation that planned to reduce water consumption by 25% from the 2013 usage rates. More than half of California's residential water use is dedicated to landscape irrigation (Sokolow, Godwin, and Cole 2016). According to the State of California Resource Agency and Department of Water Resources, trends in the movement of people as well as continued population growth impact water use patterns. The population has initiated a shift in migration away from the densely populated coastal regions and toward the interior, including the

Inland Empire, Central Valley, and Sierra Nevada foothills. The upward trend in development patterns in the interior pose an important challenge to drought management efforts. According to the State of California's drought preparation document, the interior of the State has a comparatively hotter and arid climate resulting in significantly higher rates of water usage for landscape irrigation. This article ascertained that one key drought response action is to reduce demand by monitoring local government's implementation of the Model Water Efficient Landscape Ordinance. This ordinance provides support and guidelines for water conservation in local communities (2000). Landscaping patterns will need to experience a dramatic shift in order to meet State regulations in water conservation.

According to the Los Angeles County Public Works department, the use of drought tolerant and native California plants can help residents save hundreds of gallons of water each year (2019). *Artemisia californica*, or California Sagebrush, is a drought tolerant shrub native to California. The Sagebrush's drought tolerance can be attributed to its long extensive roots that reach deep moisture laden areas of the soil (Reed & Loik 2016). Native plant nurseries such as The Theodore Payne Foundation for Wildflowers and Native Plants, play an important role in providing residents with access to native plants for water efficient landscaping (Theodore Payne Foundation 2019).

2.2. Soil moisture content

Soil moisture is a key component within the hydrological and meteorological cycle and acts as the controlling factor of contact and interaction between the land surface and the atmosphere (Tang and Piechota 2009). Soil moisture content exhibits control over the amount of rainfall that will become runoff, surface storage, and deep infiltration. It also displays controls over the rates of incoming and outgoing solar radiation (Lakshmi, Jackson, and Zehrfuhs 2003).

Additionally soil moisture is considered a major variable that contributes to drought (Trenberth and Branstator 1992).

In a state experiencing an extensive drought, it is important to increase water use efficiency in plant production. One method used is to track soil moisture content, which is the amount of water in a known amount of soil. Soil moisture provides the water that plants depend on for growth (Velpuri, Senay, and Morisette 2016). Soil moisture is one of the prominent factors that governs the ability of plant roots to gather water and essential nutrients and in turn plant growth processes. Furthermore, soil moisture can regulate the dispersal of plants and the composition of the plant communities in a region (Liu and Luo 2011). The use of soil moisture sensors to understand the soil moisture content is essential for water conservation efforts, as it provides the user with data that allows them to knowledgably determine when plants need irrigation (Ling 2005).

2.3. Environmental factors

Numerous researchers have reviewed the spatial variability of soil moisture content. These researchers ascertain that soil moisture content displays a high amount of spatial and temporal variability. Soil moisture variability is determined by various elements, including climatological factors, topography, vegetation cover, soil properties, and hydrological processes (Famiglietti et al. 1998; Entin et al. 2000; Gomez-Plaza et al. 2001; Brocca et al. 2007, Hu et al. 2017). The magnitude of the impact of these various environmental factors upon soil moisture content is dependent upon the study area as well as seasonal variations (Western et al. 1999).

2.3.1. Air temperature & relative humidity

Relative humidity, the amount of water vapor in the air, has been shown to be an important contributing factor to soil moisture content by a number of researchers. This is due to the nature of evapotranspiration. When the air is saturated with water vapor there is less potential for evapotranspiration to occur. Rates of soil moisture in arid regions, such as Southern California, that have significantly high rates of evapotranspiration are heavily impacted by changes in relative humidity (Ravi et al. 2004). Researchers have also noted that soil moisture has an inverse or negative relationship with air temperature meaning that as the air temperature increases the soil moisture content decreases (Cho and Choi 2014).

2.3.2. Precipitation

Soil moisture both influences and is influenced by various meteorological factors. There is an apparent connection between high levels of precipitation and high soil moisture content. Researchers have also shown a connection between decreasing precipitation and an increase in the spatial variability of soil moisture (Famiglietti et al. 1999, Hupet and Vanclooster 2002). Additionally, soil moisture can impact the amount of precipitation a region receives. This is due to the interchange of the moisture from the soil to the atmosphere through the process of evapotranspiration. The exchange of moisture from the soil to the atmosphere is additionally caused by the soil moistures ability to heat and cool near-surface air temperatures. This two-way interaction between soil moisture and precipitation is often referred to as soil moisture - precipitation coupling, or soil moisture - precipitation feedback (Ford et al. 2015 and Duernick et al. 2016).

The drought in California has led individuals, native plant nurseries, and municipalities to seek out new methods to conserve water through reducing consumption. The usage of drought tolerant California native plants is an impactful solution to reduce residential water demand. Understanding the role that soil moisture plays in plant growth, as well as its broader atmospheric influence is essential to effectively managing water conservation efforts. In the sections that follow, aforementioned environmental factors and how they influence the spatial variation of soil moisture, and therefore plant growth conditions, will be explored.

2.3.3. Aspect & elevation

Aspect impacts soil moisture by determining solar irradiance and therefore the rate of evapotranspiration of the soil moisture (Famiglietti et al. 1998). Previous research has found that areas under study with a comparatively higher elevation, and slope facing towards the sun (aspect) have less soil moisture than research sites at lower elevations with slopes that are shaded from the sun (Hu et al. 2017). Famiglietti also noted that under dry conditions, correlations are strongest to relative elevation, aspect and clay content. Furthermore, aspect was recognized as a leading determinant of soil moisture content under dry conditions, in addition to elevation (1998). Gomez-Plaza et al. found including aspect as a factor in their indices improved the ability to predict soil moisture patterns in semiarid areas (2001).

3. Methods

3.1. Study area

The study area for this project consists of six research sites at the Theodore Payne Foundation Native Plant Nursery and Garden in Sun Valley, California. The nursery is situated in La Tuna Canyon. The Mediterranean climate at the sites are characteristic of the Greater Los Angeles area. Los Angeles is an example of a rapidly growing city in California with an increasing demand for water resources, which under continued drought circumstances are not capable of being met (Mann & Gleick 2015).

All six research sites are located on a hill behind the Theodore Payne Foundation's nursery, aptly named Wildflower Hill due to the plethora of native California plants and wildflowers on the hill (Figure 1). This study delineated the six research sites on the hillside by the presence of *Artemisia californica,* in addition to aspect and relative elevation of the hillside. Research sites #1 and #2 are at the lowest relative elevation of the hill, with site #1 at 1002 feet and site #2 at 1016 feet. Site #1 is situated on the southern slope of the hill and site #2 is located on the northern slope of the hill. Research sites #3 and #4 are located at the middle relative elevation of the hill, at 1040 feet and 1053 feet respectively. Site #3 is positioned on the southern slope of the hill and site #4 is set on the northern slope of the hill. Research sites #5 and #6 are located at the upper most relative elevation of the hill, at 1075 feet and 1085 feet respectively. Site #5 is situated on the southern slope and site #6 is on the northern slope of the hill. The variance in aspect and relative elevation from site to site was required in order to distinguish possible relationships of aspect and relative elevation with soil moisture content. Elevation at each of the sampling locations was determined using Google Earth Pro.

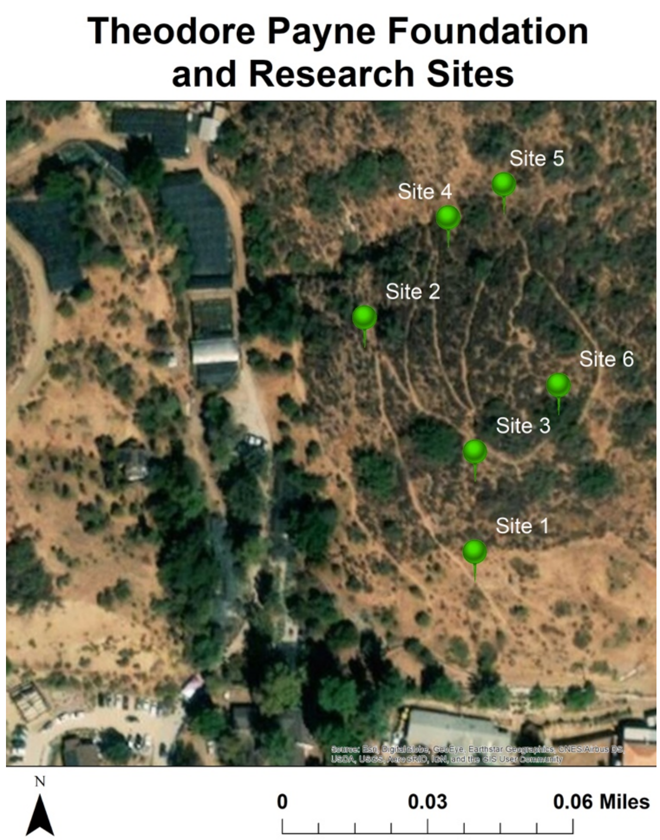

Figure 1: Map of Theodore Payne Foundation and research sites (Base map source: ArcGIS)

3.2. Data collection

3.2.1. Data sources

Primary data Collection began on January 18th and continued through April 12th, with the use of the RHT35 data logger by Extech Instruments at all six research sites. The data loggers collect relative humidity and air temperature data at each research site. The data loggers were set to collect primary data in ten-minute intervals. Due to complications, the data logger located at research site #4 collected data in five-minute intervals between the dates of January 18th and March 1st. Following March 1st, the data logger at site #4 was recalibrated to collect in ten-minute intervals. The research sites were visited three times per week in order to collect the volumetric water content (% volume) of the soil around the perimeter of six *Artemisia californica* shrubs. Using the SM 150 soil moisture kit, volumetric water content was collected for the top 5 cm of the soil. These visits also included oversight of the data logger's functioning and fidelity.

Secondary daily precipitation data, in millimeters, from 2019 was gathered from The National Oceanic and Atmospheric Administration (NOAA) public database. These data sets were essential to this study, as precipitation is a primary indicator of high soil moisture content. Additionally, soil moisture content experiences high levels of spatial variance during periods of precipitation and experiences significantly lower spatial variance during dry periods (Famiglietti et al. 1998).

3.2.2. Data management

Pivot tables were created in order to summarize daily averages of temperature and relative humidity for each research site in order to run a linear regression analysis. This increased efficiency, as the data was recorded in five- and ten-minute intervals. Additionally, daily averages of the independent variables, air temperature and relative humidity provide a representative figure of daily changes in the variables and their correlation with soil moisture conditions. This study also briefly explores the roll of aspect and elevation in the spatial variation of soil moisture by comparing the varying aspects and elevations to the soil moisture content averages throughout the study.

3.3. Data analysis

3.3.1. Multiple linear regression

This study sought to explore the relationship between soil moisture content and meteorological factors, air temperature, and relative humidity. In order to explore these relationships, multiple linear regression analysis was performed. Soil moisture content served as the dependent variable in the analysis, while air temperature and relative humidity served as the independent variables. The daily averages of each independent variable corresponded with the days that the independent variable, soil moisture content, were collected. This study used a multiple linear regression analysis to determine how the independent variables are related to the dependent variable. Multiple linear regression analysis models the correlation between independent, or explanatory, variables and a dependent variable by aligning a linear equation with the data (Yale University 2019) (Figure 2). Regression analysis has been used to provide a good explanation for the spatial variance of soil moisture due to environmental factors (Famiglietti et al. 1998). The significant variables of the regression formula are explained in Table 1.

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \ldots + b_pX_p$$

Figure 2: Multiple linear regression formula

Symbol	Variable
$\hat{y}$	Soil moisture content
b_0	Y intercept
b_1	Slope
x_1	Air Temperature
x_2	Relative Humidity

Table 1: Regression formula variables

3.3.2. Precipitation analysis: soil moisture reaction & soil moisture variability

In order to examine the trends of precipitation events with soil moisture content reactions, soil moisture was analyzed across sites. Precipitation values were graphed alongside soil moisture content values for the entire study period. Additionally, soil moisture variability analysis was conducted between sites to analyze how wetting periods or drying periods impact the spatial variability of soil moisture content. In order to this the range of soil moisture content between all sites was calculated for each available date and graphed alongside the precipitation data for the entire study period.

4. Results

4.1. Environmental factors and soil moisture content data over study period

4.1.1. Temperature

Over the study period, daily average temperatures across the research sites ranged between a low of 5.25 °C to a high of 24.09 °C. The range in temperature was 18.84 °C with a median of 13.09 °C. From February 8th onwards, the average temperatures consistently increased across all six research sites (Figure 3). Research sites average temperature from lowest to highest are as follows; Site 4, Site 2, Site 5, Site 1, and Site 6, Site 3 (Table 2). The sites with the three lowest average daily temperatures are north facing, while the sites with the 3 highest average daily temperatures are south facing.

Site	Sample size	Aspect	Average (°C)	Median (°C)	Min (°C)	Max (°C)	Range (°C)
Site 1	85	South	13.26	13.17	6.78	21.96	15.17
Site 2	79	North	12.89	13.18	6.03	22.24	16.20
Site 3	85	South	13.66	13.57	6.99	23.93	16.94
Site 4	85	North	11.61	12.07	5.25	19.74	14.48
Site 5	85	North	12.95	13.23	6.17	22.51	16.34
Site 6	85	South	13.49	13.16	6.72	24.09	17.37

Table 2: Variation of temperature data

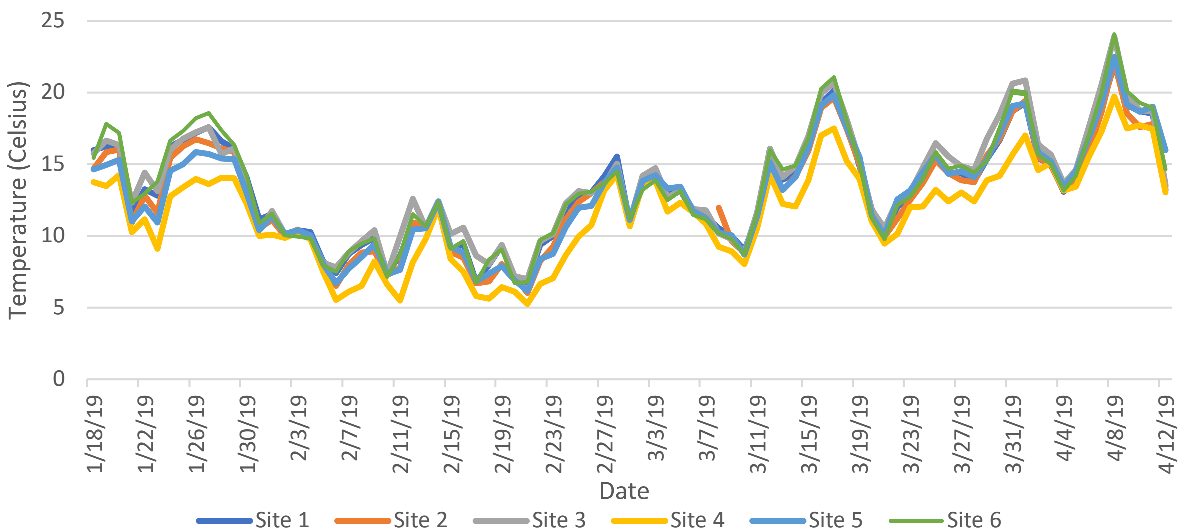

Figure 3: Average daily temperature across study sites

4.1.2. Relative humidity

Over the study period, daily average relative humidity across the research sites ranged between 23.17% to 99.9%. The range in relative humidity was 76.73% with a median of 67.48% (Table 3). Although the range in relative humidity was high, there was no clear increasing or decreasing trend (Figure 4). Research sites average relative humidity from lowest to highest are as follows; Site 3, Site 2, Site 6, Site 5, and Site 1, Site 4. Two of the three lowest relative humidity values are south facing, which include Sites 3 and 6, while two of the three highest relative humidity values are north facing, including Sites 4 and 5.

Site	Sample size	Aspect	Average (%)	Median (%)	Min (%)	Max (%)	Range (%)
Site 1	85	South	67.83	70.96	27.92	99.90	71.98
Site 2	79	North	62.54	62.55	23.17	99.90	76.73
Site 3	85	South	61.23	59.68	23.92	99.90	75.98
Site 4	85	North	74.46	78.47	31.47	99.90	68.43
Site 5	85	North	65.74	65.95	23.76	99.90	76.14
Site 6	85	South	63.55	65.54	23.83	99.90	76.07

Table 3: Variation of relative humidity data

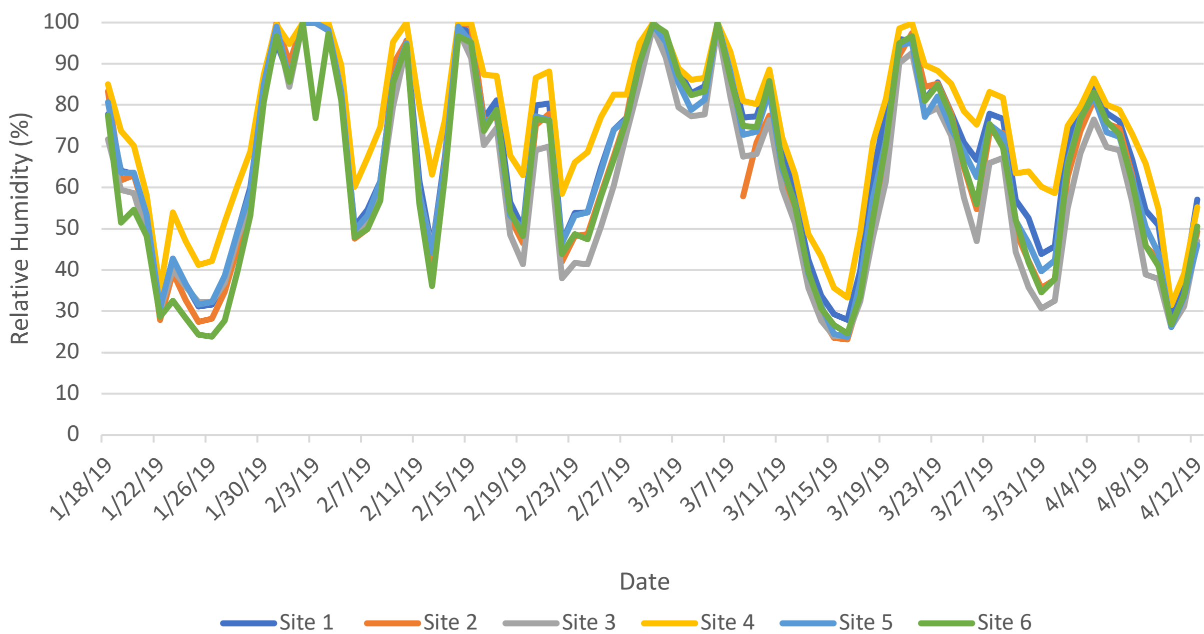

Figure 4: Average daily relative humidity across study sites

4.1.3. Soil moisture

Over the study period, average soil moisture content across the research sites ranged between 6.34% to 40.58%. The range in soil moisture content was 46.92% with a median of 29.38% (Table 3). There is a clear decreasing trend in the soil moisture content across all sites, following peak soil moisture content on March 8th (Figure 5). Research sites average soil moisture content from lowest to highest are as follows; Site 3, Site 6, Site 5, Site 2, and Site 1, Site 4.

Site	Sample size	Aspect	Average (%)	Median (%)	Min (%)	Max (%)	Range (%)
Site 1	25	South	27.25	31.64	9.50	40.58	31.08
Site 2	24	North	27.15	28.88	11.14	38.10	26.96
Site 3	25	South	23.13	27.30	6.34	35.44	29.10
Site 4	25	North	29.91	34.30	11.78	41.62	29.84
Site 5	25	North	24.72	27.66	10.60	35.62	25.02
Site 6	25	South	23.61	26.58	6.44	38.64	32.20

Table 4: Variation of soil moisture data

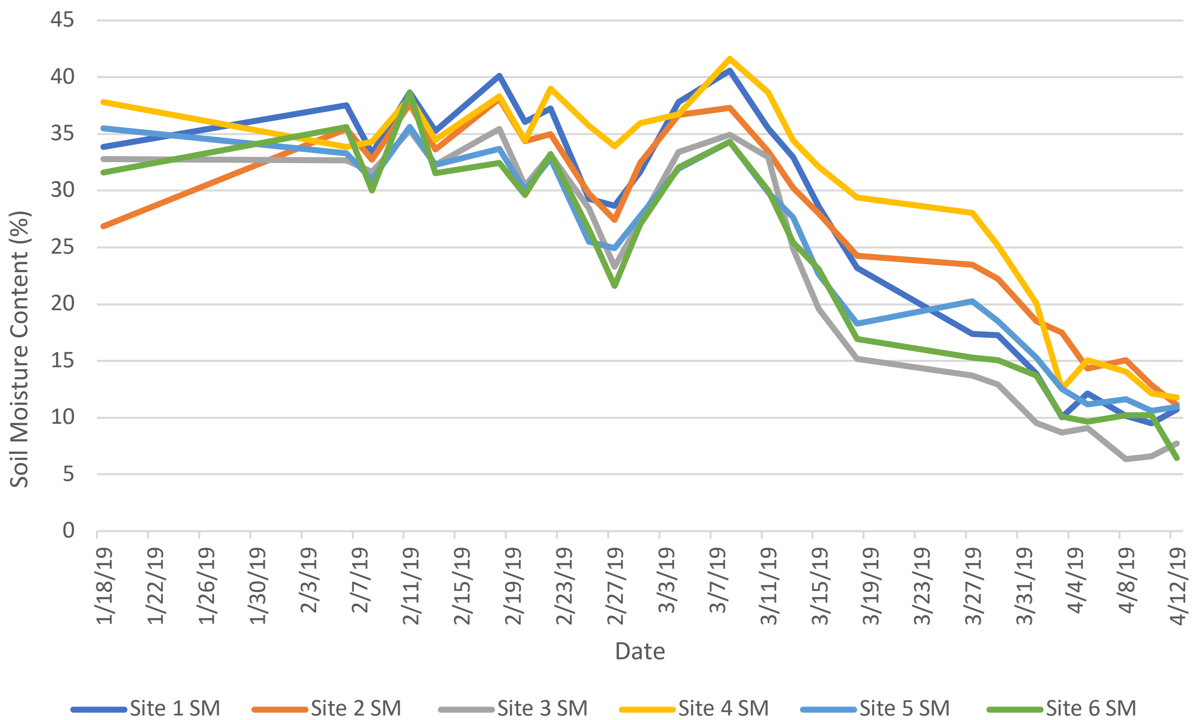

Figure 5: Daily soil moisture volumetric content across study sites

4.2. Multiple linear regression of environmental factors

Results of the linear regression model provided insight into the relationship between the environmental factors studied and soil moisture content across research sites (Table 5). R^2 for each site demonstrates the percentage of the variability of soil moisture explained by temperature and relative humidity. The success of the model to explain the variability of soil moisture by research site from lowest to highest is as follows; site 4, site 1, site 6, site 2, site 3, and site 5.

The p-values expressed the extent to which each individual independent variable has some relationship with the dependent variable. A low p-value indicated a high confidence in the probability of a relationship between the independent variable and soil moisture content. The p-values for the relationship between temperature and soil moisture content were significant at all research sites. However, the p-values for relative humidity at all six research sites indicate that there is not a significant relationship between relative humidity and soil moisture content. The significance F, which is the p-value for the overall F test, provided a low value for all six research sites allowing for the rejection of the null hypothesis and providing evidence that the model delivers and effective representation.

The coefficients represent the average change in the dependent variable for one unit of change in the independent variables. The coefficient values with the greatest impact for temperature for research sites are as follows; Site 1, Site 3, Site 6, Site 5, Site 2, Site 4. Due to the inability of the model to reject the null hypothesis for relative humidity it is unimportant to consider the coefficient values.

Scatterplots provide a visual representation of regression analysis results by plotting the dependent variable along the y-axis and the independent variable along the x-axis (Figures 7 & 8). The closer the points fit to the linear trendline the stronger the positive or negative statistical relationship is. The scatterplots display a negative linear relationship across all six research sites for temperature as they follow the linear trendline. The scatterplots for relative humidity do not follow the trendline indicating that there is no linear relationship.

Site	R^2	Signif. F	p-value: Temperature	p-value: Relative humidity	Coefficient: Temperature	Coefficient: Relative humidity
Site 1	0.557716	0.000127	0.000041	0.821807	-2.139588	-0.021788
Site 2	0.601319	0.000064	0.000019	0.754368	-1.631416	-0.021041
Site 3	0.631125	0.000017	0.000015	0.905086	-2.039445	0.010516
Site 4	0.527675	0.000261	0.000273	0.301010	-1.604552	0.097817
Site 5	0.650869	0.000009	0.000005	0.673529	-1.660989	0.027619
Site 6	0.588877	0.000057	0.000019	0.512817	-1.863353	-1.863353

Table 5: Multiple linear regression output

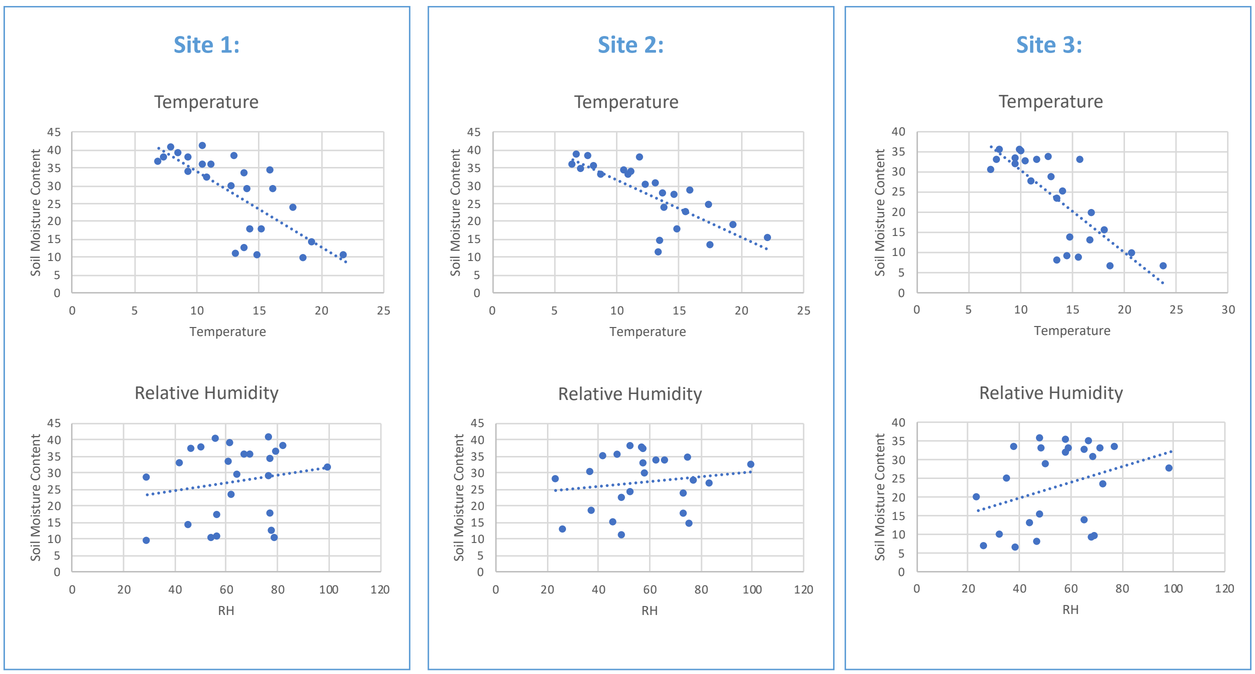

Figure 6: Scatterplots of regression analysis: sites 1-3

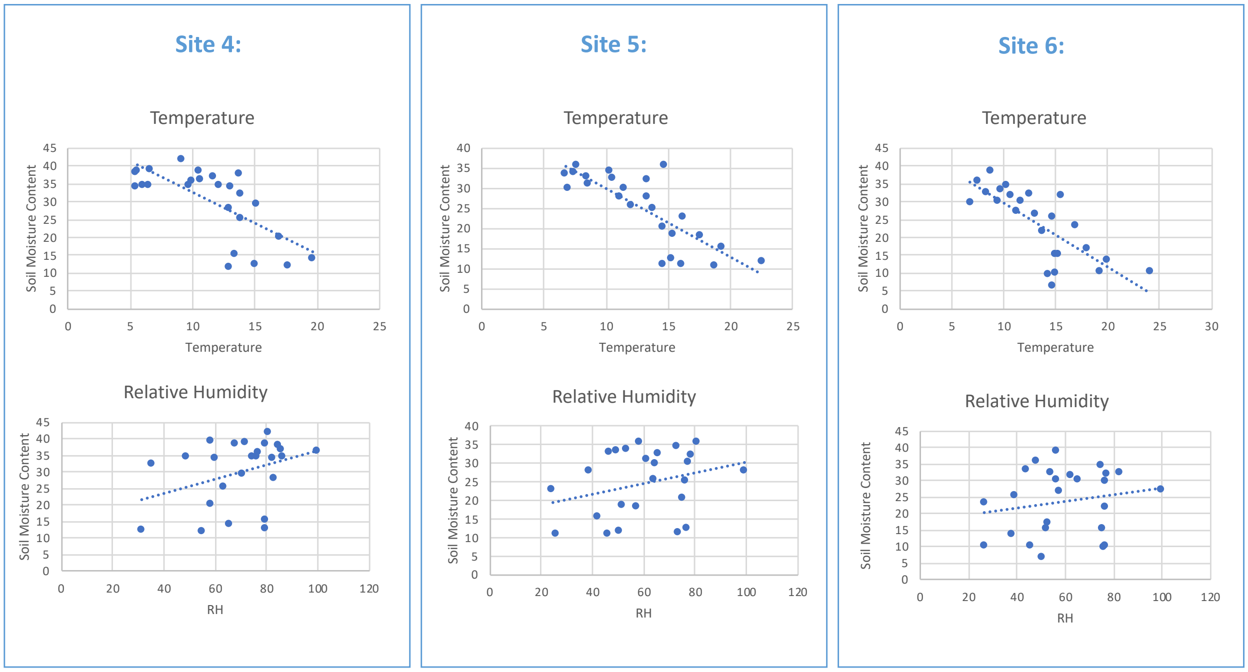

Figure 7: Scatterplots of regression analysis: sites 4-6

4.3. Precipitation analysis: soil moisture reaction & soil moisture variability

4.3.1. Soil moisture reaction

In order to examine the trends of precipitation events with soil moisture content reactions, average soil moisture was analyzed across all study sites. Precipitation values were graphed alongside soil moisture content values for the entire study period (Figure 9). The maximum precipitation recorded over the study period was 54.1 mm on February 2nd. The minimum precipitation recorded was 0mm and occurs over 76% of the study period dates. 24% of the study dates experienced rain. There were three main wetting periods during the study period. Each wetting period decreased in intensity over time. As these wetting events decreased, soil moisture content decreased as well. This can be seen from the downward trend in soil moisture content following the final rain event of the study period on March 21st. The lowest soil moisture content observed occurs after the longest period of no rain. Results of the soil moisture reaction analysis indicated a strong relationship in the trends between precipitation and soil moisture content.

Spikes in soil moisture content mirrored spikes in precipitation. These spikes in soil moisture content are clearly visible following the rain events that began on February 27th.

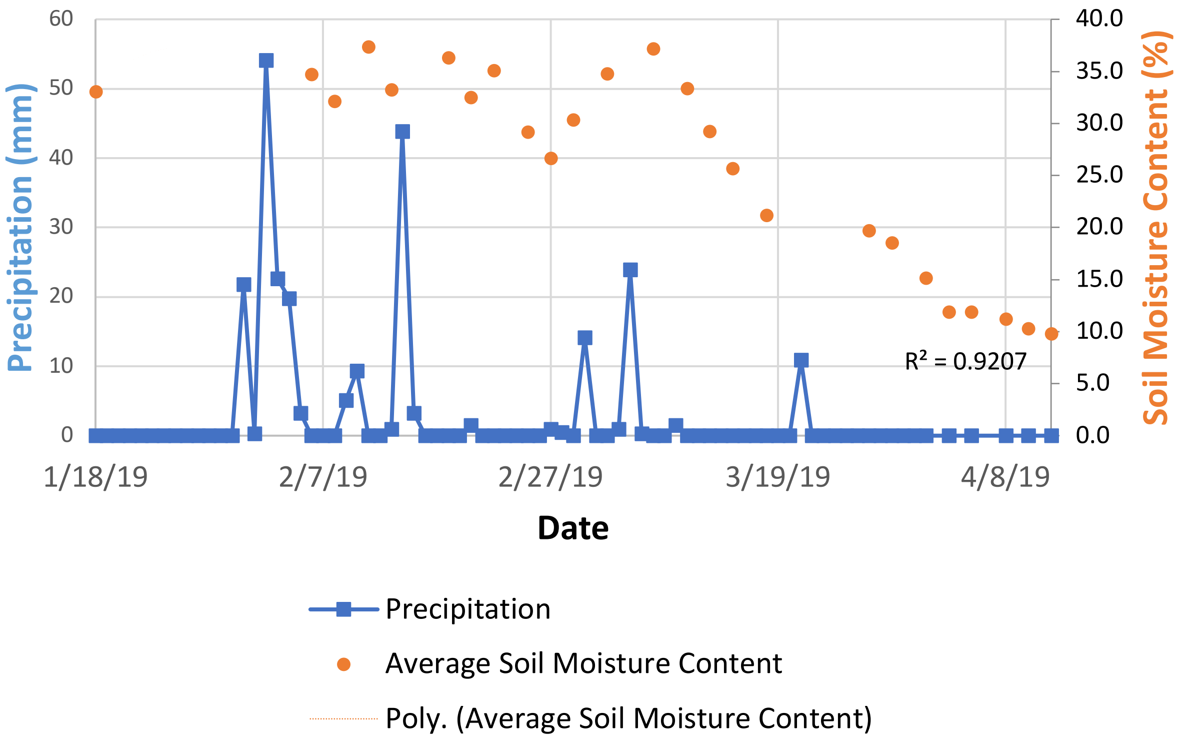

Figure 8: Soil moisture reaction graph

4.3.2. Soil moisture variability

The soil moisture variability analysis was conducted between research sites to analyze how wetting periods and drying periods impact the spatial variability of soil moisture content. In order to do this the range of soil moisture content between all sites was calculated for each available date and graphed alongside the precipitation data for the entire study period (Figure 10). The soil moisture variation analysis indicated that soil moisture content experienced less variation between research sites during wetting periods. Inversely, the analysis indicated that there was a greater range of soil moisture content across sites during drying periods. The highest range between research sites occurred on March 27th with a range of 14.34 %. The lowest range in soil moisture content between research sites was recorded on February 11th with a range of

3.32 %. The two peak ranges of soil moisture content between sites both occurred during drying periods. Following the peak range of soil moisture content on March 27th the range declined to 5.34 % on April 12th, the final day of the study period.

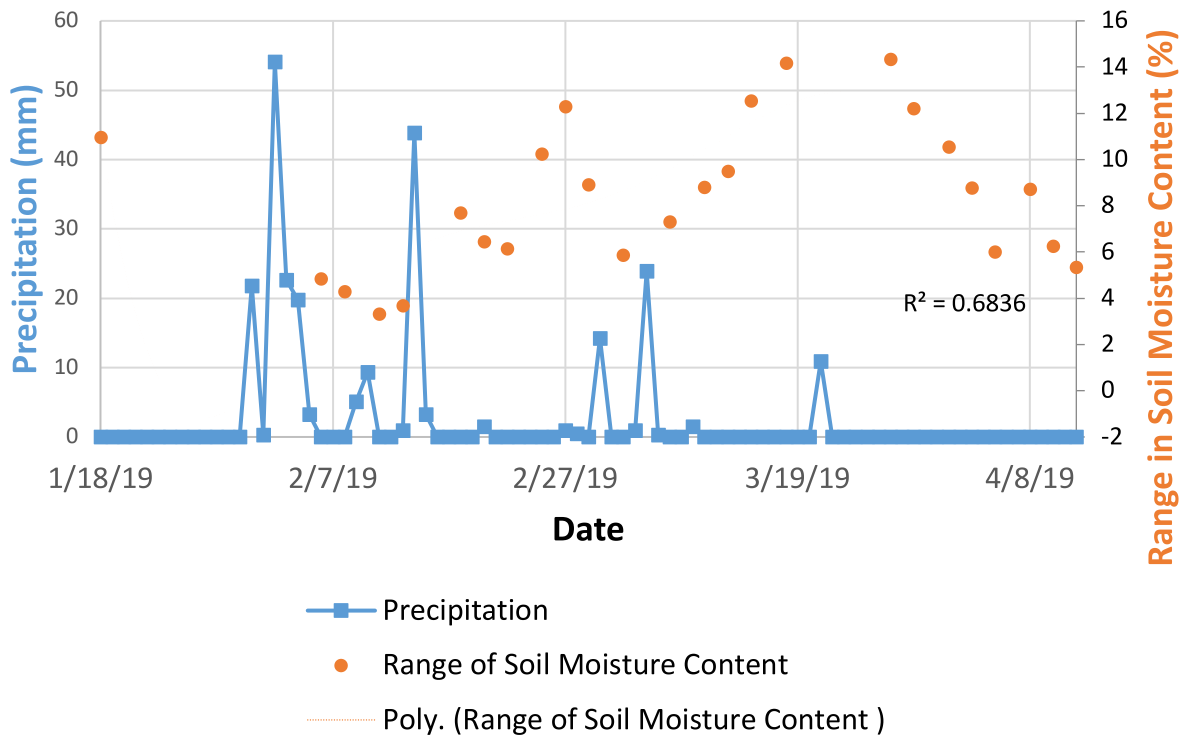

Figure 9: Soil moisture variation graph

5. Discussion

5.1. Summary and explanations

According to the results of the multiple regression analysis temperature acts as the leading factor in soil moisture content variability. As temperature increased, soil moisture content decreased across all six research sites. The lowest average temperature, 11.61 degrees Celsius, was found at site 4 which retained the highest average soil moisture content over the course of the study. The regression analysis results support past research which also noted that soil moisture has an inverse or negative statistical relationship with air temperature (Cho and Choi 2014).

The results of the soil moisture reaction analysis indicated that as precipitation events increased soil moisture content increased. As rain events decreased, soil moisture content decreased as well. Additionally, more rain does not necessarily imply a higher soil moisture content. The soil moisture content reaches a maximum of 37.3 % after the heaviest wetting period in early February. However, following a much shorter and less intense wetting period which occurred after February 27th the soil moisture content reached 37.2 %. This indicated that there was a threshold for soil moisture content.

The soil moisture variation analysis indicated that soil moisture content displays a high amount of spatial and temporal variability even across the small hillside where the research sites were located. The highest amount of variability between research sites occurred during drying periods. The lowest amount of variability between research sites occurred during wetting periods. In the past, various researchers have also noted the high spatial and temporal variability of soil moisture content (Famiglietti et al. 1998; Entin et al. 2000; Gomez-Plaza et al. 2001; Brocca et al. 2007, Hu et al. 2017).

The role of aspect cannot be overlooked considering that site 4 was located on the northern slope of the hill. The three research sites on the northern slope of the hill experienced the lowest average temperatures over the course of the study indicating that aspect plays a key role in air temperature. Researchers have recognized aspect as an important determinant of evapotranspiration through increased air temperature on sun exposed slopes (Famiglietti et al. 1998). The impacts of elevation were negligible, but this is most likely due to the small variation in elevation across all six research sites.

5.2. Limitations and future research

A larger sample size and extended study period to collect data would make the study more robust and provide better results. A preliminary analysis was prepared March 1st with 11 total observations. By adding 14 additional, for a total of 25 observations, and extending the study to April 12th the impact of the weather variables on soil moisture variation became much greater. By extending the study period the study could account for seasonality. The data logger located at research site #4 collected data in five-minute intervals between the dates of January 18th and March 1st. This could potentially have impacted the results of the study. Additionally, the small study area that the six research sites were located within contained little elevation change. Previous research has found that areas under study with a comparatively higher elevation have less soil moisture than research sites at lower elevations with slopes that are shaded from the sun (Hu et al. 2017). With a larger study area and greater variance in elevation a study of this nature could better account for the impacts of elevation on soil moisture.

5.3. Conclusions

The results of this study offered insight into the various environmental variables impacting soil moisture variability in California sagebrush terrain in Sun Valley California. Modelling the impacts of the various environmental factors is extremely important for water conservation efforts. The results indicated that temperature plays a significant role in the spatial variation and availability of soil moisture content. This information can be useful for individuals, native plant nurseries, and municipalities looking to reduce their water consumption when irrigating native plants.

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