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Effect of grazing on soil-water content in semiarid rangelands of southeast Idaho

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ABSTRACT

Although numerous factors influence soil-water content, it is considered a key indicator of rangeland health. This paper investigates the effect of grazing on soil-water content using three treatments within the same soil association. The treatments, simulated holistic planned grazing (SHPG), rest-rotation (RESTROT), and total rest (TREST) applied stocking rates of 36, 6, and 0 animal days/hectare respectively. Soil-water content was measured continuously from 2006 to 2008 using 36 capacitance sensors. Statistical analyses revealed differences in percent volumetric-water content (%VWC) and in all treatments, the SHPG pasture had the highest %VWC. Mixed procedures models indicate strong environmental and treatment effects as explanatory variables for the observed difference in %VWC. Although results of vegetation cover analyses indicated no difference in percent shrub cover in the two production pastures (SHPG and RESTROT), percent litter cover differed in the latter years of this study. It was concluded that in addition to a variety of other factors, management decisions (grazing and rest) can have substantial influence upon soil-water content and that soil-water content can vary substantially as a result of animal impact and the duration of grazing.

1. Introduction

The semiarid rangelands of southeast Idaho are important to the livestock industry of the state and the sustainability of this industry relies in large part upon the viability and health of the rangeland ecosystem. Sagebrush-steppe rangelands also provide critical habitat for Greater sage-grouse (*Centrocercus urophasianus*) and other sagebrush-obligate species (Fischer et al., 1993). Underlying both ecosystem services is a prerequisite of productive and healthy rangelands. The term rangeland health describes an important concept, but is fraught with varying definitions and connotations (National Research Council, 1994; O'Brien et al., 2003; Pellant et al., 2005; Savory, 1999; Williams and Kepner, 2002). However, some commonalities exists among these definitions including the importance of ground cover for proper hydrologic function (O'Brien et al., 2003) and effective soil-water management (Snyman, 1998, 2005). While hydrologic function has been defined as the ability of rangelands to capture, store, and release water (Pellant et al., 2000) it is difficult to accurately measure and monitor the inputs and outputs *in situ*. Instead, several indicators have been developed to characterize hydrologic function with percent bare ground and soil-water content being two of the most commonly applied and accepted (Booth and Tueller, 2003; Taylor, 1986). Indeed, Thomas and Squires (1991) and Snyman (2009) argue that soil-water content is the principal determinant of productivity and the primary driver of rangeland condition in semiarid ecosystems.

Soil-water content is an important environmental indicator for the energy-water balance (Snyman, 1989; Sheppard et al., 2009), soil-water balance, and of a soil's ability to regulate the hydrologic cycle. While soil-water content is dependent upon soil type, structure, porosity, and organic matter (Werner, 2002), it can also be affected by changes in vegetation, runoff from adjacent areas (Aguiar and Sala, 1999), as well as a number of other factors (Snyman, 1998). One factor, land use, may impact the soil-water content of semiarid rangelands through differential use of the landscape by grazing animals. Voisin (1988) and Savory (1999) have suggested that rangelands will respond in different ways to changes in grazing system (e.g., rotational versus continuous), seasonality of the grazing period, the species and density of livestock, and the duration of the grazing/rest period (Snyman, 1998). Relatively recent observations suggest that holistic planned grazing (HPG) allows much higher grazing animal density over a short time period and may result in higher soil-water content through the development of higher levels of ground-surface litter (cf. standing-dead litter and moribund grasses) (Savory, 1999). The ability of HPG to effect these desirable results depends very much upon the goals of the grazier, proper execution of good land stewardship skills, and application of the correct recovery period (Snyman, 1998; Savory, 1999; Voisin, 1988). The goal of this study was to determine if soil-water content is affected by land management

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decisions (e.g. grazing and rest) within the semiarid sagebrush-steppe rangelands of southeast Idaho. Specifically, this study sought to experimentally determine if a positive relationship exists between soil-water content and litter cover and if land use treatments can be used to beneficially manipulate litter cover.

2. Methods

2.1. Study area

Soil-water content measurements were collected at the O'Neal Ecological Reserve in southeast Idaho approximately 30 km southeast of Pocatello, Idaho (42° 42′ 25"N 112° 13′ 0" W) (Fig. 1). The study area is relatively flat with a mean elevation of 1427 m (1418–1436 m; SE = 0.24) and receives < 380 mm of precipitation annually. Nearly 50% of precipitation falls as snow in the winter (October 1–March 31) while rainfall during the growing season (April–September, 2006–2008) averages 148 mm (SE = 55.4). Potential evapotranspiration (ET_0) during the growing season is high (945.3 mm; SE = 9.5) and far exceeds total annual precipitation inputs. Typical of semiarid ecosystems, these rangelands are considered water-limited.

The dominant plant species at the O'Neal study area include Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) with various native and non-native grasses and forbs, including Indian rice grass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*). Soils throughout the study area are homogeneous and of the McCarey series-McCarey variant soil association. These shallow, well-drained soils lie over basalt flows and were originally formed from weathered basalt, loess, and silty alluvium (USDA NRCS, 1987).

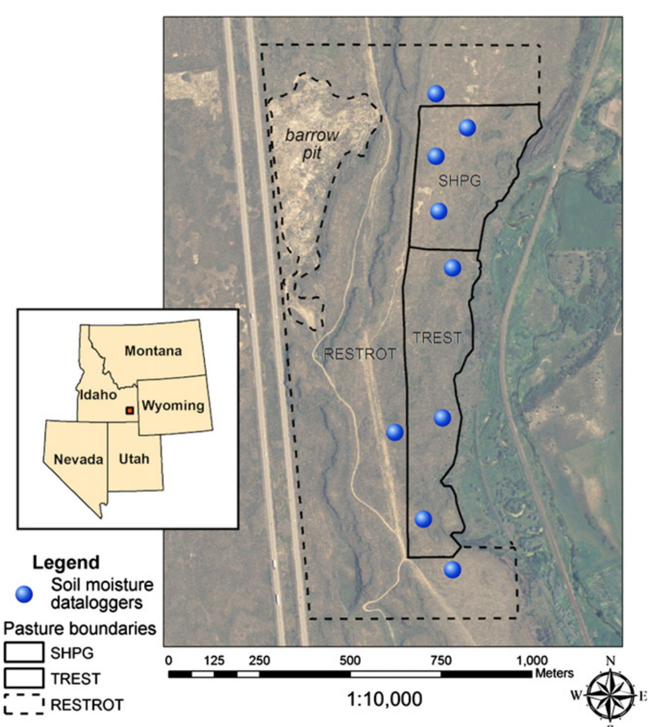

Fig. 1. The O'Neal study area and location of soil-water content sensors. Sensor placement followed a star-like pattern around the data loggers (shown as large dots on the map). Placement was pseudo-random to avoid both rock outcrops and existing cattle trails. The rest-rotation pasture extends beyond this map to both the north and south. Note: no samples were taken from the barrow pit in the northwest corner of this map for any part of this study.

The O'Neal study area has a history (>20 years) of livestock grazing. Prior to the initiation of this experiment, no fences existed at the study area to restrict movement of cattle from an adjacent USDI BLM grazing allotment where rest-rotation grazing treatment has been applied (300 AU/1467 ha [6 AUD ha^{-1}]) for decades.

2.2. Field data

In 2005, and prior to any experimentation, the vegetation at the study area was sampled ($n = 60$) to establish pre-treatment land cover conditions. To supplement these data, high spatial resolution (0.15 m per pixel) aerial imagery was acquired to provide a census of ground cover conditions that could be revisited after fences were constructed and grazing treatments implemented. Field-based ocular estimates of percent cover were made for bare ground, litter, grass, shrub, and dominant weed within a 10 m × 10 m area centered over each randomly generated observation point. Cover was classified into one of nine general cover categories (1. None, 2. 1–5%, 3. 6–15%, 4. 16–25%, 5. 26–35%, 6. 36–50%, 7. 51–75%, 8. 76–95%, and 9. >95%) with all observations made by viewing the vegetation perpendicular to the ground following the rest-rotation grazing period of 2005.

Treatment pastures were fenced in late summer 2005 followed in 2006, 2007, and 2008 by a more intensive land cover sampling campaign to monitor each treatment pasture shortly after (within 1 month) that year's grazing period. For each sample plot ($n = 50$ sample plots/pasture) two-10 m line transects were arranged perpendicular to each other and crossing at the 5 m mark of each line transect. Using the point-intercept method (Gysel and Lyon, 1980), observations were recorded every 0.2 m along each 10 m line, beginning at 0.10 m and ending at 9.8 m ($n = 50$ observations per line or 100 observations per plot). Percent shrub, grass, litter, and bare ground were estimated for each 10 m × 10 m. Beginning in 2007, forage biomass was measured using a plastic coated cable hoop 2.36 m in circumference (0.44 m^2). The hoop was randomly tossed into each of four quadrants (NW, NE, SE, and SW) centered over the sample point. All vegetation within the hoop that was considered forage for cattle, sheep, and wild ungulates was clipped as close the soil surface as possible (within 5 mm) and weighed (1 g) using a Pesola scale tared to the weight of an ordinary paper bag. Grasses and forbs were weighed separately while woody species (i.e., sagebrush) were not clipped or included in the forage biomass measurements. The measurements were later used to arrive at an estimate of forage expressed in kilograms per hectare (Sheley et al., 2003).

2.3. Instrumentation

While soil-water content is dependent upon soil type, structure, porosity, and organic matter (Werner, 2002), it can also be affected by changes in vegetation and runoff from adjacent areas, as well as other factors (Snyman, 1998). Various methodologies exist to measure soil-water content (electrical resistance blocks, tensiometers, gravimetric calculations, neutron probe, time domain reflectrometry, and capacitance probes) with some being more accurate and better accepted than others (Werner, 2002). Regardless of the methodology used, site specific calibration curves must be developed (GLOBE, 2005).

The depth at which soil-water content instruments are placed is important if results are to be meaningful. For most rangeland applications, instruments should be located within the root zone of the site-specific plant community, which may be quite shallow. For instance, Snyman (2009) found 60–75% of cumulative root distribution occurred within the first 100 mm of the soil surface, with shallower root distributions consistently found in rangelands in poor condition.

Thirty-six Decagon ECH_2O (EC-10) capacitance sensors were installed across the O'Neal study area (Fig. 1) in spring 2006 with 12 probes used in each of three treatment pastures (SHPG, RESTROT, and TREST). The EC-10 capacitance sensors (2% accuracy) used for this study were buried at a depth of 100 mm. This depth was selected as it is within the root zone of the sagebrush-steppe plant community and at a depth where soil-water content responds rapidly to precipitation events and plant water use. More shallow placements were avoided as the sensors were more likely to be moved or damaged by livestock, rodents, and freeze/thaw cycles. Deeper placements were not possible in all sites across the study area due to underlying rock.

The sensors were placed pseudo-randomly as true random placement was not possible because of numerous rock outcroppings and the concern that cattle would disturb or destroy the sensors/data loggers if placed near existing trails or water tanks. To accomplish this, random locations were pre-selected within each pasture based upon the following criteria; 1) sites were not within 10 m of a gate or fence and 2) sites were not within 70 m of a watering point. Based upon field conditions found during the time of installation, final placement of the sensors was dependent upon the presence of rocks, existing cattle trails, and other objects which might inhibit their placement or bias measurement results. In these cases, the sensor was moved as little as possible to an acceptable location.

Nine data loggers were used (three per pasture) with four EC-10 capacitance sensors attached to each data logger. The EC-10 capacitance sensors were placed the maximum distance away from the data loggers as allowed by the data cables (approximately 18 m).

In June 2006, six soil core samples (approximately 7 cm diameter $\times$ 24 cm depth [15.31 cm^3]) were removed from the ground immediately adjacent to six EC-10 probes (approximately 15% of the probes were sampled, two from each pasture). Core holes were then refilled and leveled. The soil was weighed (1 g) and stored in marked plastic bags for further analysis. Soil samples were then oven-dried and weighed again. Using these data, soil bulk density (g cm^{-3}), water volume (ml), and volumetric-water content (VWC m^3 water/m^3 soil) were determined. VWC (Y-axis) was regressed against raw probe output values (X-axis) to derive a line-of-best-fit and a quadratic calibration function calculated using third-order polynomial regression. The calibration equation ($R^2 = 99.7$) used in this study was:

$$Y = 4.86\text{E}-07x^2 + 6.22\text{E}-05x - 7.81\text{E}-02 \tag{1}$$

where Y = calibrated volumetric-water content (m^3/m^3), x = raw output values from the EC-10 capacitance sensor.

Percent volumetric-water content was found by multiplying the calibrated VWC by 100. All soil-water content values are expressed as %VWC.

Soil-water content measurements were collected every 6 h beginning 8 July 2006 and throughout the duration of this study (ending 1 September 2008). All data were calibrated (using the equation above) and stored in an ArcSDE Geodatabase along with all spatial, temporal, and raw sensor data. For the purposes of this study, soil-water content data were analyzed through August 31st of each year. Soil-water content observations were replicated by treatment ($n = 3$ data loggers) and by year ($n = 3$).

Neufeld (2008) noted that soil-water balance is affected by various factors, including climate. To better understand the interaction between site specific weather conditions and soil-water content, a Davis Vantage Pro2 Weather Station (http://www.davisnet.com) was deployed at the O'Neal study area. Beginning 1 June 2006, the weather station has measured and recorded temperature, humidity, barometric pressure, wind speed and direction, precipitation, solar radiation, and solar energy every 2 h. The Vantage Pro2 weather station also calculated dew point, various heat indices, and potential evapotranspiration (ET_0). Evapotranspiration was calculated following the Penman–Monteith equation (Allen et al., 1998) using temperature and humidity measurements (used to calculate saturation vapor pressure and actual water vapor pressure), wind speed, and measurements from the on-board solar radiation sensor (Jensen et al., 1990; Davis, 2006). Potential ET_0 (mm) was calculated hourly and mean ET_0 throughout the archiving interval was recorded every 2 h. Due to the small size (1491 ha) of the study area, uniformity of environmental conditions having the potential to affect soil-water content (e.g., precipitation) was assumed.

2.4. Grazing

Prior to this experiment the entire study area (1491 ha) was managed as a single unit under a rest-rotation grazing system. For over two decades cattle grazed at low density (approximately 300 head) for long periods of time (30 days). In late summer 2005, the study area was divided into three treatment pastures. The first was a simulated holistic planned grazing (SHPG) pasture (11 ha) where cattle grazed at high density (66 AU/11 ha [36 AUD ha^{-1}]) for a short period of time (6 days) during the first week of June each year (2006–2008). The second treatment was a rest-rotation (RESTROT) pasture where cattle grazed at low density (300 AU/1467 ha [6 AUD ha^{-1}]) for long periods of time (30 days) during the month of May each year. One grazing period was applied each year allowing 359 days and 335 days of recovery/reset within each production pasture (SHPG and RESTROT), respectively. By following this grazing schedule, both production pastures were grazed at as near the same time as was logistically possible. Stocking rates differed between the production pastures to compare the effect of high-intensity/short-duration grazing (i.e., SHPG) with a more traditional low-density/long-duration grazing treatment (i.e., RESTROT). While the number of cattle grazed in each pasture was constant between years, the size of these herds was dictated by the availability of cattle from the cooperating ranchers. The third treatment was a total rest (TREST) pasture (13 ha) where no livestock grazing has occurred since June 2005.

2.5. Statistical analysis

Pre-treatment percent shrub, grass, litter, and bare ground were compared between pastures using ANOVA (i.e. SHPG was compared with RESTROT, SHPG was compared with TREST, and RESTROT was compared with TREST) to determine if a difference in land cover pre-existed that could account for any observed differences in % VWC of the soils.

An inverse relationship was expected between soil-water content and percent cover when all other factors were constant (precipitation, soil association, etc.) across the study area. This relationship suggests the treatment pasture having the highest soil-water content should have the lowest percent cover of vegetation. To investigate this, ANOVA was used to compare shrub cover (primarily Wyoming big sagebrush) between pastures using field data collected in 2007 and 2008.In addition, since litter acts as a mulch and can affect the %VWC of soils, differences in percent litter within each treatment pasture were investigated using point-intercept transect data from 2007 to 2008. ANOVA was used for pair-wise comparison of treatments (i.e., SHPG and RESTROT, SHPG and TREST, RESTROT and TREST).

Forage biomass provides an additional measure of range quality that is especially important to producers and land managers. For this reason, forage biomass was measured and used to interpret differences in soil-water content. Similar to percent cover, forage biomass estimates (kg ha^{-1}) were compared between treatment pastures using ANOVA.

Daily average %VWC was calculated for each treatment pasture ($n = 48$ [12 probes were located in each pasture with four measurement made per day]). In addition, weekly average %VWC was calculated for each treatment replicate (three data loggers were located in each pasture and treated as replicates). All data were compiled in MS Excel spreadsheets and ANOVA were calculated comparing pairs of treatments individually (i.e., SHPG and RESTROT, SHPG and TREST, RESTROT and TREST) within each year. To better account for the interactive effects of treatment and the environment (weekly and annual differences in soil-water content due primarily to precipitation and temperature) and to provide a more robust and conservative statistical test, a mixed procedures model was applied using SAS software and 2007 and 2008 data (note: data from 2006 were not used in this test as the same number of weeks were not sampled, thereby causing a lack of convergence error in the SAS procedure). Fixed effects calculations followed Prasad-Rao-Jeske-Kackar-Harville methodologies while the degrees of freedom calculation followed the Kenward-Roger method.

Spatial heterogeneity of the soil was investigated to determine the degree of variability that existed within the soils. To accomplish this, 2006 soil-water content data were used (these data would tend to show the least treatment effect) and each pasture was subsampled by selecting six EC-10 capacitance sensors (two diagonally juxtaposed sensors were selected from each data logger [having four sensors each]) and the daily mean %VWC was compared with the daily mean %VWC for the remaining six EC-10 capacitance sensors in the same treatment pasture. ANOVA was used to compare within pasture daily mean %VWC.

This study was part of a larger study focusing upon the use of satellite imagery to detect changes in vegetation land cover. To augment understanding of detected changes, soil-water content sensors were deployed in 2006 concurrent with commencement of experimental grazing and satellite imagery acquisition. Soil type was the same (McCarey series-McCarey variant soil association [USDA NRCS, 1987]) across all experimental pastures and pre-treatment vegetation cover data (2005) showed little overall difference in shrub, grass, litter, or bare ground. Consequently, soil-water content was assumed to be similar prior to treatment. However, the authors acknowledge that to draw a firm conclusion regarding the effect of treatment on soil-water content, pre-treatment conditions should be known and not assumed.

3. Results

3.1. Vegetation cover and forage biomass

The comparisons of pre-treatment conditions within each pasture indicate no difference in ground cover pre-existed with the exception of shrub cover, which was found to be slightly higher in the TREST pasture than in the SHPG pasture (Table 1). No other differences were found.

The results of land cover comparisons throughout the experimental period (2006–2008) indicate no difference in percent shrub cover between the SHPG and RESTROT pastures ($P = 0.687$ and $P = 0.584$) in both 2007 and 2008, while in 2007 shrub cover was slightly higher in the TREST pasture relative to the SHPG pasture ($P = 0.002$). This difference was attributable to the pre-existing condition noted above and was no longer evident when comparing 2008 field sample data ($P = 0.417$). Given the heterogeneity of land cover in semiarid rangelands, coupled with the fact that specific sample points were not revisited each year, it is noteworthy that between pasture comparisons (where within year environmental conditions were constant) revealed no difference in percent cover of shrubs in nearly all cases.

Table 1
Comparisons of pre-treatment (2005) land cover conditions and results of statistical comparisons.

	Median Cover Class			
Treatment	Shrub	Grass	Litter	Bare Ground
SHPG	1–5%[a]	1-5%[a]	16–25%	36–50%
RESTROT	1–5%	1–5%	16–25%	36–50%
TREST	16–25% [a]	1-5%[a]	6–15%	26–35%

[a] indicates a statistical difference was found ($P < 0.001$).

Comparisons of percent litter cover revealed significant differences among all three treatments ($P < 0.001$) beginning in 2007 but no difference prior to this time. Pair-wise comparison showed significantly higher litter cover in the SHPG pasture compared to the RESTROT pasture ($P < 0.001$) in both 2007 and 2008, as well as higher litter cover in the SHPG pasture relative to that found in the TREST pasture in 2007. No difference in litter cover was found between the SHPG and TREST pastures in 2008 ($P = 0.07$) and no difference was found between the TREST and RESTROT pastures ($P > 0.001$) at any time throughout the study.

Forage biomass comparisons indicate more above-ground grass biomass was found in the SHPG pasture ($\bar{x} = 58.6$ kg ha^{-1} [S.E. = 3.2]) relative to that found in the RESTROT pasture ($\bar{x} = 39.5$ kg ha^{-1} [S.E. = 3.8]) in 2007 ($P < 0.001$). This difference was not observed in 2008 ($P = 0.17$) although mean above-ground grass biomass was still slightly higher in the SHPG pasture ($\bar{x} = 79.9$ kg ha^{-1} [S.E. = 5.1]) than in the RESTROT pasture ($\bar{x} = 68.5$ kg ha^{-1} [S.E. = 6.4]). This difference was most likely attributable to how livestock utilized the pastures, the time span between when the cattle were removed from the pastures and when the pastures were sampled, and perhaps the slight difference in precipitation between years (105 mm of precipitation fell from January 1st to June 30th in 2007 whereas 97 mm of precipitation fell over the same time period in 2008).

The TREST pasture was not grazed by livestock since 2005, and as a result, was expected to have higher above-ground grass biomass compared to the production pastures. Consequently, above-ground grass biomass was significantly higher in the TREST pasture ($P < 0.001$) compared to either of the production pastures (SHPG and RESTROT) in 2007 ($\bar{x} = 131.9$ kg ha^{-1} [S.E. = 10.2]) and 2008 ($\bar{x} = 239.2$ kg ha^{-1} [S.E. = 24.0]). However, since field sampling occurred shortly after the grazing period (within one month) this difference is perhaps a better indicator of forage utilization than primary productivity.

3.2. Soil-water content

Comparisons of daily %VWC among treatment pastures indicate a significant difference ($P < 0.001$) when all treatments were compared at once. Pair-wise comparisons indicate %VWC was significantly higher in the SHPG pasture compared to the RESTROT and TREST pastures in 2006, 2007, and 2008 ($P < 0.001$). No difference in %VWC was found between the RESTROT and TREST pastures in either 2006 ($P = 0.161$) or 2007 ($P = 0.749$) although %VWC was higher in the RESTROT pasture in 2008 ($P < 0.001$) (Table 2).

Within pasture comparisons indicate very little difference existed in %VWC across each individual pasture. The SHPG pasture revealed the greatest heterogeneity ($P < 0.025$) while both the RESTROT and TREST pastures showed no detectable difference

Table 2
Mean %VWC comparisons by treatment.

$\bar{x}$ %VWC			
Treatment	2006	2007	2008
SHPG	23.3[a]	44.1[a]	45.8[a]
RESTROT	19.7[a]	34.8[a]	34.7[a]
TREST	19.2[a]	31.9[a]	29.8[a]

[a] indicates a statistical difference was found between paired comparisons ($P < 0.001$).

($P = 0.15$ and $P = 0.12$ respectively). It is difficult to know if the difference observed within the SHPG pasture was due to an *a priori* difference in soils or an early observable effect of treatment. While it is impossible to know, it is most likely a combined effect of both treatment and soil heterogeneity.

Results from the mixed procedures model and type three test of fixed effects indicate the observed differences in %VWC at the O'Neal study area were principally due to weekly effects ($F = 91.87$, $P < 0.0001$) (e.g., early season %VWC differs from late season %VWC suggesting a purely environmental influence) followed by the year × pasture interaction ($F = 20.03$, $P < 0.0001$). This secondary effect indicates that while %VWC differs annually, it is differentially variable by pasture, suggesting both an environmental and treatment influence. The third significant explanatory effect was the week × year interaction ($F = 6.29$, $P < 0.0001$) while the final significant effect was attributable to the pasture variable alone ($F = 4.89$, $P = 0.05$). This latter effect indicates that the treatment applied within each pasture accounts for some significant portion of the total variability seen in %VWC at this study area and, coupled with the year × pasture interaction, suggests that grazing treatment made substantial changes to rangeland soil-water content.

The response of %VWC (Daily % VWC) to precipitation events was investigated using data collected in 2007 to better understand the hydrologic cycling dynamics within the study area and within each pasture (Fig. 2). As expected, soil-water content at 100 mm increased rapidly after precipitation events and declined at equivalent rates. During the summer months, the rate of soil-water decline was much greater than autumn rates. Furthermore, while absolute %VWC was highest in the SHPG pasture (Table 2) the trend followed in all pastures was nearly identical.

3.3. Assessment of error and bias

The accuracy of the Decagon ECH_2O (EC-10) capacitance sensors was 2%. Conservatively applying known instrumentation error indicates that if mean %VWC was within 4% for any two treatment pastures then the real difference between those treatments may be questionable even if they were found to be statistically different. This condition occurred only in 2006 (Table 2). All other comparisons do not satisfy the error condition tolerance of 4% and are considered valid.

A potential bias of this study is related to the pseudo-random positioning of the Decagon ECH_2O (EC-10) capacitance sensors. Ideally, all sensors would have been placed in an absolutely random fashion, however this was not possible for two reasons: 1) the McCarey series-McCarey variant soil association found throughout the study area is typified by having very shallow bedrock (approximately 250 mm) which precluded a true random placement of sensors and required *in situ* placement adjustments, 2) the study area is actively grazed by cattle and placement of sensors could not be located close to trails or water sources as the increased presence of cattle concomitantly increased the probability that the sensors, their buried wire connections, and above-ground data loggers would be accidentally damaged or destroyed. To minimize potential damage and avoid rock outcroppings we chose to use a pseudo-random location strategy where true random locations were first generated using Hawth's tools (within ESRI's ArcGIS) and final placement was decided during installation based upon field conditions and the considerations noted above. In all cases, final placement of the sensors was made as close to the randomly generated location as possible.

Another potential bias in this study and one the authors have tried to accommodate for is the uneven sampling duration. The Decagon ECH_2O (EC-10) capacitance sensors became operational on 8 July 2006 and continued in operation throughout this study. As a result, the 2006 growing season records do not include measurements made prior to 8 July. This shortcoming was corrected in 2007 and 2008 as records from 1 April through 31 August were available and used in this study. For this reason, empirical comparisons of %VWC between 2006 and latter years were limited.

4. Discussion

The water absorption and retention capacity of soils depends upon soil type (e.g., sand, silt, and clay), porosity, organic matter or colloidal content (Singer and Munns, 1991; Werner, 2002), vegetation cover (Snyman, 2009), topographic effects (Aguiar and Sala, 1999; Weber et al., 2009), and numerous other factors. The effect of treatment on soil-water content is not well recognized although some studies have documented the effect of grazing on carbon dynamics (Haferkamp and Macneil, 2004) or evaluated the effect of grazing on various physical properties of soil (Wheeler et al., 2002).

The results of this study suggest that TREST and RESTROT (partial rest) treatments have similar effects on litter and that grazing has the ability to modify litter cover. Litter affects soil nutrients and soil structure as its decay adds nutrients to the soil, improves soil structure, reduces soil erosion (Nagler et al., 2000), and lowers soil surface temperature (Du Preez and Snyman, 1993; Follett et al., 2001). Reduced soil surface temperature also impedes the volatilization of soil carbon, thereby reducing greenhouse gas emissions (Follett et al., 2001). In turn, reduced soil surface temperature lowers surface evaporation further improving the soil-water balance (Davidson et al., 1998; Snyman, 2005; Willms et al., 1993). In a study focusing upon grazing impacts on litter and soil organic matter, Naeth et al. (1991a; 1991b) reported higher levels of small- and medium-sized organic matter particles were found in grazed pastures compared to un-grazed pastures (cf., TREST). In their study, increased organic matter resulted from grazing animal impact and a related increase in the biological decomposition of litter in contact

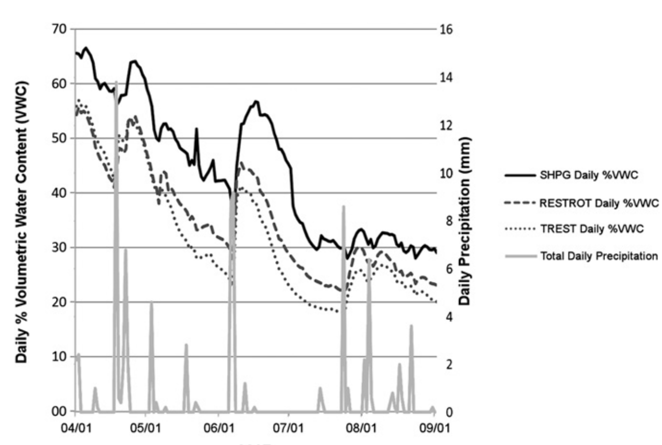

Fig. 2. Soil-water content response in each treatment pasture relative to rainfall events during the summer of 2007.

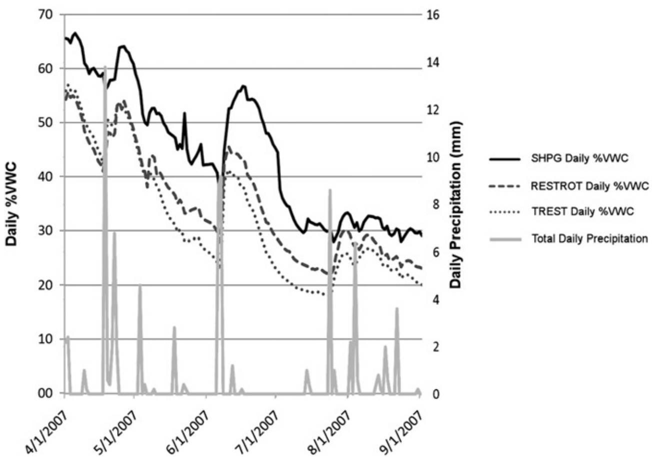

Fig. 3. Mean annual %VWC within each treatment pasture.

with the soil surface (compare with standing-dead litter). More recently Neufeld (2008) evaluated how litter affects soil-water content and recognized its positive effects, while noting the complex soil-water relationship is dependent upon various factors including climate, landscape, soil properties, and vegetation type.

The changes observed in the SHPG treatment pasture appear to be the result of several interactive affects (high-intensity/short-duration grazing, animal impact, and increased litter cover) that produced a positive feedback cycle which may ultimately improve the condition and sustainability of these rangelands (Fynn, 2008; Redman, 1978; Snyman, 2002). This study demonstrates that season-long mean soil-water content (expressed as %VWC) can vary significantly even within areas having similar vegetation cover, soil type (McCarey series-McCarey variant soil association) and presumably, the same soil porosity and organic matter content. The latter may not be entirely true however and was not analyzed as part of this study. Indeed the different grazing treatments may have altered the porosity and organic matter of the soils within each treatment pasture through differential production and decomposition of litter (Snyman, 2005), thereby offering a likely explanation of how these soils were able to retain more water throughout the growing season (Naeth et al., 1991b). Longer-term assessments of this type are needed however, to validate these inferences.

Observations made during this experiment illustrate that treatment has statistically important effects. Furthermore the trend of continued divergence in %VWC among the treatments is interesting and appears promising for both the research and land management communities (Fig. 3). Future research should be directed toward addressing this same question using a larger replicated study with at least one full year of pre-treatment data collection.

5. Conclusions

While soil type and shrub cover were effectively the same across the study area, mean %VWC differed. Pair-wise comparisons indicate that mean %VWC for the SHPG treatment pasture was significantly higher than that found in either the RESTROT or TREST treatment pastures while mixed procedures models in SAS revealed strong environmental as well as treatment effects. These results suggest that animal impact and the duration of grazing (i.e., spatio-temporal effects) were responsible for some of the observed differences. As a direct result of animal impact, increased litter cover in the SHPG pasture likely played a key role. Although the relationship between litter and soil-water content is complex, the current literature (Naeth et al., 1991a; Neufeld, 2008; Snyman, 2005, 2009) suggests that litter can affect soil-water content and soil organic matter. While a variety of factors influence soil-water content, holistic planned grazing appears to offer a management alternative with beneficial results measurable on the landscape. In light of these findings, additional studies are warranted relative to the merits of holistic planned grazing and the ability of grazing to favorably modify semiarid landscapes.

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