Effects of Grazing Management on Carbon Stocks in an Arid Rangeland

by

Aaron Boydston

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Graduate Supervisory Committee:

Osvaldo Sala, Chair
Heather Throop
Sharon Hall

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ABSTRACT

Rangelands are an extensive land cover type that cover about 40% of earth's ice-free surface, expanding into many biomes. Moreover, managing rangelands is crucial for long-term sustainability of the vital ecosystem services they provide including carbon (C) storage via soil organic carbon (SOC) and animal agriculture. Arid rangelands are particularly susceptible to dramatic shifts in vegetation cover, physical and chemical soil properties, and erosion due to grazing pressure. Many studies have documented these effects, but studies focusing on grazing impacts on soil properties, namely SOC, are less common. Furthermore, studies testing effects of different levels of grazing intensities on SOC pools and distribution yield mixed results with little alignment. The primary objective of this thesis was to have a better understanding of the role of grazing intensity on arid rangeland soil C storage. I conducted research in long established pastures in Jornada Experimental Range (JER). I established a 1500m transect in three pastures originating at water points and analyzed vegetation cover and SOC on points along these transects to see the effect of grazing on C storage on a grazing gradient. I used the line-point intercept method to measure and categorize vegetation into grass, bare, and shrub. Since soil adjacent to each of these three cover types will likely contain differing SOC content, I then used this vegetation cover data to calculate the contribution of each cover type to SOC. I found shrub cover and total vegetation cover to decrease, while grass and bare cover increased with decreasing proximity to the water source. I found areal (g/m^2) and percent (go SOC to be highest in the first 200m of the transects when accounting for the contribution of the three vegetation cover types. I concluded that SOC is being redistributed toward the water source via foraging and defecation and foraging, due to a negative trend of both total vegetation cover and percent SOC (g/g). With the decreasing trends of vegetation cover and SOC further from pasture water sources, my thesis research contributes to the understanding of storage and distribution of SOC stocks in arid rangelands.

DEDICATION

To my parents and Russell and Tammy and girlfriend Kailey Rumbo who always encouraged me to play outside, do what I love, and believed in me when I wasn’t able to.

ACKNOWLEDGMENTS

This thesis would not have been possible alone. I have so many great friends, family, visiting scholars, fellow graduate students, and supportive professors that poured into me during my time as a graduate student here. You all helped me with needs as simple as blowing off steam playing volleyball, board games, basketball, or hiking to calming me down during episodes of high anxiety or even reviewing my drafts on short notice when I needed it.

I would like to thank Jornada LTER for summer financial support and access to using their top tier research facility. The century of scientific knowledge has been an unbelievable resource that I was lucky enough to use. Thank you to David Thatcher, John Anderson, Joe Ramirez, Brandon Bestelmeyer, Kris Havstad for helping me with all my problems ranging from “where can I store my soil?” to “This ATV is broken and I’m stranded. Help.” to giving me an extensive history of Jornada’s grazing history including reading material, it goes without saying that this thesis would never be possible without all of you.

I would also like to thank past and present Sala lab members for all of the pizza parties, help with R, being ears to bounce ideas off of. I need to specifically thank Amy Wiedenfeld, Luis Weber, Xiaobo Yuan, Courtney Currier, Owen McKenna, Laureano Gherardi, and Raymond Cooley. Your assistance, guidance, advice, and sympathy of graduate school life was truly life-saving.

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difficult of times. Christian and Kailey also offered me their advice in technical and general matters, and I truly hope I can offer the same to you both if you ever become as stressed as I was at times. A special thanks to my officemate Amy Wiedenfeld for suffering the frigid office temperatures, the bulk density measurements, and thesis writing rants.

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Introduction

Rangelands offer many vital societal benefits as ecosystem services. These services range from a local to a global scale, like agriculture and carbon (C) sequestration respectively. Estimates of land surface cover of rangelands are difficult due to variability in definition of rangelands and whether or not ice-covered land is incorporated into the calculation. However, accounting for these variations puts rangeland cover between 18% and 80% (Verburg, Kathleen, & Nol, 2011). In fact, rangelands are so extensive that close to all non-cropped grasslands experience managed grazing from large herbivores (McSherry & Ritchie, 2013). A widely used definition for rangelands in North America comes the National Resources Conservation Service states they are "land on which the historic climax plant community…or the potential vegetative cover…is principally native grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing." Rangelands are diverse and exist on every ice-free continent in nearly every biome including grasslands, woodlands, shrublands, deserts, tundra, and forests. In particular, arid and semi-arid rangelands are heterogenous landscapes displaying patchy vegetation cover and differing dominant vegetation types within and among grasses and shrubs, while soil texture also varies from sandy to clayey. Additionally, artificial water points lead to higher degradation from high grazing intensity near these points, also known as piospheres (Golluscio et al., 2009; Nash et al., 1999; Thrash & Derry, 1999).

Rangelands as potential pools for C storage

Among rangeland's potential biomes, grasslands are the most productive, specifically belowground. Around 10% (Anderson, 1991) to 30% (Eswaran, Berg, Reich, Van Den Berg, & Reich, 1993) of global terrestrial soil organic carbon (SOC) stocks are contained in grasslands. This large carbon pool is partially attributed to grassland's relatively large belowground production. In fact, 95% of C in grasslands resides in soil as living and dead organic matter, a characteristic unique to grasslands that implies more direct inputs into these SOC pools through belowground production than aboveground production (Follet, Kimble, & Lal, 2001). As a result, they contain comparable soil organic matter levels to temperate and boreal forests, despite having approximately 25% of the total plant biomass (Anderson, 1991). As a result, grass-like vegetation types store C in a different manner than woody vegetation. As rangelands rely on grass availability for animal forage, understanding drivers that dictate SOC accumulation is crucial for responsible grassland ecosystem management decisions. Due to their amount of land cover and organic matter inputs, small increases to rangeland SOC storage could potentially lead to a substantial impact on atmospheric C pools, making rangeland management pivotal (Schuman, Janzen, & Herrick, 2002).

Literature reviews and meta-analyses have provided support for multiple techniques to increasing rangeland SOC stocks including fertilization, fire, legumes for nitrogen fixation, irrigation, and reclamation (R. T. Conant, Paustian, & Elliott, 2001; Richard T. Conant, Cerri, Osborne, & Paustian, 2017; McSherry & Ritchie, 2013). However, the impact of grazing management regimes is less understood. Stocking rates and grazing management regimes such as continuous, rotational, deferred grazing or intermediates of these regimes, likely play a role in rangeland ecosystem functioning. Key abiotic characteristics contributing to SOC pools include soil chemical properties, soil physical properties, and climatic conditions. Complementing abiotic factors, key biotic characteristics include primary production, species composition, decomposition, and herbivory. Few studies have attempted to isolate different management strategies from these biotic and abiotic effects on rangeland SOC (Derner & Schuman, 2007). Studies comparing the effects different grazing management strategies have on SOC are rare, while the few studies that have done so yield unclear results. Reviews on grazing management have uncovered positive, negative, and neutral effects of grazing regimes on SOC and attribute the majority of these results to environmental differences (D. D. Briske et al., 2008; Derner & Schuman, 2007; McSherry & Ritchie, 2013). Another criticism of these results emphasizes a lack of large-scale, consistent continuous or rotational grazing regimes (Teague, Provenza, Kreuter, Steffens, & Barnes, 2013). Thus, environmental drivers are likely overpowering many of these management differences (Briske et al., 2005; McSherry and Ritchie, 2013;).

Carbon Dynamics in Rangelands

C cycling in rangeland systems is a highly site-specific and complex phenomenon. Firstly, the contribution of soil inorganic carbon (SIC) to terrestrial C pools is far less studied than organic C pools, but it has begun to gain momentum recently (Batjes, 2014; Plaza-Bonilla et al., 2015). Research today is much more familiar with organic C. After transitioning from atmospheric to terrestrial pools, organic C exists in two broad pools with diverse turnover rates among them: above- and belowground biomass (one to ten years), and organic matter (days to thousands of years) (Burke et al., 1997; Follet et al., 2001; Lal et al., 2015). Turnover of litter into SOC relies on abiotic and biotic factors while varying widely between ecosystems as a result. Microbial biomass and composition are likely the largest driver of SOM turnover and likely have the largest influences on C stocks in the soil (Bagchi, Roy, Maitra, & Sran, 2017; Banerjee, Burton, McCaughey, & Grant, 2000; Lal et al., 2015).

Microbial biomass and bacteria-fungi ratios are also greatly altered under grazing conditions (Bagchi et al., 2017). Additionally, SOM composes up to 90% of biologically derived C in rangeland system which, when combined with the slow turnover rate and higher residence time compared to litter, makes SOM an ideal target for C sequestration (Burke et al., 1997; Eswaran et al., 1993; Follet et al., 2001; Lal et al., 2015; McSherry and Ritchie, 2013; Scurlock and Hall, 1998).

Land Manager Perceptions

Social and economic factors influence management decisions, granting social factors a sizeable role in grazing strategies chosen, which will change grazing patterns and stocking rates. Anecdotal evidence often influences grazing regime decisions over experimental evidence, particularly regarding continuous and rotational grazing regimes (D. D. Briske et al., 2008, 2011; Sanderman, Reseigh, Wurst, & Young, 2015; Teague et al., 2013; Wang, Richard Teague, Park, & Bevers, 2015). Many rangeland improvement strategies are also costly in terms of both time and money. With much of this empirical evidence yielding mixed conclusions, it is not surprising that managers are unmotivated to consider scientific research when implementing grazing regimes. Briske et. al document the myriad of techniques recommended to managers over the last century be it from empirical or anecdotal evidence (D. D. Briske et al., 2008). They go on to highlight that 50 years of empirical evidence offers no support of rotational grazing being ecologically or economically superior.

Piosphere Influences

Artificial water points in these drier rangelands usually lead to potent and abundant piospheres (Golluscio et al., 2009; Nash et al., 1999; Thrash & Derry, 1999). Grazing produces major impacts on rangeland soil and vegetation. The majority of piosphere studies focus on impacts on vegetation, but grazing also influences soil chemical, physical, and biological properties both directly and indirectly (Golluscio et al., 2009; Meglioli et al., 2017; Shahriary et al., 2012).

There is ample evidence documenting vegetation response on piospheres in arid and semi-arid rangelands around the world including the US southwest (Nash et al., 1999), southern Africa (Smet & Ward, 2006), the Middle East (Shahriary et al., 2012), and South America (Golluscio et al., 2009). Higher grazing intensities tend to increase shrub and bare cover while decreasing grass cover, although the extent of this influence may vary based on evolutionary history. (Adler, Milchunas, Sala, Burke, & Lauenroth, 2005; Milchunas, Sala, & Lauenroth, 1988). However, piosphere studies like the four previously mentioned in different regions of the globe either overlook the effects of grazing intensity on biogeochemical properties in soils along these piosphere gradients or attain conflicting biogeochemical results. Additionally, some meta-analyses conclude a general decreasing underground C storage trend with increasing grazing intensity (Zhou et al., 2017), but these effects remain mostly unclear in arid rangelands. More specifically, the effects of grazing intensity on ecosystem level SOC storage, that is above and belowground pools, are not well understood. Lastly, it is also uncommon to consider both vegetative and soil C in rangeland C stocks.

Question and Hypothesis

My goal is to lessen this gap of knowledge on the relationship of grazing intensity and soil resources, namely SOC. With these concepts of grazing effects on vegetation and soil in mind, this study addresses the question about the possible role of grazing on rangeland C stocks: Does long-term grazing affect SOC stocks in an arid rangeland? I propose two hypotheses that could explain this. (1) Higher grazing pressure near the water source will lead to reduced vegetation cover and C inputs into the soil, leading to higher SOC stocks in soil with far proximity to the water source. (2) Grazing very close to the water source will exert high disturbance and deposit SOC via defecation, leading to higher SOC stocks in soil with close proximity to the water source. By taking advantage of U.S. Department of Agriculture's long-term records and consistent grazing regimes, we analyzed long-term effects of grazing impacts on SOC in an arid rangeland in New Mexico.

Methods

Research Approach

To answer my research question, I established three 1500m transects radiating outward from cattle water sources. These water sources are the oldest in the study site, aging from 85-106 years old, and serve as a consistent water source for cattle. Distances farther from the water source are assumed to experience lower grazing impacts, forming a gradient of grazing intensity. To test hypothesis 2, I measured dominant vegetation cover type at each sampling location along the three transects. Bare, shrub, and grass/forb were measured as the dominant cover types. I then fitted these values to a regression model to see if the cover changed along the grazing gradient. To test hypothesis 1, I extracted one soil core for each vegetation cover type at each sampling location along the three transects and measured the amount of percent SOC (%) and bulk density(g/cm^3). I then used these two values to calculate SOC on a land area basis (g/m^2) and fitted the values to a regression model to see if SOC changes along the grazing gradient.

Site Description and Selection

I conducted all field work in the summer of 2016 at the Jornada Experimental Range (JER) in the Jornada Basin long-term ecological research (LTER) site in New Mexico. Consisting of 1000 km^2, JER sits in the Chihuahuan Desert at an elevation of around 1340 meters. The mean annual precipitation is 230 mm, 50% of which falls from July-September (http://jornada.nmsu.edu/lter). Jornada contains three dominant shrubland ecosystem types and two dominant grassland ecosystem types. However, beginning in the middle of the 19th century, the grassland ecosystem types have been shrinking from woody encroachment. The three shrub ecosystem types include creosote bush (*Larrea tridentata*), dune mesquite (*Prosopis glandulosa*), and tar bush (*Flourensia cernua*). Grassland ecosystem types consist of black grama (*Bouteloua eriopoda*) grassland and playa grasslands featuring Tobosa grass (*Pleuraphis mutica*) with vine mesquite grass (*Panicum obtusum)*.

The Jornada Basin is estimated to have been subjected to higher stocking rates by livestock in the mid and late 1800's compared to more modern rates. This prompted JER to be established by the United States Department of Agriculture (USDA) and agricultural research service (ARS) in 1912. Since its establishment, JER has experienced well documented grazing with consistent, moderate to light regimes compared to previous grazing management prior to its establishment. Ranch mangers of JER have been using a “best forage” approach to grazing by moving livestock to pastures with ideal forage. In addition, salt blocks have been used to further influence livestock toward areas with better forage (B. Bestelmeyer, K. Havstad, T, Schrader, D. Thatcher, personal communication, April 11, 2016).

Pasture names in JER are derived from their water source, which is predominantly from wells that pump ground water to the surface. I chose three pastures in JER by prioritizing pastures with the longest and most consistent grazing regimes: Headquarters well (HQ), Middle well (MI), and Taylor well (TA). These pastures all have detailed grazing histories documented for at least 80 years, and feature typical grazing regimes previously described. Moreover, these pastures cover multiple ecosystem types found in JER including mesquite shrubland, creosote shrubland, black gramma grassland, and playa grassland. HQ and MI wells were dominated by mesquite shrubland with small patches of both grassland types while TA well contains all four ecosystem types mentioned.

Soil Organic Carbon Measurements

Along each transect, soil cores with a depth of 5cm (5.75cm diameter) were collected at increasing distances from the pasture water source. The cores were collected every 50m until 500m from the water source, when cores were collected every 100m until the end of the transect at 1500m. Changes in SOC are most likely to be found in the top 5cm (Derner, Briske, & Boutton, 1997). Cores were extracted with a cylindrical core and a spatula to prevent any loose soil in the core from escaping through the bottom. As SOC is likely to vary depending on the above vegetation type, I extracted a soil sample from each cover type (shrub, grass and bare) at each sample interval if they were available within 20m of the sample location.

In the lab, I sieved samples through a 2mm sieve to remove root and leaf litter before drying at 105°C for 24 hours in preparation for measuring bulk density (g/cm^3) using methods suggested by (Throop et al., 2012). I then measured soil organic carbon concentration using elemental combustion analysis. First, I ground each sample to a fine powder using a mortar and pestle before placing 30mg of the ground samples into a silver capsule and acid fumigating them to eradicate any inorganic carbon (Harris et al., 2001). I then sealed and combusted the tins to measure the percent C of each capsule using a PE 2400 CHN analyzer. With the percent C data, I could then calculate mass of C per core (mg), convert it to (g), and use bulk density measurements (g/cm^3) to convert SOC into a per unit area SOC measurement (g/cm^2) of each sample.

Vegetation Cover

At the same sample locations as the soil cores extracted, I used line-point intercept on 30m cover lines to estimate percent vegetation type cover (shrub, grass/forb, bare soil) at each sample location on the transect. Vegetation cover lines were perpendicular to the 1500m transect, and cover type was recorded every 10cm. The measurements were then totaled by vegetation type at each sample location. Not every sample location, however, contained all three cover types. I applied and summed the cover data at each point to the SOC data of each vegetation cover type to see the effect on the ecosystem. It is important to note that this was measured in July, which comes just at the start of the wet monsoon season, before the plants are able to take advantage of the favorable soil moisture levels that come with the monsoons. Sampling vegetation cover took around four weeks, beginning two weeks before the first monsoon rainfall event. All vegetation cover data from Taylor well and around half of cover data from Middle well were measured after the first significant rainfall event. This led to lower vegetation cover compared peak production months (September and October).

I also calculated a weighed SOC amount for each sample location with the following equation:

$C_{Ln} = (C_{BLn} * \% \text{ Cover}_{BLn}) + (C_{G*Ln} * \% \text{ Cover}_{GLn}) + (C_{S*Ln} * \% \text{ Cover}_{SLn})$ where C is the amount of carbon with the restrictions of cover type (G, B, or S) at a particular location (L) along the transect and n is the distance. By doing so if one cover type dominates the area around the sample location, it will contribute more to the total C at that location.

Statistical Analysis

To determine the trends of vegetation cover along a grazing gradient, I fitted the vegetation cover data with a regression model according to best fit. Best fit was determined by a combination of low p values (<0.05), F-statistics, RMSE, and R^2 value to obtain a relationship of distance from water source to the cover types shrub, grass, bare, as well as shrub and grass combined. Any linear relationships were primarily determined by R^2 values, while F-stat Similarly, to determine the trends of SOC along a grazing gradient, I fitted the SOC data with a regression analysis according to the best fit, also by a combination of low p values (<0.05), F-statistics, RMSE, and R^2 values to obtain a relationship of distance from water source to percent SOC and areal SOC. I conducted all analyses and created figures using R version 3.4.3 (R Core Team 2017).

Results

Vegetation Cover

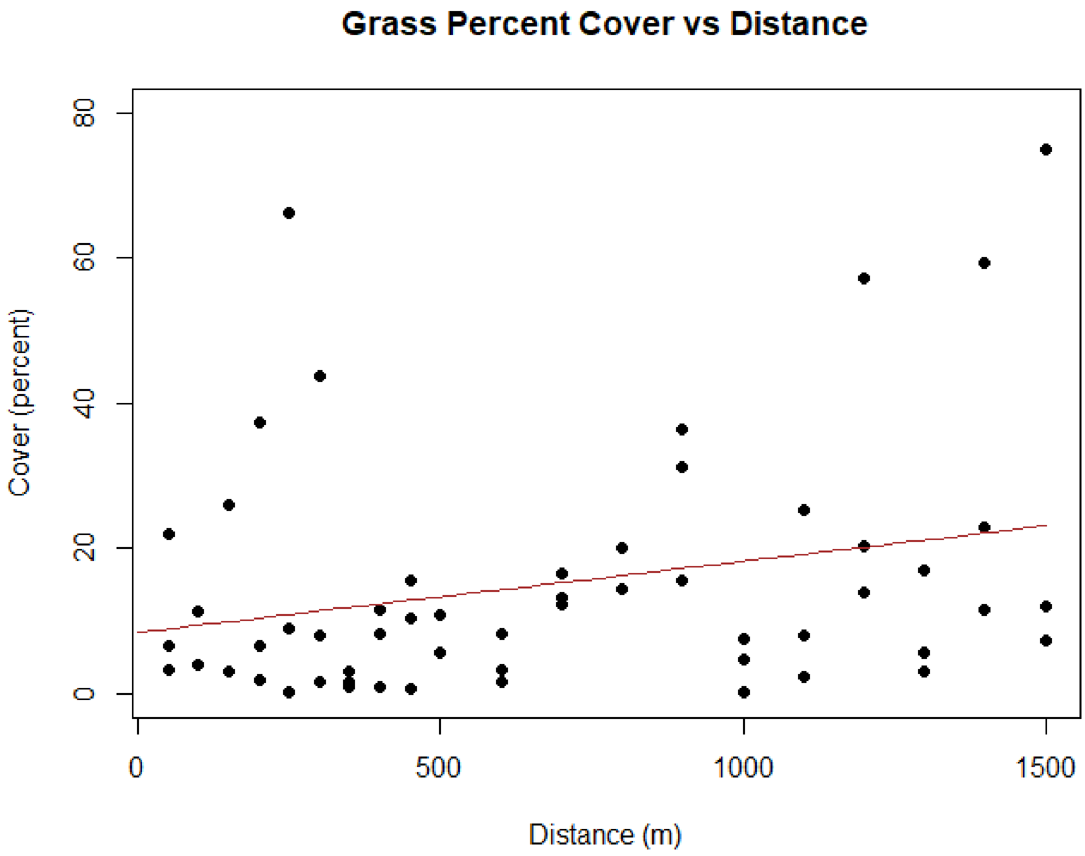

Figure 1. Relationship of distance from water source and percent grass cover using vegetation cover data from all three pastures. Dots represent total percent grass cover at that particular distance from water source for all three pastures. The relationship was

obtained with regression analysis. The black line represents the line of best fit (y = 0.0098x + 8.5) with $R^2 = 0.068$. The trend was insignificant due to $p = 0.052$.

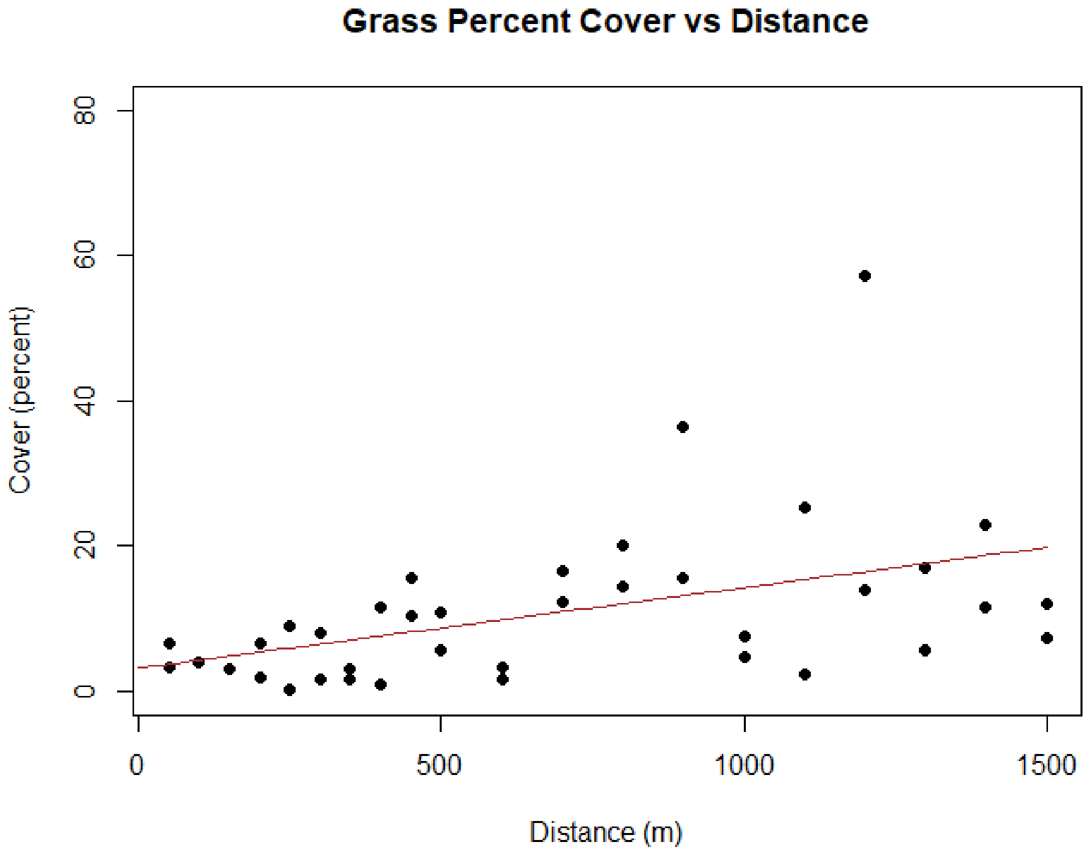

Figure 2. Relationship of distance from water source and percent grass cover using vegetation cover data from MI and HQ pastures. Dots represent total percent grass cover at that particular distance from water source for two pastures. The relationship was obtained with regression analysis. The black line represents the line of best fit (y = 0.011x + 3.21) with $R^2 = 0.21$. The trend was significant due to $p = 0.0042$.

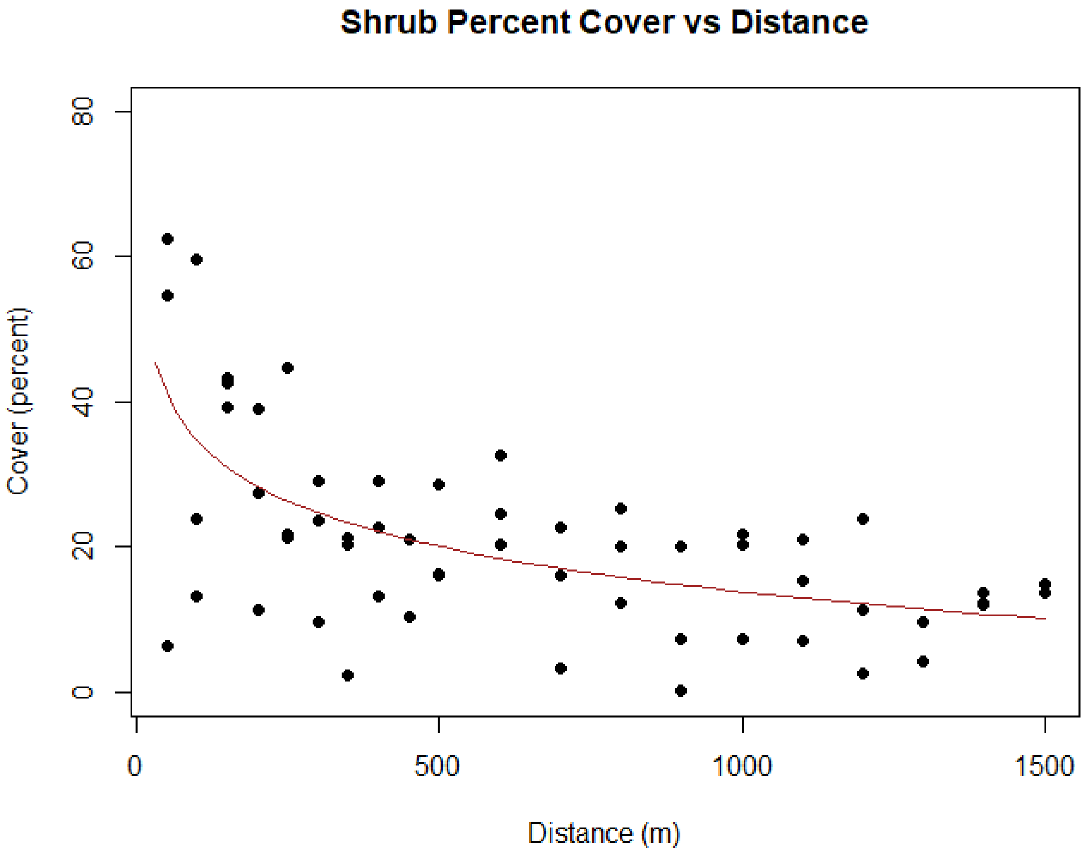

Figure 3. Relationship of distance from water source and percent shrub cover using vegetation cover data from all three pastures. Dots represent total percent shrub cover at that particular distance from water source for all three pastures. The relationship was obtained with regression analysis. The black line represents the line of best fit (y = log(-9.05x) + 76.38) with $R^2 = 0.38$. The trend was significant due to $p = 3.1 * 10^{-7}$. Regression analysis of shrub cover vs. distance for all three pastures.

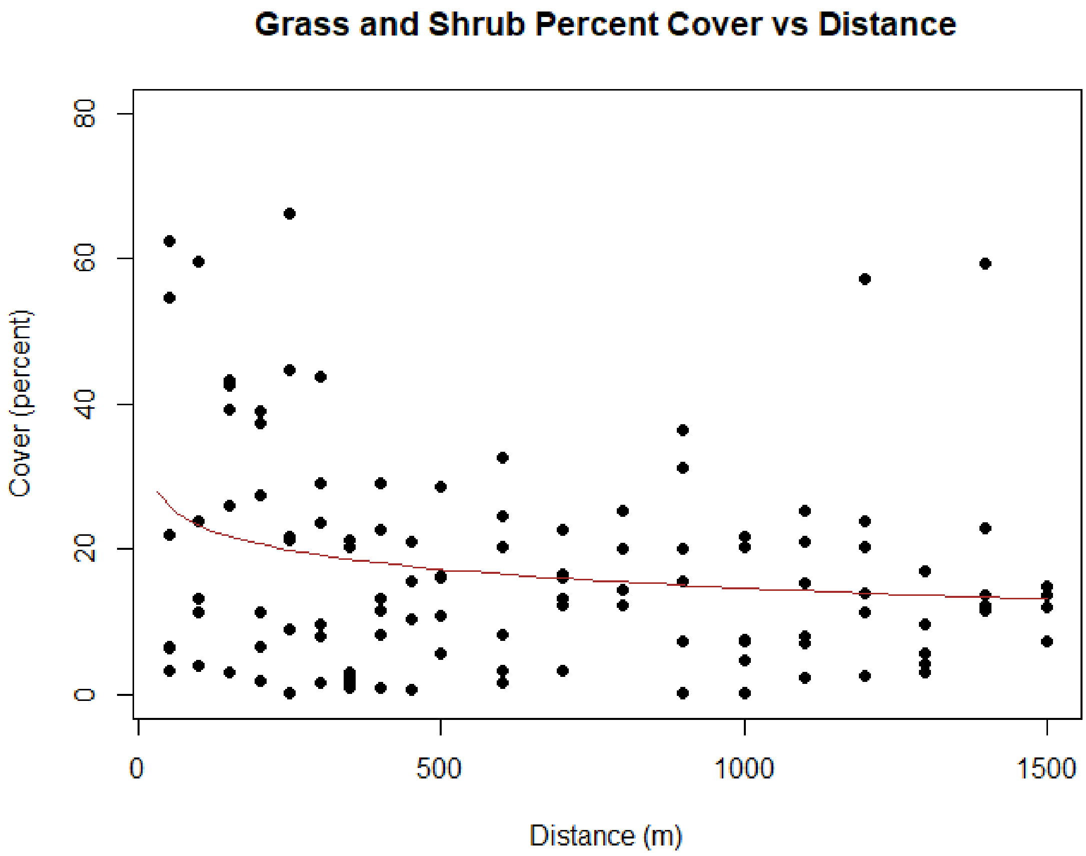

Figure 4. Relationship of distance from water source and percent shrub and grass cover using vegetation cover data from all three pastures. Dots represent summed total percent shrub and grass cover at that particular distance from water source for all three pastures. The relationship was obtained with regression analysis. The black line represents the line of best fit ($y = \log(-3.76x) + 40.66$) with $R^2 = 0.055$. The trend was significant due to $p = 0.013$.

Addressing my second hypothesis regarding vegetation cover, I found grazing intensity to have an effect on grass, shrub, and grass and shrub combined cover types ($p < 0.05$), though regression analyses displayed an insignificant fit for bare cover. Regarding grass cover, I did not find a significant fit ($p = .052$) when analyzing data from all three pastures (Figure 1). However, when omitting data from the highly variable TA pasture, I found a significant ($p < 0.01$) positive, linear trend (Figure 2). This regression shows a slope of 0.011, amounting to a 20% change in grass cover over the 1500m. As a linear fit, grass cover gradually increases with increasing distance from water source rather than experiencing a sharp increase in the first few sample areas.

Similarly, grazing intensity affected shrub cover in agreement with my expectations. Unlike grass cover, I found shrub cover to be significantly ($p < 0.01$) higher within the first few sample areas close to the water source, following a log fit pattern (Figure 3). Shrub cover continues to decrease afterwards, but at a lower rate. Similarly, grass and shrub cover together significantly ($p = 0.013$) decreased along the transects following a log pattern, though the rate is much lower (Figure 4).

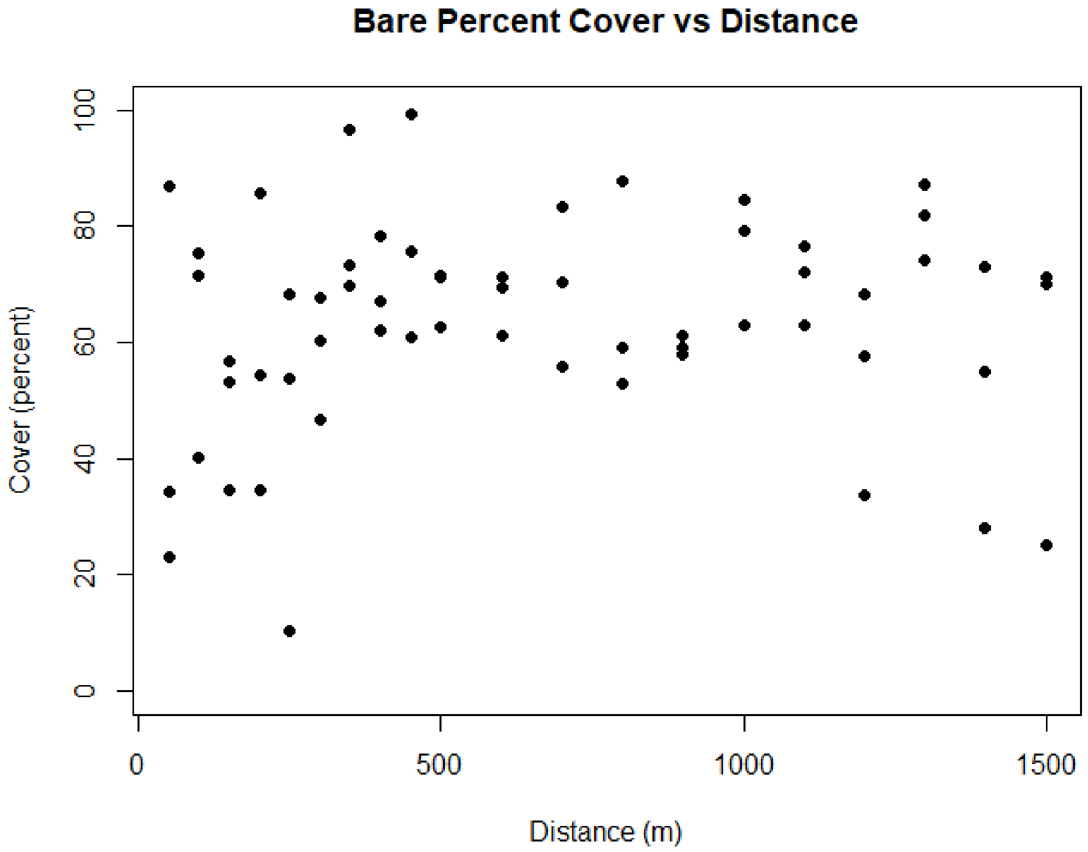

Figure 5. Relationship of distance from water source and percent bare cover using vegetation cover data from all three pastures. Dots represent total percent bare cover at that particular distance from water source for all three pastures. The relationship was obtained with regression analysis. The trend was insignificant due to p = 0.10.

On the contrary, the effect of grazing intensity on bare ground cover was insignificant (p = 0.10) (Figure 5). I expected grazing intensity to increase bare cover leading to higher bare cover close to the water source. Vegetation and soil variability could be contributing to the unexpected results. With opposite trends in shrub and grass cover, this outcome is plausible.

Soil Organic Carbon

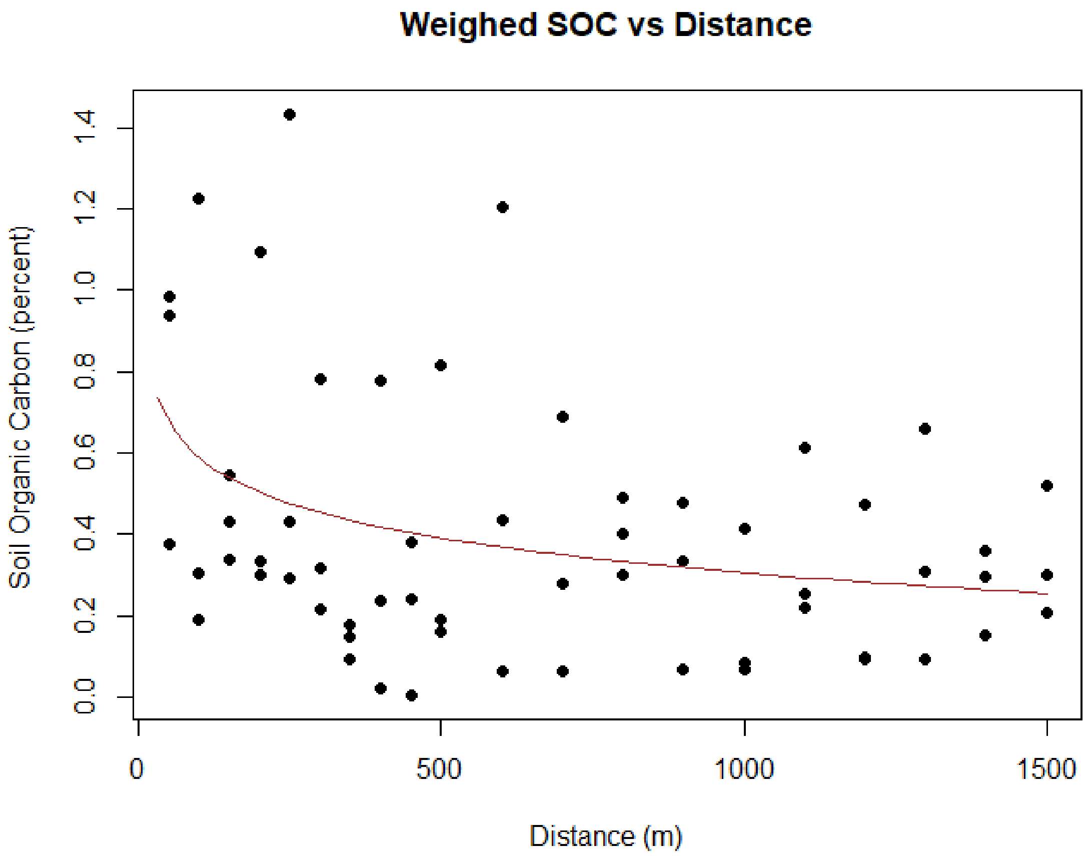

Figure 6. Relationship of distance from water source and weighted SOC using vegetation cover data and SOC data from all three pastures in the equation $C_{Ln} = (C_{BLn} * \%\ Cover_{BLn}) + (C_{G*Ln} * \%\ Cover_{GLn}) + (C_{S*Ln} * \%\ Cover_{SLn})$. SOC is in percent of C(mg) per mg of soil. Dots represent one input from the equation used to calculate the weighted average at that particular distance from water source for all three pastures. The relationship was obtained with regression analysis. The black line represents the line of best fit ($y = \log(-0.12x) + 1.16$) with $R^2 = 0.13$. The trend was significant due to $p = 0.0053$.

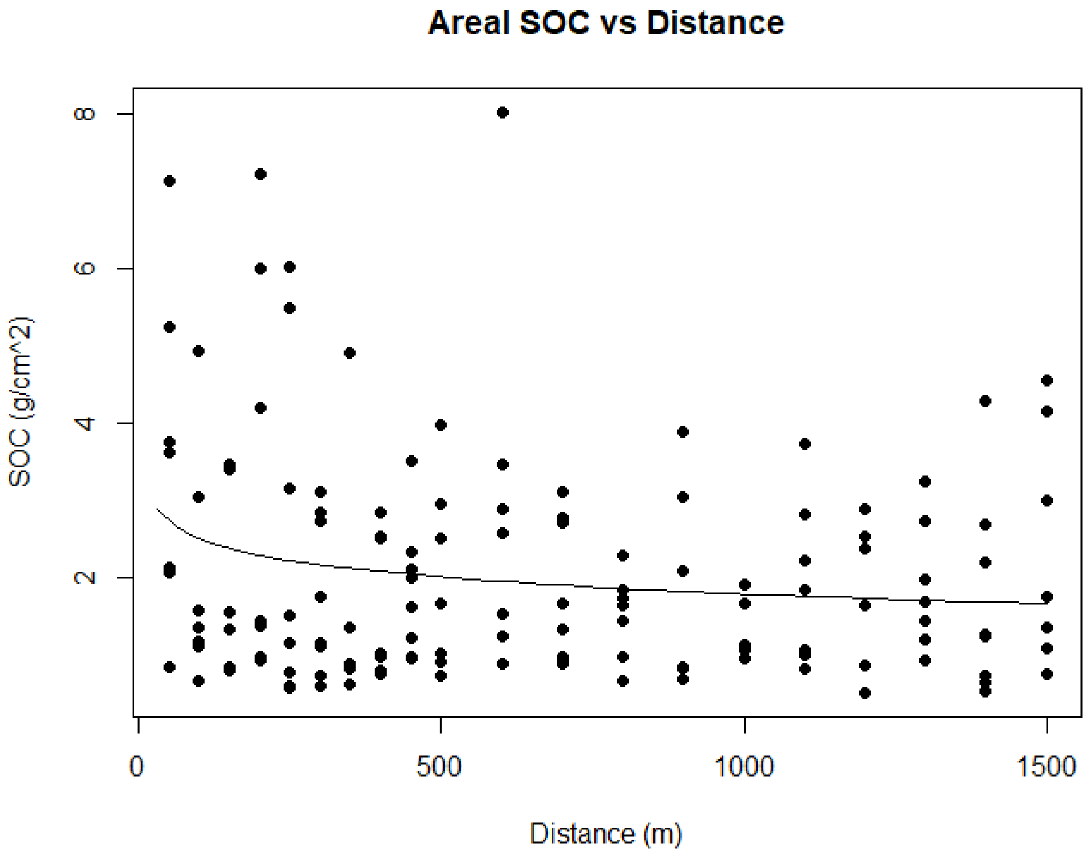

Figure 7. Relationship of distance from water source and areal SOC using SOC data from all three pastures. Dots represent analysis of one soil core from equation used to calculate the weighted average at that particular distance from water source for all three pastures. The relationship was obtained with regression analysis. The black line represents the line of best fit ($y = \log(-0.31x) + 3.95$) with $R^2 = 0.032$. The trend was significant due to $p = 0.018$.

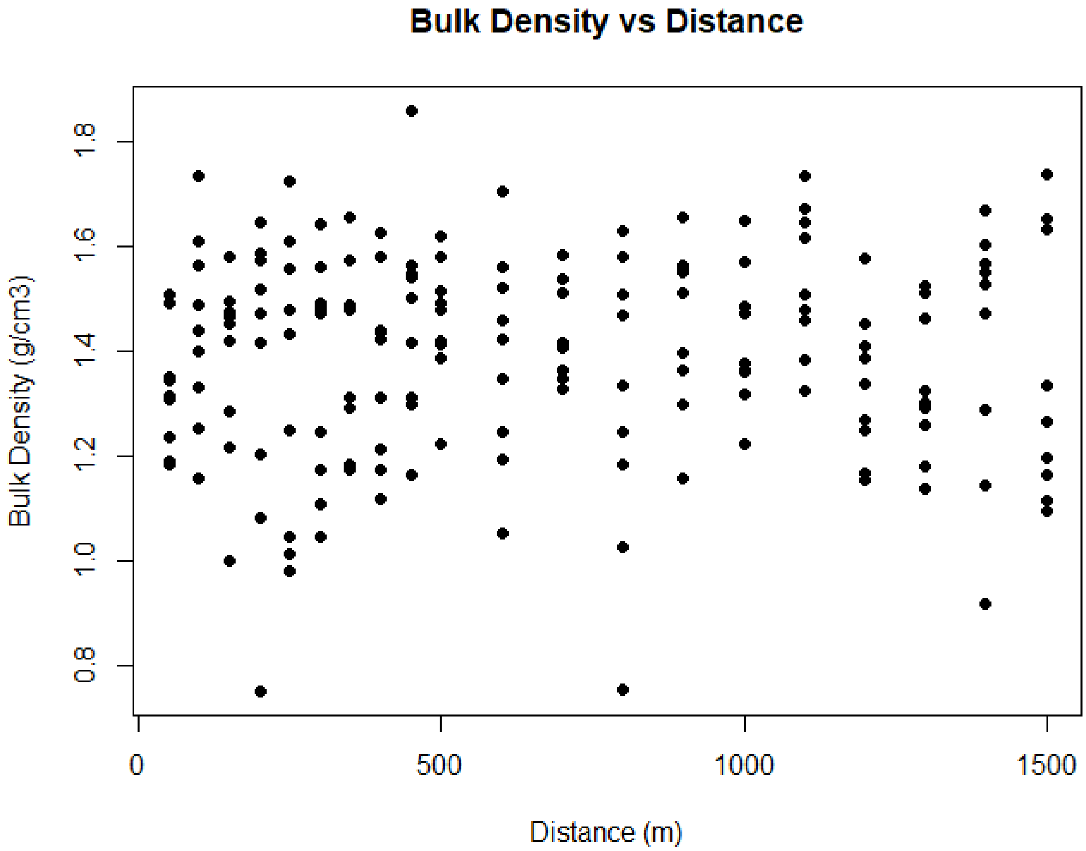

Figure 8. Relationship of distance from water source and bulk density of soil from all pastures. Dots represent the measured bulk density of each soil core extracted. The relationship was obtained with regression analysis. No significant trend was found due to $p = 0.78$.

Addressing my first hypothesis regarding a deposition of organic matter, I found a significant ($p < 0.01$) influence of grazing intensity on percent SOC values that follows a log pattern (Figure 6). Highest percent SOC values exist in areas closer to the water source while lowest percent SOC values exist farthest from the water source. While considering total vegetation cover (figure 4) as well as SOC values peaking in areas with closest proximity to water sources, my results suggest that SOC is in fact being deposited toward water sources. On the contrary, grazing intensity had no effect ($p > 0.05$) on areal SOC values (Figure 7). Lastly, grazing intensity also had no effect ($p > 0.05$) on bulk density measurements. Although the areal SOC boasts a higher sample size due to plotting each soil sample individually rather than combining them all as one data point, but it is still insignificant. Grazing is also known to compact soil, thereby increasing bulk density values (Franzluebbers and Stuedemann, 2008). Soil that is impacted will occupy less volume, but maintain its mass which could in turn skew percent SOC values (Throop, Archer, Monger, & Waltman, 2012).

Discussion

My results support the idea that that grazing intensity impacts arid rangeland vegetation and SOC. The source of SOC is from C fixation by plants, so changes in vegetation cover directly affect C fixation rates, potentially altering SOC values indirectly. My results show a decrease in shrub cover (Figure 3), increase in grass cover (Figure 2), and decrease in total vegetation cover (Figure 4) from distance to water source. This change in vegetation cover leads to a decrease in C fixation, which would likely then affect SOC values. Total vegetation cover, SIC, and SOC constitute the bulk of terrestrial C pools, making them common measurement tools for C stocks. Global inorganic soil carbon pools are found to be about half the size of organic carbon pools (Plaza-Bonilla et al., 2015). Arid regions in particular have high IC activity that significantly contribute to terrestrial C pools, possibly even more so than OC (Plaza-Bonilla et al., 2015)With the longer turnover rates that most SOC pools experience, any change in the size of these pools could have longer lasting impacts on atmospheric C. This makes understanding impacts of C pools in rangelands, especially arid and semi-arid rangelands that experience shifts in dominant vegetation, of pivotal importance (Schuman et al., 2002).

Although areal SOC values offer a better estimate of ecosystem level SOC stocks, my results show no significant difference in areal SOC (g/cm^2) at the locations sampled (Figure 7). Grazing has the potential to compact soil, leading to altered SOC (g/g) values (Throop et al., 2012). For example, if a study measures the top 5cm of heavily trampled soil is analyzed for SOC, it could effectively be measuring 6cm of soil leading to a 20% increase in SOC value. My data, however, suggests no change in bulk density in soil closer to water source (Figure 8). My weighed SOC values (Figure 6) measurements, however, still have important conclusions. Grass cover increases while shrub cover decreases significantly over decreasing grazing intensity. Soil around grass and shrub cover have different SOC amounts attached to them. Areal SOC amounts could then be dependent on how cover types change because of this, though my data did not find any evidence supporting this. Data from my weighted SOC measurements support my first hypothesis regarding deposition of SOC via grazing patterns. With higher SOC closer to water sources, it is likely this is due to redistribution of organic material deriving from grasses found farther away from the water sources. However, it is also possible that the higher total vegetation cover is also contributing to these SOC values close to the water source.

I found total vegetation cover to be higher in areas experiencing a higher grazing intensity near water sources, though the majority of this consisted of shrub cover (Figure 3). This conclusion also supports my hypothesis addressing an interaction between ANPP and C fixation rates. Areas with higher total vegetation cover close to the water source also exhibit higher SOC values.

Additionally, I supported past experiments conclusions that higher grazing intensity increases shrub cover, but decreases grass cover (Meglioli et al., 2017; Tessema, de Boer, Baars, & Prins, 2011). Bare soil in these studies, however, also increases at higher grazing intensities, which my results neither supported or rejected. This is likely due a combination of opposite trends of grass and shrub cover that could keep bare cover relatively steady as well as high variability within each site. Nonetheless, changes in vegetation cover leads to altered C fixation rates and thus, inputs of C into SOC pools. I measured higher vegetation cover and SOC close to water sources.

Lastly, grazing intensity has been shown to both increase SOC near water sources, but decrease total SOC stocks (Larreguy, Carrera, & Bertiller, 2014; Meglioli et al., 2017; Smet & Ward, 2006), which my results partially support. I did find increased percent SOC values close to water sources, but found insignificant effects on areal SOC. This is surprising as there is ample evidence for high grazing intensity to decrease SOC. However, it is plausible that my results suggest lower total SOC values due to a significant decrease in total vegetation cover.

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APPENDIX A

VEGETATION COVER

These data represent plant vegetation cover along three transects radiating outward from a pasture's water source in Jornada Experimental Range in Las Cruces, New Mexico, USA. Data was collected at HQ well, pasture 12A (32.618718, -106.739971), MI well, pasture 12C (32.690968, -106.786900), and TA well, pasture 15 (32.575205, -106.672896). Transects were NW in TA and HQ wells, and SE in MI well. These transects are 1500m in length, and were sampled at 50m increments (beginning at 50m) along the first 500m, then 100m increments for the remaining 1000m starting at XXm. The line point intercept method was used at each sample point (50, 100, 150 etc.) and labeled as such in the column "*Line*", for a total of 20 vegetation cover lines on each transect.

Each vegetation cover line (30m in length) is perpendicular to the larger 1500m transect line. Every 10cm along the line, cover type was determined as bare soil (B), grass (G), forb (F) and shrub (S) as the possible cover types. Every 10cm, the vegetation cover type is determined, and the distance along the 30m cover line is recorded (cm) under the column "*total_length*". If multiple sequential increments of 10cm are the same cover type, they are combined. For example, if grass cover persists consistently for the first 100cm of the cover line, it is recorded once at 100cm, rather than every 10cm.

The actual cover type (B, G, F, S) was also recorded in the adjacent column labeled "*Cover*." It is possible for a location on cover lines to experience multiple, overlapping vegetation cover types. It is important to note that the number in the same row as the cover type in the "*total_length*".

These values were recorded in the field by hand. Whenever the cover type changed, the duration and type of the new cover was recorded in cm. The data was then entered into a CSV file compatible with R, which is where percent cover was then calculated.

tran	Distance (m)	cover	total_length (cm)
HQ	50	B	1030
HQ	50	G	100
HQ	50	S	1870
HQ	100	B	1210
HQ	100	S	1790
HQ	150	B	1700
HQ	150	F	20
HQ	150	S	1280
HQ	200	B	2570
HQ	200	F	30
HQ	200	G	60
HQ	200	S	340
HQ	250	B	1610
HQ	250	F	40
HQ	250	G	10
HQ	250	S	1340
HQ	300	B	2030
HQ	300	F	50
HQ	300	G	50
HQ	300	S	870
HQ	350	B	2200
HQ	350	F	110
HQ	350	G	50
HQ	350	S	640
HQ	400	B	2010
HQ	400	F	90
HQ	400	G	30
HQ	400	S	870
HQ	450	B	2270
HQ	450	F	110
HQ	450	G	310
HQ	450	S	310
HQ	500	B	2150
HQ	500	F	200

HQ	500	G	170
HQ	500	S	480
HQ	600	B	2080
HQ	600	F	130
HQ	600	G	50
HQ	600	S	740
HQ	700	B	2110
HQ	700	F	40
HQ	700	G	370
HQ	700	S	480
HQ	800	B	1590
HQ	800	F	50
HQ	800	G	600
HQ	800	S	760
HQ	900	B	1740
HQ	900	F	160
HQ	900	G	1090
HQ	900	S	10
HQ	1000	B	2540
HQ	1000	F	100
HQ	1000	G	140
HQ	1000	S	220
HQ	1100	B	1890
HQ	1100	F	140
HQ	1100	G	760
HQ	1100	S	210
HQ	1200	B	1010
HQ	1200	F	190
HQ	1200	G	1720
HQ	1200	S	80
HQ	1300	B	2460
HQ	1300	F	80
HQ	1300	G	170
HQ	1300	S	290
HQ	1400	B	2190
HQ	1400	F	100
HQ	1400	G	350
HQ	1400	S	360
HQ	1500	B	2100
HQ	1500	F	90
HQ	1500	G	360
HQ	1500	S	450
MI	50	B	2610

MI	50	G	200
MI	50	S	190
MI	100	B	2150
MI	100	F	10
MI	100	G	120
MI	100	S	720
MI	150	B	1600
MI	150	F	10
MI	150	G	90
MI	150	S	1300
MI	200	B	1630
MI	200	G	200
MI	200	S	1170
MI	250	B	2050
MI	250	F	40
MI	250	G	270
MI	250	S	640
MI	300	B	1810
MI	300	F	240
MI	300	G	240
MI	300	S	710
MI	350	B	2090
MI	350	F	210
MI	350	G	90
MI	350	S	610
MI	400	B	1860
MI	400	F	110
MI	400	G	350
MI	400	S	680
MI	450	B	1830
MI	450	F	70
MI	450	G	470
MI	450	S	630
MI	500	B	1880
MI	500	F	300
MI	500	G	330
MI	500	S	490
MI	600	B	1840
MI	600	F	80
MI	600	G	100
MI	600	S	980
MI	700	B	1680
MI	700	F	140

MI	700	G	500
MI	700	S	680
MI	800	B	1770
MI	800	F	200
MI	800	G	430
MI	800	S	600
MI	900	B	1770
MI	900	F	160
MI	900	G	470
MI	900	S	600
MI	1000	B	1890
MI	1000	F	230
MI	1000	G	230
MI	1000	S	650
MI	1100	B	2160
MI	1100	F	140
MI	1100	G	70
MI	1100	S	630
MI	1200	B	1730
MI	1200	F	130
MI	1200	G	420
MI	1200	S	720
MI	1300	B	2230
MI	1300	F	130
MI	1300	G	510
MI	1300	S	130
MI	1400	B	1650
MI	1400	F	250
MI	1400	G	690
MI	1400	S	410
MI	1500	B	2140
MI	1500	F	230
MI	1500	G	220
MI	1500	S	410
TA	50	B	690
TA	50	F	10
TA	50	G	660
TA	50	S	1640
TA	100	B	2260
TA	100	G	340
TA	100	S	400
TA	150	B	1040
TA	150	G	780

TA	150	S	1180
TA	200	B	1040
TA	200	F	20
TA	200	G	1120
TA	200	S	820
TA	250	B	310
TA	250	F	50
TA	250	G	1990
TA	250	S	650
TA	300	B	1400
TA	300	G	1310
TA	300	S	290
TA	350	B	2900
TA	350	G	30
TA	350	S	70
TA	400	B	2350
TA	400	G	250
TA	400	S	400
TA	450	B	2980
TA	450	G	20
TA	500	B	2140
TA	500	S	860
TA	600	B	2140
TA	600	G	250
TA	600	S	610
TA	700	B	2500
TA	700	G	400
TA	700	S	100
TA	800	B	2630
TA	800	S	370
TA	900	B	1840
TA	900	G	940
TA	900	S	220
TA	1000	B	2380
TA	1000	G	10
TA	1000	S	610
TA	1100	B	2300
TA	1100	G	240
TA	1100	S	460
TA	1200	B	2050
TA	1200	G	610
TA	1200	S	340
TA	1300	B	2620

TA	1300	G	90
TA	1300	S	290
TA	1400	B	840
TA	1400	F	10
TA	1400	G	1780
TA	1400	S	370
TA	1500	B	750
TA	1500	G	2250

APPENDIX B

SOIL DATA: CHN OUTPUT AND BULK DENSITY MEASUREMENTS

These data represent outputs from CHN analysis of soil samples collected at Jornada Experimental Range near Las Cruces, NM in July and August of 2016 using a CHN PE-2400. Data was collected at HQ well, pasture 12A (32.618718, -106.739971), MI well, pasture 12C (32.690968, -106.786900), and TA well, pasture 15 (32.575205, -106.672896). These samples were collected with the intent of measuring soil bulk density (BD) (g/cm^3) and soil organic carbon (SOC) (g/g and g/cm^2), then ultimately analyze the effects of grazing intensity on SOC stocks.

Soil cores with a 5.75cm diameter were collected to a depth of 5cm from three pastures named after their corresponding wells: Headquarters (HQ), Middle (MI) and Taylor (TA). At each pasture, a transect was established originating at the pasture's well radiating outward for 1500m. Transects were NW in TA and HQ wells, and SE in MI well. Sample locations along these 1500m transects begin 50m from the well, with 50m increments up until 500m, when they are 100m apart for a total of 20 sample locations. At each sample location three cores were extracted of soil corresponding to the three dominate soil cover types of shrub (S), bare soil (B) and grass (G). This equals 60 samples per transect, and 180 samples total. Not every sample location, however, contained all three cover types (recorded with NA).

The first column titled "well" documents the pasture that the sample was collected from. "Distance _m" represents the sample location, or distance from the well for each soil core in meters. "Veg" represents the cover type of that particular sample (S, B, or G).

The next five columns are data that was collected in the lab. "Weight_mg" is the mass of the subsample (mg) that was ran with the CHN analyzer. This was used to find the values of the next three columns. “carbon”, “nitrogen”, and “hydrogen” are all outputs from the CHN PE-2400 machine which are expressed as % of the soil weight. These are expressed in percent by weight (g/g), calculated from the previous “Weight” column. The last column titled “bd” is the bulk density that was measured previously. The column labeled “percent” is percent of vegetation cover that was transferred from the “2016_JER_VegCover_Stacked” file.

The “carbon” and “bd” columns are used in making calculations and creating figures for the thesis (figures 6 and 7). Bulk density (g/cm^3) was used to convert the C data (%) to areal SOC (g/m^2).

well	Distance (m)	veg	Weight (mg)	C (mg)	N (mg)	Bd (g/cm3)	Cover (%)
HQ	50	B	29.798	0.19	0.07	1.4928	34.3333333
HQ	50	G	29.359	0.5961	0.0559	1.1908	3.33333333
HQ	50	S	30.134	0.47	0.06	1.5084	62.3333333
HQ	100	B	29.15	0.235	0.0274	1.7347	40.3333333
HQ	100	G	NA	NA	NA	1.6112	NA
HQ	100	S	30.587	0.35	26.87	1.4895	59.6666667
HQ	150	B	30.763	0.18	0.02	1.4653	56.6666667
HQ	150	G	30.453	0.19	11.8	1.4956	NA
HQ	150	S	29.894	0.77	0.07	1.4762	42.6666667

HQ	200	B	29.66	0.3	0.03	1.6466	85.6666667
HQ	200	G	30.513	0.211	0.0238	1.5193	2
HQ	200	S	29.827	0.33	1.03	1.4182	11.3333333
HQ	250	B	29.218	0.12	0.01	1.7271	53.6666667
HQ	250	G	29.111	0.128	0.018	1.5599	0.33333333
HQ	250	S	30.726	0.8231	0.075	1.2494	44.6666667
HQ	300	B	30.033	0.2505	0.0278	1.5623	67.6666667
HQ	300	G	30.027	0.2	0.02	1.2467	1.66666667
HQ	300	S	29.28	0.14	0.04	1.4728	29
HQ	350	B	30.719	0.1974	0.0271	1.4812	73.3333333
HQ	350	G	30.681	0.21	0.03	1.3115	1.66666667
HQ	350	S	NA	NA	NA	1.4832	21.3333333
HQ	400	B	29.353	0.2456	0.0316	1.424	67
HQ	400	G	29.992	0.2043	0.0243	1.3128	1
HQ	400	S	29.698	0.2339	0.0304	1.4376	29
HQ	450	B	30.384	0.35	20.56	1.5433	75.6666667
HQ	450	G	29.025	0.8091	0.0928	1.5012	10.3333333
HQ	450	S	29.24	0.2958	0.0388	1.4163	10.3333333
HQ	500	B	29.451	0.17	0.02	1.4915	84.3333333
HQ	500	G	30.012	0.17	0.01	1.4803	0
HQ	500	S	30.503	0.2141	0.0582	1.4129	16

HQ	600	B	NA	NA	NA	1.3474	69.3333333
HQ	600	G	29.148	0.7	0.08	1.4238	1.66666667
HQ	600	S	29.584	0.21	0.02	1.4595	24.6666667
HQ	700	B	NA	NA	NA	1.4165	70.3333333
HQ	700	G	29.815	0.2016	0.0261	1.5137	12.3333333
HQ	700	S	29.904	0.2343	0.0318	1.3302	16
HQ	800	B	30.389	0.39	0.05	1.4686	53
HQ	800	G	30.395	0.3	0.03	0.7548	20
HQ	800	S	29.553	0.53	0.08	1.1843	25.3333333
HQ	900	B	NA	NA	NA	1.5119	58
HQ	900	G	30.435	0.18	0.07	1.5663	36.3333333
HQ	900	S	29.36	0.1734	0.0269	1.3638	0.33333333
HQ	1000	B	30.905	0.4506	0.0536	1.3784	84.6666667
HQ	1000	G	29.046	0.2847	0.0378	1.3614	4.66666667
HQ	1000	S	30.432	0.2529	0.0325	1.4854	7.33333333
HQ	1100	B	30.965	0.23	0.03	1.4613	63
HQ	1100	G	29.674	0.24	12.38	1.5099	25.3333333
HQ	1100	S	29.785	0.21	0.03	1.3245	7
HQ	1200	B	NA	NA	NA	1.4097	33.6666667
HQ	1200	G	30.386	0.1485	0.0212	1.1561	57.3333333
HQ	1200	S	30.043	0.22	0.02	1.3387	2.66666667

HQ	1300	B	30.033	0.31	25.15	1.2927	82
HQ	1300	G	30.555	0.24	0.03	1.3019	5.66666667
HQ	1300	S	29.929	0.43	51.49	1.1381	9.66666667
HQ	1400	B	29.238	0.16	0.02	1.6059	73
HQ	1400	G	30.62	0.1387	0.0183	1.551	11.6666667
HQ	1400	S	30.579	0.1588	0.0221	1.1441	12
HQ	1500	B	29.925	0.49	0.06	1.1989	70
HQ	1500	G	29.254	0.35	1.04	1.3362	12
HQ	1500	S	30.146	0.9084	0.1026	1.0964	15
MI	50	B	29.706	0.91	72.01	1.3455	87
MI	50	G	30.678	1.3	33.13	1.316	6.66666667
MI	50	S	30.703	0.91	3.15	1.3507	6.33333333
MI	100	B	30.294	0.2587	0.027	1.4389	71.6666667
MI	100	G	30.802	0.14	0.02	1.5655	4
MI	100	S	NA	NA	NA	1.401	24
MI	150	B	29.642	0.37	0.04	1.4205	53.3333333
MI	150	G	30.534	0.1759	0.0239	1.5817	3
MI	150	S	29.933	0.31	0.03	1.455	43.3333333
MI	200	B	29.742	0.2038	0.0239	1.5742	54.3333333
MI	200	G	30.26	1.5076	0.1304	1.5864	6.66666667
MI	200	S	30.362	0.31	0.04	1.4717	39

MI	250	B	29.726	0.32	0.03	1.6105	68.3333333
MI	250	G	30.22	0.18	0.02	1.4332	9
MI	250	S	30.091	0.26	0.03	1.4782	21.3333333
MI	300	B	29.357	0.2318	0.0252	1.6437	60.3333333
MI	300	G	29.844	0.4	0.04	1.4839	8
MI	300	S	30.956	0.6157	0.0546	1.4945	23.6666667
MI	350	B	NA	NA	NA	1.5735	69.6666667
MI	350	G	29.614	1	55.33	1.6579	3
MI	350	S	29.515	0.31	0.03	1.489	20.3333333
MI	400	B	NA	NA	NA	1.6281	62
MI	400	G	29.317	0.1655	0.0201	1.5822	11.6666667
MI	400	S	NA	NA	NA	1.4421	22.6666667
MI	450	B	30.859	0.17	0.02	1.8607	61
MI	450	G	30.005	0.21	0.03	1.5657	15.6666667
MI	450	S	30.248	0.5	0.05	1.5479	21
MI	500	B	NA	NA	NA	1.5822	62.6666667
MI	500	G	29.323	0.23	0.03	1.5167	11
MI	500	S	29.573	0.82	0.08	1.2246	16.3333333
MI	600	B	29.753	0.57	47.58	1.5211	61.3333333
MI	600	G	29.668	0.27	0.03	1.5629	3.33333333
MI	600	S	30.82	0.24	0.03	1.7073	32.6666667

MI	700	B	29.904	0.29	36.89	1.5395	56
MI	700	G	30.986	0.2	0.02	1.5831	16.6666667
MI	700	S	29.223	0.3714	0.0392	1.5387	22.6666667
MI	800	B	29.109	0.35	37.48	1.6291	59
MI	800	G	29.476	0.22	0.03	1.5103	14.3333333
MI	800	S	30.519	0.3	0.03	1.5814	20
MI	900	B	29.828	0.18	0.02	1.5626	59
MI	900	G	30.091	0.45	0.05	1.5524	15.6666667
MI	900	S	29.809	0.79	77.75	1.6553	20
MI	1000	B	NA	NA	NA	1.6493	63
MI	1000	G	29.551	0.23	0.02	1.5705	7.66666667
MI	1000	S	30.028	0.22	0.02	1.4748	21.6666667
MI	1100	B	31.011	0.1998	0.0219	1.6463	72
MI	1100	G	30.117	0.68	18.64	1.3854	2.33333333
MI	1100	S	29.385	0.44	0.04	1.7341	21
MI	1200	B	29.622	0.51	43.79	1.5784	57.6666667
MI	1200	G	29.611	0.62	0.05	1.3883	14
MI	1200	S	30.126	0.38	0.04	1.4549	24
MI	1300	B	NA	NA	NA	1.5118	74.3333333
MI	1300	G	29.121	0.4431	0.0451	1.325	17
MI	1300	S	30.383	0.43	0.04	1.5272	4.33333333

MI	1400	B	29.046	0.2808	0.0253	1.5299	55
MI	1400	G	29.946	0.29	0.11	1.4721	23
MI	1400	S	29.481	0.55	15.83	1.6701	13.6666667
MI	1500	B	29.911	0.2205	NA	1.6541	71.3333333
MI	1500	G	29.703	0.16	0.01	1.6336	7.33333333
MI	1500	S	29.925	0.2642	0.0277	1.74	13.6666667
TA	50	B	NA	NA	NA	1.2386	23
TA	50	G	NA	NA	NA	1.1858	22
TA	50	S	30.297	1.8	0.21	1.308	54.6666667
TA	100	B	29.842	1.43	80.59	1.1584	75.3333333
TA	100	G	29.325	0.35	0.04	1.3337	11.3333333
TA	100	S	29.748	0.82	32.24	1.2543	13.3333333
TA	150	B	30.678	0.88	0.11	1.2853	34.6666667
TA	150	G	30.592	0.92	0.11	1.2166	26
TA	150	S	NA	NA	NA	1.0027	39.3333333
TA	200	B	30.926	1.13	43.15	1.2048	34.6666667
TA	200	G	29.417	1.88	27.05	1.0847	37.3333333
TA	200	S	NA	NA	NA	0.7523	27.3333333
TA	250	B	30.697	2	0.22	0.9826	10.3333333
TA	250	G	29.24	1.85	0.22	1.0141	66.3333333
TA	250	S	NA	NA	NA	1.0489	21.6666667

TA	300	B	30.176	0.88	0.1	1.1743	46.6666667
TA	300	G	29.151	0.85	0.11	1.1094	43.6666667
TA	300	S	NA	NA	NA	1.0473	9.66666667
TA	350	B	29.656	0.18	2.85	1.1739	96.6666667
TA	350	G	29.233	0.22	0.03	1.2942	1
TA	350	S	NA	NA	NA	1.1852	2.33333333
TA	400	B	29.736	0.79	48.22	1.2136	78.3333333
TA	400	G	30.013	0.75	0.08	1.1181	8.33333333
TA	400	S	29.625	0.73	0.29	1.1735	13.3333333
TA	450	B	NA	NA	NA	1.1637	99.3333333
TA	450	G	29.708	0.52	8.29	1.2985	0.66666667
TA	450	S	29.283	0.55	47.11	1.3118	NA
TA	500	B	29.29	0.98	52.48	1.388	71.3333333
TA	500	G	29.341	0.53	62.54	1.621	NA
TA	500	S	29.484	0.4	30.93	1.4214	28.6666667
TA	600	B	30.345	0.92	0.12	1.2467	71.3333333
TA	600	G	30.23	0.43	0.06	1.1938	8.33333333
TA	600	S	30.202	2.52	0.27	1.0552	20.3333333
TA	700	B	29.146	0.68	0.09	1.4078	83.3333333
TA	700	G	30.847	0.74	0.1	1.3657	13.3333333
TA	700	S	30.533	0.66	0.09	1.3489	3.33333333

TA	800	B	30.687	0.56	0.07	1.3356	87.6666667
TA	800	G	NA	NA	NA	1.2461	NA
TA	800	S	NA	NA	NA	1.0281	12.3333333
TA	900	B	30.197	0.78	3.7	1.2993	61.3333333
TA	900	G	NA	NA	NA	1.3966	31.3333333
TA	900	S	NA	NA	NA	1.1576	7.33333333
TA	1000	B	NA	NA	NA	1.2237	79.3333333
TA	1000	G	NA	NA	NA	1.3652	0.33333333
TA	1000	S	30.921	0.41	0.05	1.3182	20.3333333
TA	1100	B	29.457	0.76	0.86	1.6722	76.6666667
TA	1100	G	30.047	0.38	30.63	1.6182	8
TA	1100	S	NA	NA	NA	1.4784	15.3333333
TA	1200	B	NA	NA	NA	1.2713	68.3333333
TA	1200	G	NA	NA	NA	1.2491	20.3333333
TA	1200	S	29.427	0.84	0.09	1.1699	11.3333333
TA	1300	B	29.768	0.73	0.09	1.2601	87.3333333
TA	1300	G	29.684	0.75	67.12	1.4643	3
TA	1300	S	NA	NA	NA	1.1827	9.66666667
TA	1400	B	30.912	1.08	0.15	1.2899	28
TA	1400	G	NA	NA	NA	0.9203	59.3333333
TA	1400	S	30.584	0.46	0.05	1.5672	12.3333333

TA	1500	B	30.048	1.2	0.16	1.2661	25
TA	1500	G	NA	NA	NA	1.1638	75
TA	1500	S	30.026	1.24	0.15	1.1156	NA