VEGETATION CANOPY COVER EFFECTS ON SEDIMENT AND SALT LOADING IN THE UPPER COLORADO RIVER BASIN MANCOS SHALE, PRICE AND FERRON, UTAH

Erik Cadaret, Graduate Program of Hydrologic Sciences, Desert Research Institute, Division of Earth and Ecosystem Sciences, Reno, Nevada Erik.Cadaret@dri.edu; Robert Blank, Research Soil Scientist, United States Department of Agriculture, Agricultural Research Service, Reno, Nevada bob.blank@ars.usda.gov; Kenneth McGwire, Associate Research Professor, Desert Research Institute, Division of Earth and Ecosystem Sciences, Reno, Nevada Ken.McGwire@dri.edu; Sayjro K. Nouwakpo, Research Professor, University of Nevada Reno, Department of Natural Resources and Environmental Science, Reno, Nevada snouwakpo@cabnr.unr.edu; Colleen G. Rossi, Water Quality Salinity Specialist, Bureau of Land Management, Salt Lake City, Utah crossi@blm.gov; Mark Weltz, Rangeland Hydrologist and Research Leader, United States Department of Agriculture, Agricultural Research Service, Reno, Nevada mark.weltz@ars.usda.gov; Todd Adams, Rangeland Ecologist, University of Nevada Reno, Department of Natural Resources and Environmental Science, Reno, Nevada todd.adams@ars.usda.gov; Alice Boizet, University of Nevada Reno Summer 2014 Environmental Science Scholar, Montpellier SupAgro, Montpellier, France; Sandra Li, Biological Science Lab Technician, United States Department of Agriculture, Agricultural Research Service, Reno, Nevada sandra.li@ars.usda.gov; Tye Morgan, Biological Science Lab Technician (Soils), United States Department of Agriculture, Agricultural Research Service, Reno, Nevada tye.morgan@ars.usda.gov; Jacob Phillips, Biological Science Lab Technician (Soils), United States Department of Agriculture, Agricultural Research Service, Reno, Nevada

ABSTRACT: The Price River contributes only one percent of the water but three percent of the total dissolved solids in the Colorado River. To investigate mechanisms driving salinity loads in the Price River Basin we are focusing on saline and sodic soils associated with the Mancos Shale formation. Rainfall simulations have been performed at study areas across a variety of slope angle and rainfall intensity to evaluate the effects vegetation has on salinity and sediment concentration in runoff. A 6x2 meter, computer-controlled Walnut Gulch rainfall simulator was ran with rainfall event intensities derived from the NOAA ATLAS 14 precipitation database: 2 year (5.08 cm/hour), 10 year (8.89 cm//hour), 25 year (11.43 cm/hour), and 50 year (13.97 cm/hour) and each intensity was replicated three times at each site. For each simulated rainfall event, we measured the time-varying concentration of major cations (Calcium, Magnesium, Sodium, Potassium, and Ammonium) and anions (Chlorine, Sulfate, Nitrite, and Nitrate) in runoff. We also compare depth-varying soil chemistry in soil cores at vegetated and un-vegetated areas to identify the effects of plants on soil chemistry distribution. Results of these simulations will be used to parameterize the dynamic Rangeland Hydrology and Erosion Model (RHEM) for saline and sodic soils of the Price rangeland areas and to assess the feasibility of mitigation strategies for reducing salinity loads to the Colorado River.

INTRODUCTION

The Bureau of Land Management, USDA Agricultural Research Service, Bureau of Reclamation, and Desert Research Institute are investigating salinity contributions to the

Colorado River from saline and sodic soils of rangelands in the Colorado Plateau. Field sites in Price and Ferron, Utah were selected to perform rainfall simulations to measure the response of salinity and sediment loads with respect to vegetation canopy cover (Figure 1). It is suspected that vegetation canopy cover has a large effect on water erosion and runoff processes primarily because of rainfall interception (Wischmeier and Smith, 1978). Interception of rainfall by vegetation is a function of precipitation and canopy characteristics (Hamilton and Row, 1949; Slatyer, 1965; Navar and Bryan, 1990; Domingo et al., 1994). Vegetation interception reduces runoff volumes, and stemflow may promote deep infiltration in the soil directly beneath the canopy (Branson et al., 1972). At the beginning of a rainfall event, canopies efficiently intercept almost all rainfall within the area they project over the ground until a maximum is reached when the cumulative interception (through-fall, foliar drip, and stemflow) is equal to the amount of precipitation. The amount of time to reach maximum cumulative interception is dependent upon the type of plant and the rainfall intensity (Wood et al., 1998). Proportionally, rainfall lost to vegetation interception is most prominent under conditions of lower rainfall intensities and may strongly influence erosion rates under such conditions (Simanton et al., 1991). Vegetation-driven spatial heterogeneity (VDSH) explains the relationship between soil development and evolution processes between vegetation and interspace areas (Puigdefabregas, 2005). VDSH influences sheet runoff and concentrated flow processes that in turn influence rill and channel development, and thereby affect salinity and sediment loading along those flow paths (Wilcox et al., 1996; Davenport et al., 1998; Urgeghe et al., 2010). Rills and gullies are considered erodible sediment conveyors, transporting detached sediment downslope depending on VDSH and the detachment and conveyance hydraulic factors (Puigdefabregas, 2005; Al-Hamdan et al., 2012).

There are two goals for this project: (1) improve the understanding of sources and transport mechanisms of salinity and sediment loads into streams from rainfall induced runoff within the Upper Colorado River Basin (UCRB) and specifically in the Price River Basin and (2) parameterize our findings for vegetation canopy cover so they can be implemented into the Rangeland Hydrology Erosion Model (RHEM). We hypothesize that the amount of vegetation canopy cover has a strong influence on the salinity and sediment loading in runoff during a rainfall event due to reduced splash erosion, increased infiltration, and reduced flow velocity. To accomplish these goals and test our hypotheses, we conducted rainfall experiments with the Walnut Gulch rainfall simulator (WGRS) (Paige et al., 2004) using four rainfall intensities replicated three times at two different field sites differing in slope, geology, and vegetation canopy cover. This rainfall simulator was chosen to perform these experiments because of the long history of successful use to measure how rainfall affects runoff and erosion, transportability, and its computer controlled interface. Using the WGRS, we may conduct experiments that accurately simulate specified rainfall intensities, and in turn, measure representative runoff and erosion processes occurring at the plot scale (6x2 m). Ultimately, our experiments will produce meaningful data to incorporate into the RHEM model so it can be used as a management tool by determining how vegetation affects the surface hydrology and controls salinity in the UCRB.

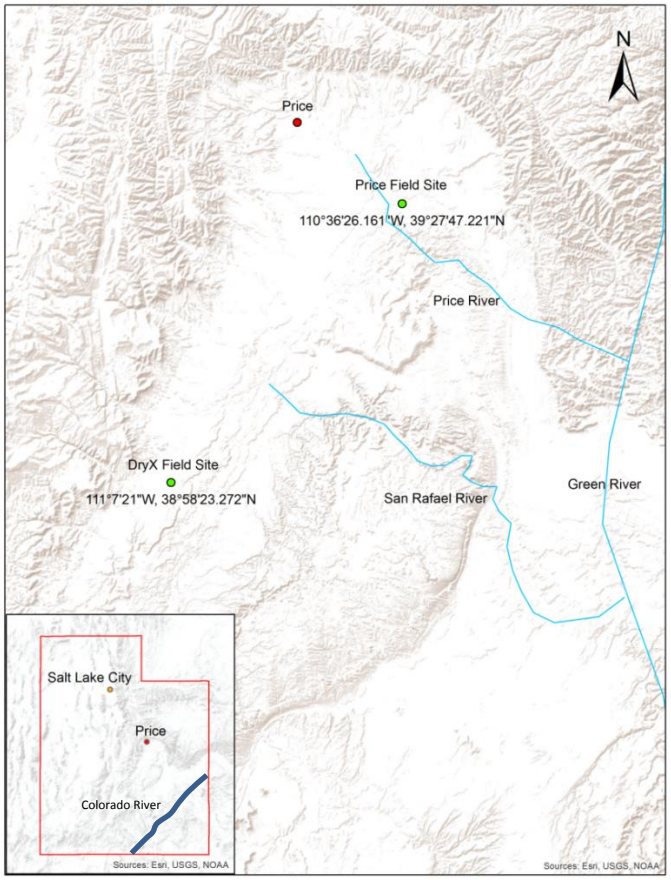

Figure 1 Map of field area in Price, Utah

MATERIALS AND METHODS

Location, Field Site Characteristics, and Experimental Design: The experimental sites were at Price (-110° 36' W, 39° 27' N) and Dry-X Ranch (-111° 7' 21" W, 38° 58' N) located in Utah. The Price field site contains well developed, light gray soil crusts surrounded by sparse vegetation on shallow grade slopes (0.6% - 10%). The vegetation at the site is comprised of halophytes that include a mixture of four shrubs (*Krascheninnikovia lanata*, *Chrysothamnus nauseosus*, *Atriplex gardneri*, *Ephedra viridis*), two subshrubs (*Eriogonum microthecum* & *Helianthella microcephala*), and three grass species (*Achnatherum hymenoides*, *Hilaria jamesii*, *Elymus elymoides*). The most predominant plant species were *Ephedra viridis*, *Atriplex gardneri*, and *Achnatherum hymenoides*. The Dry-X field site contains poorly developed, light-medium gray soil crusts surrounded by dense vegetation on steep grade slopes (11.4% - 24.5%). The vegetation at the site is solely comprised of salt tolerant shrub species *Atriplex Corrugata*. Both sites contained a marginal amount of cattle and antelope hoof impressions as they were a part of the natural landscape.

At both Price and Dry-X, 6x2 m rainfall simulation plots were installed and placed on the hillsides representative and NEPA approved for this study. The locations of each plot on the hillside were based upon where rills were already developed and would carry water down-gradient. Once the locations of each plot were determined, a Nikon NPR 352 total station was

used to make the borders square to one another. Metal stakes and construction string where then used to indicate where the 2x0.2 m steel plates are installed on the top and side borders. At the bottom of the plot, a flume was installed to channel runoff from the plot into the runoff collection pit. At each site, there were 5 types of plots: (1) control (no rainfall), (2) 2 year storm, (3) 10 year storm, (4) 25 year storm, and (5) 50 year storm. Each intensity, except for the controls, was replicated three times (Figure 2) resulting in 12 rainfall plots per site and 4 control plots per site.

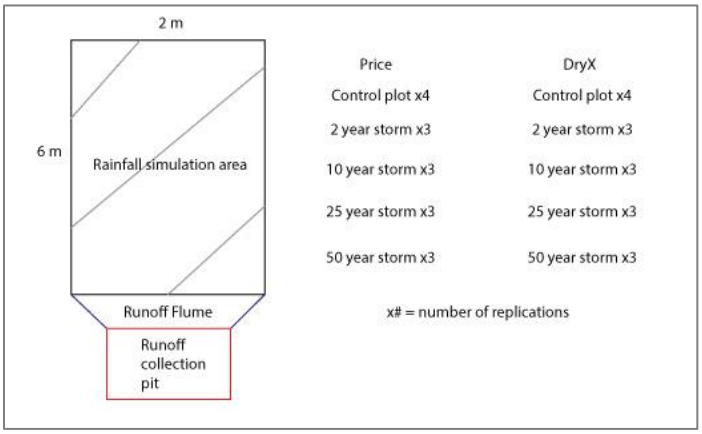

Figure 2 Rainfall plot design and types

Rainfall Simulations and Sampling Protocol: In this study, we used the WGRS that covers the 6x2 m plots. The WGRS was connected to a Husky 3785 L self-supporting onion tank using a series of water hoses and pumps. Intensities for our rainfall simulations were determined from 5 minute rainfall amounts reported in the NOAA Atlas14 point precipitation frequency estimates for the Price area.

Runoff was collected during each simulation using two different collection containers. The source water supply and runoff water quality samples were collected using VWR 50 mL centrifuge tubes. Runoff sediment samples were collected using 1 liter Nalgene bottles. Neither type of bottle was pretreated. The source water supply was sampled before each rainfall simulation was initiated. The same runoff sampling protocol was applied to each field site with the exception of the timing intervals. At Price, runoff was collected every 30 seconds for the first nine minutes and after the ninth minute, runoff was collected every minute until the end of the rainfall simulation. At Dry-X, runoff was collected every 30 seconds for the first three minutes and after the third minute, runoff was collected every 3 minutes until the end of the rainfall simulation. The timing interval was different at the two field sites because of the difference in vegetation cover and slope which influence runoff response timing. The runoff sediment samples were labeled and stored without refrigeration in plastic crates. The runoff water quality samples were para-filmed to reduce the chance of leakage and placed in large plastic Ziploc bags that were pre-labeled and stored inside coolers with dry ice in order to reduce subsequent bacterial reactions.

Samples of pre-rainfall soils were collected on the control plots using a standard hand shovel due to the lack of soil adhesion. Separate control plots were used to provide information on pre-simulation soil characteristics, since sampling in the rainfall plots prior to simulation would affect the flow and erosion. After rainfall simulations, soil samples were collected using an AMS

split soil core sampler with a 5 cm inside diameter. At each plot, soils were collected at three locations under the vegetation canopy and three interspace locations. Soil sample locations were quasi-randomly chosen by the field technician (Figure 3) in an area towards the middle portion of the plot to minimize the lateral flow affects that may occur near the plot borders. Soil samples were separated by depth increments into the surface crust (~0 cm), depth increment 1 (0-5 cm), and depth increment 2 (5-10 cm) (Figure 4). Finally, soil samples from each plot were aggregated by vegetation versus interspace for each depth increment, resulting in 6 composite samples per plot. The number of depth increments and the total depth to be collected was based on the wetting front from a test soil core taken from the first plot of each intensity. It was determined that two 5 cm depth increments were sufficient to capture the changes in soil moisture status during a rainfall event. We collected a total of 192 soil samples; 96 from Price and 96 from Dry-X.

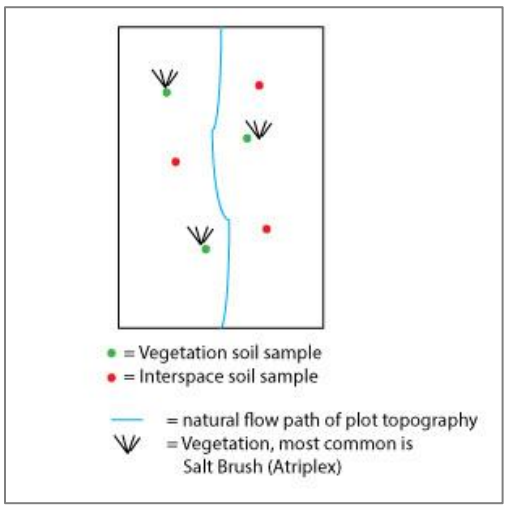

Figure 3 Aerial view of plot

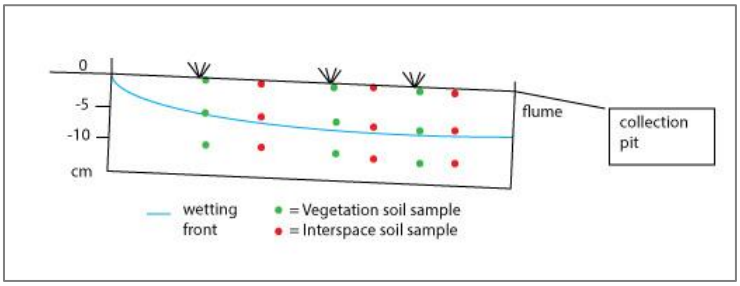

Figure 4 Profile view of plot

<u>Vegetation Canopy Cover:</u> A field technician took digital photographs spaced approximately 1 m apart all around the plot before and after the simulation. These digital images will be processed to planimetrically accurate orthophotographs and we will measure the distribution of canopy, litter, and bare soil. There was minimal detached litter, likely due to grazing on the site.

<u>Laboratory Processing:</u>

Water Chemistry

Runoff water quality samples were processed and measured at the USDA-ARS soils laboratory in Reno, NV. Price samples were centrifuged at 2000 rpm for three minutes to settle sediments and DryX samples were centrifuged at 5000 rpm for 5 minutes to settle sediments due to suspected high sodium concentrations. We measured the ions directly from the sample VWR 50 mL centrifuge tube. Major cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) were measured using a Perkin Elmer Atomic Absorption (AA) Spectrometer. Ammonium ($NH4^{+}$) was measured using a Lachat Quickchem FIA+ instrument. Major anions (NO_2^{-}, NO_3^{-}, SO_4^{2-}, Cl^{-}) were measured using a Dionex Ion Chromatograph (IC). Water pH and EC were measured in the lab using an Oakton pH Meter 510 Series and VWR Scientific EC Meter Model 2052, respectively.

Soil Chemical Content and Texture

Soil samples were processed using several different methods. The total pool of soluble phase ions from the soils was processed by performing immiscible displacement (ID) (Mubarak and Olsen, 1977). To get the total pool of available exchangeable cations from the soils (mineral phase cations), we performed ammonium acetate ($NH_4C_2H_3O_2$) extractions (Thomas, 1982). Ammonium and nitrate were processed from the soils by performing KCl extractions (Bundy and Meisinger, 1994). Cation exchange capacity (CEC) was measured according to methods of Bower et al. (1952). Major cations were measured on the AA; major anions were measured on the IC, and ammonium and CEC on the Lachat. Soil soluble phase ion solution produced by ID was measured for pH and EC using an Oakton pH Meter 510 Series and VWR Scientific EC Meter Model 2052, respectively. Soil texture was measured using methods of Jackson and Barak (2005).

<u>Data Analysis:</u>

Principal Component Analysis, T-tests, and Regression Analysis

Data analysis is currently underway. Principal Component Analysis will be used as a data exploration tool that will aid us to determine sources of variability across different categories of interest. Data distributions will be normalized to correct for severe skewness and substantial outliers will be investigated. Two-sample T-tests with unequal variances will be performed on the runoff and soil data to ascertain whether or not the following hypotheses are true:

1. Is there a significant difference between Price soils (μ1) and DryX soils (μ2)?

    i. H_o: The Price and DryX soils mean difference = 0

    b. Is there a significant difference between Price soils SAR (μ1) and DryX soils SAR (μ2) (SAR = sodium absorption ratio)?

    i. H_o: The Price and DryX soils SAR mean difference = 0

    c. Is there a significant difference between Price soils CEC (μ1) and DryX soils CEC (μ2) (CEC = cation exchange capacity)?

    i. H_o: The Price and DryX soils CEC mean difference = 0

2. Is there a significant difference between Price runoff (μ1) and DryX runoff (μ2)?

    a. Is there a significant difference between Price sediment load in Runoff (μ1) and DryX sediment load in Runoff (μ2) (Sediment load units = g/L)?

    i. H_o: The Price and DryX soils sediment load mean difference = 0

    b. Is there a significant difference between Price salinity load in runoff (μ1) and DryX salinity load in runoff (μ2) (Salinity load = total dissolved solids (mg/L))?

    i. H_o: The Price and DryX soils Salinity Load mean difference = 0

3. Is there a significant difference between vegetation soils (μ1) and interspace soils (μ2) at each site?

a. Is there a significant difference between vegetation soils sum of ions (μ1) and interspace soils sum of ions (μ2) at each site (Sum of ions (mg/L))?

i. H_o: The vegetation and interspace soils sum of ions mean difference = 0

4. Is there a significant difference between vegetation (μ1) and interspace soils sum of ions (μ2) with depth at each site (Sum of ions (mg/L))?

a. H_o: The vegetation and interspace soils mean difference = 0 at depth 1; 2; 3

We will conduct regression analyses of salinity concentration versus sediment concentration in runoff in order to evaluate if sediment concentration can be used as a proxy for salinity (TDS) when using the RHEM model.

1. By using sediment load (g/L) data, can sediment load be used as a proxy to reasonably estimate salinity load represented by TDS (mg/L)?

a. H_o: Slope of salinity load against sediment load is zero; m = 0

PRELIMINARY RESULTS

Figures 5-7 present the mean sodium absorption ratio (SAR) values at Price and Dry-X for the pre- and post-rainfall soil samples and the mean runoff sediment load.

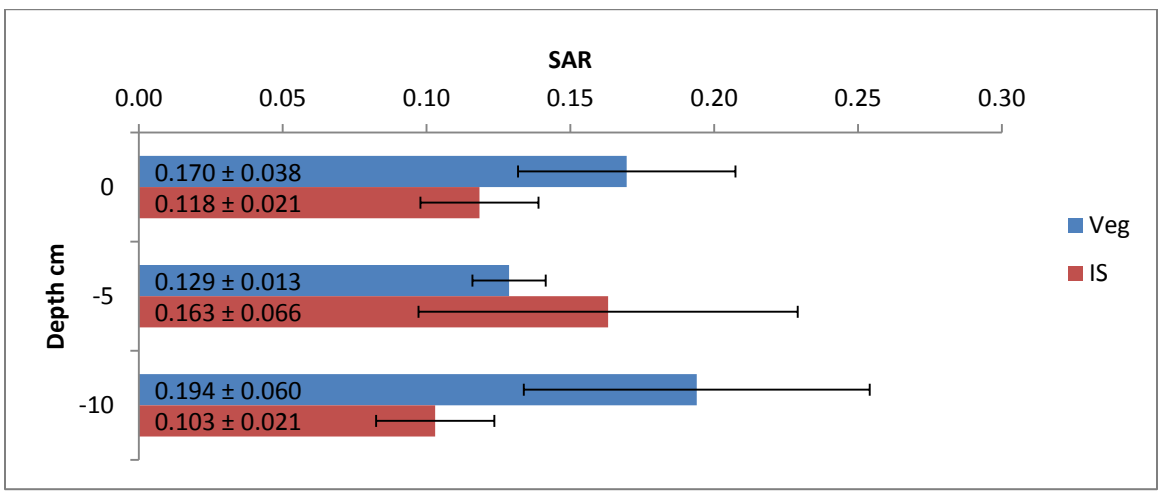

Figure 5 Price mean SAR ± standard error values with depth

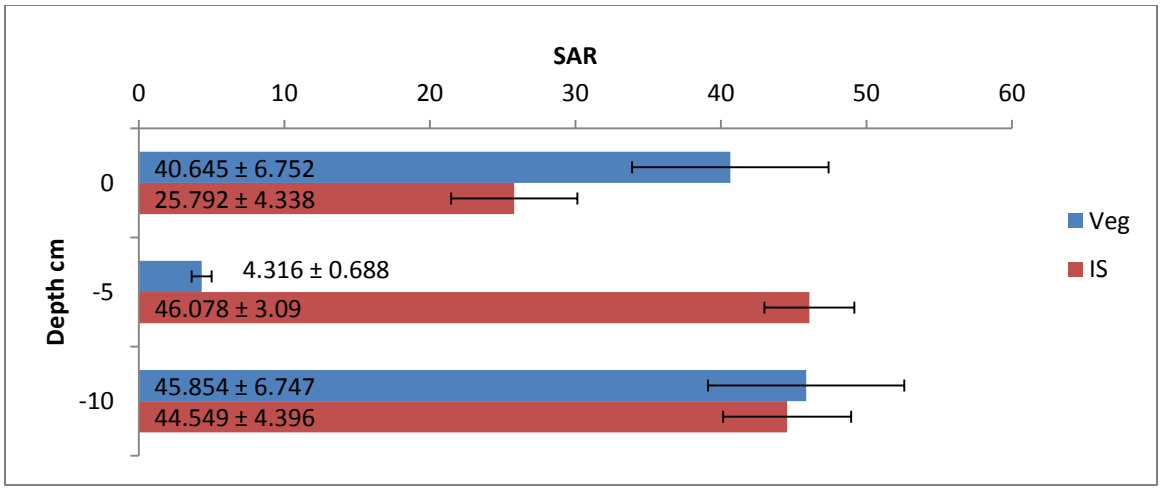

Figure 6 Dry-X mean SAR ± standard error values with depth

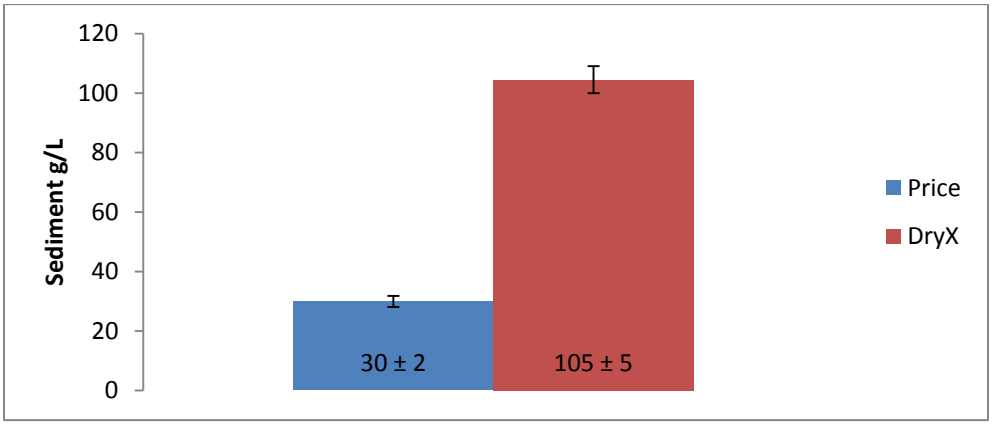

Figure 7 Mean sediment load ± standard error values at Price and Dry-X

The mean EC values at Price and Dry-X for the applied rainwater and runoff (Figure 8).

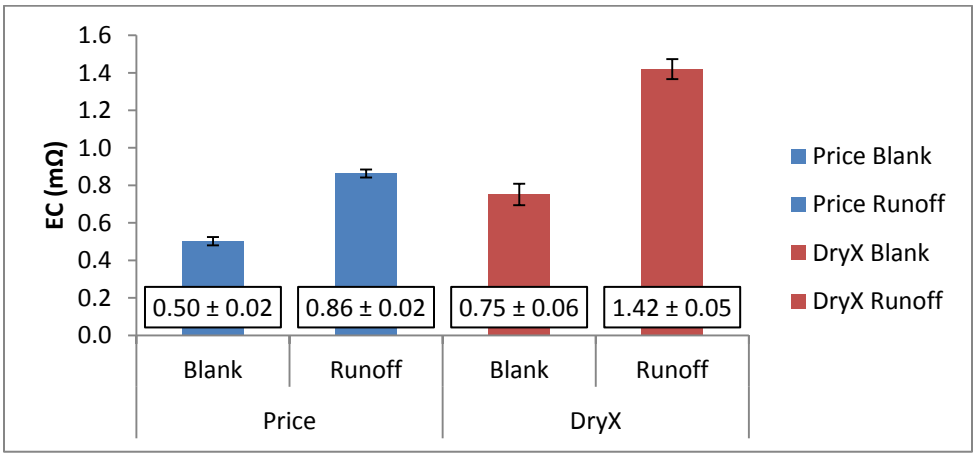

Figure 8 Mean EC ± standard error values for both Price and Dry-X

Price mean SAR values are < 1.0, indicating the soils have low dispersion (Figure 5). Almost all the Dry-X mean SAR values are substantially greater than 15.0 indicating the soils have high dispersion which indicates high erodibility (Figure 6). Price soils have substantially lower mean SAR values than Dry-X and indicate variation with depth, but there is no major difference between soil samples collected under the vegetation canopy (Veg) and those from the interspace soil (IS). Dry-X soils have substantially greater mean SAR values than Price and clearly present a decrease with depth at -5 cm for Veg. Dry-X mean sediment load and EC are much greater than Price (Figures 7 and 8). This may be a result of the level of soil dispersion and slope.

CONCLUSIONS

This study investigates vegetation canopy cover effects on salinity and sediment loading in runoff. Vegetation canopy cover may control salinity and sediment loads by rainfall interception and VDSH. Our data analysis will evaluate the complexity of interactions within our system and determine: 1) if sediment load may be used as a proxy for salinity load, 2) the sensitivity of vegetation canopy cover in RHEM, 3) the role of VSDH on salinity and sediment loading. Studies at these two sites which have substantial differences despite being from the same Mancos Shale formation will inform our understanding of the difficulties in applying the RHEM model to saline-sodic soils with variable vegetation canopy cover. Future results will help to prioritize improvements to the RHEM model and ultimately be used to assess mitigation strategies to reduce salinity loads into the Colorado River Basin.

REFERENCES

Al-Hamdan, O.Z., Pierson, F.B., Nearing, M.A., Williams, C.J., Stone, J.J., Kormos, P.R., Boll J., and Weltz, M.A. (2012). “Concentrated flow erodibility for physically based erosion models: temporal variability in disturbed and undisturbed rangelands”. Water Resources Research 48. Doi: 10.1029/2011wr011464.

Branson, F.A., Gifford, G.F., and Owen, J.R. (1972). Rangeland hydrology society for range management Denver, Colorado.

Bower, C.A., Reitemeier, R.F., and Fireman, M. (1952). “Exchangeable cation analysis of saline and alkali soils”. Soil Sci., 73, 251-261.

Bundy, L.G., and Meisinger, J.J. (1994). Nitrogen availability indices. In: Weaver, R.W., Angle, S., Bottomley, P., Bezdicek, D., Smith, S., Tabatabai, A., Wollum, A. (Eds.), Methods of Soil Analysis. Part 2. Microbiological and Biochemical Properties, Soil Science Society of America, Madison, WI, pp. 951–984.

Davenport, D.W., Breshears, D.D., Wilcox, B.P., and Allen, C.D. (1998). “Viewpoint: Sustainability of pinon-juniper ecosystems: A unifying perspective of soil erosion thresholds”. Journal of Range Management 51:231-240.

Domingo, F., Puigdefabregas, J., Moro, M.J., and Bellot, J. (1994). “Role of vegetation cover in the biogeochemical balances of a small afforested catchment in southeastern Spain”. Journal of Hydrology 159:275-289

Hamilton, E.L., and Row, P.B. (1949). “Rainfall interception by chaparral in California”

Jackson, M.L., and Barak, P. (2005). Soil chemical analysis: advanced course. UW-Madison Libraries Parallel Press.

Mubarak, A., and Olsen, R.A. (1977). A laboratory technique for appraising in situ salinity of soil. Soil Sci Soc Am J 41:1018–1020.

Navar, J., and Bryan, R. (1990). “Interception loss and rainfall redistribution by three semi-arid growing shrubs in northeastern Mexico”. Journal of Hydrology 115:51-63.

Paige, G.B., Stone, J.J., Smith, J.R., and Kennedy, J.R. (2004). “The walnut gulch rainfall simulator: a computer-controlled variable intensity rainfall simulator”. American society of agricultural engineers, 20(1), 25-31.

Puigdefabregas, J. (2005). “The role of vegetation patterns in structuring runoff and sediment fluxes in drylands”. Earth surface processes and landforms 30:133-147. Doi: 10.1002/esp.1181.

Simanton, J. R., Weltz, M. A., and Larsen, H. D. (1991). “Rangeland experiments to parameterize the water erosion prediction project model: vegetation canopy cover effects”. Journal of Range Management, 276-282.

Slatyer R. (1965). “Measurements of Precipitation Interception by an Arid Zone Plant Community (Acacia Aneura F. Muell)”, Unesco Arid Zone Research, Vol. 25, pp 181-192, 1956, 7 Fig, 2 Tab, 13 Ref, Disc.

Thomas, G.W. (1982). Exchangeable cations. In A.L. Page, R. H. Miller, and D. R. Keeney (eds.). Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed., Agron. Monogr. 9, ASA and SSSA, Madison, WI. p. 159-165.

Wilcox, B., Davenport, D., Pitlick, J., and Allen, C. (1996). “Runoff and erosion from a rapidly eroding pinyon-juniper hillslope”, Los Alamos National Lab., NM (United States).

Wischmeier, W. H., and Smith, D. D. (1978). “Predicting rainfall erosion losses-A guide to conservation planning”. Predicting rainfall erosion losses-A guide to conservation planning.

Wood, M. K., and Blackburn, W. H. (1981). “Grazing systems: their influence on infiltration rates in the Rolling Plains of Texas”. Journal of Range Management, 331-335.

Urgeghe, A.M., Breshears, D.D., Martens, S.N., and Beeson, P.C. (2010). “Redistribution of runoff among vegetation patch types: on ecohydrological optimality of herbaceous capture of run-on”. Rangeland ecology & management 63:497-504.