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Runoff and sediment yield relationships with soil aggregate stability for a state-and-transition model in southeastern Arizona

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A B S T R A C T

Soil erosion has been identified as the primary abiotic driver of site degradation on many semiarid rangelands. A key indicator of erosion potential that is being increasingly implemented in rangeland evaluations is soil aggregate stability (AS) as measured by a field soil slake test. However, there have been few studies that test if decreasing AS is an indication of increasing soil erosion. A rainfall simulator experiment was conducted in southeastern Arizona to measure runoff and erosion, aggregate stability, and cover attributes on three vegetation states of the state-and-transition model (STM) of the Loamy Upland ecological site (R041XC313AZ). The states included the reference state (RS), a site encroached by mesquite (MN), and a site invaded by *Eragrostis lehmanniana* (ML). Within the context of the STM, runoff was only different between very high and low cover states. Erosion and AS values differentiated among states, particularly between the RS and MN states. Relationships between runoff and erosion with canopy cover and interspace bare soil suggest that certain cover levels exist where runoff and erosion have the potential to increase. The results also indicated that for this ecological site, AS < 4 may represent an increased risk of erosion occurrence.

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1. Introduction

Rangelands covering approximately 312 million hectares of the United States serve as an important source of forage for livestock, wildlife habitat, natural beauty, wilderness, and recreational opportunities (National Research Council, 1994). Loss of this vital resource through degradation is an ongoing concern. As rangelands degrade, they can no longer perform their normal functions, vegetation is lost, and runoff and soil loss increases. Loss of soil through erosion can affect plant composition, deplete soil biodiversity, lead to losses of reservoir storage and wildlife habitat, disrupt stream ecology and cause flooding (Pimentel et al., 1995).

The need to inventory, evaluate, and manage this extensive resource has resulted in the United States Department of Agriculture (USDA) Natural Resources Conservation Service's (NRCS) establishment of a landscape classification system called ecological sites. An ecological site is an area of land that differs from other areas in its ability to produce a distinctive kind and amount of vegetation due to its specific physical characteristics (USDI BLM, 2001). Each site is the result of the environmental factors (e.g. soils, relief or topography, climate, and natural disturbances like fire, drought, and herbivory) responsible for its development (Boltz and Peacock, 2002), and may contain several plant communities, known as vegetation states. Although the dominant species in each of the plant communities are commonly used to describe the state, a state is truly defined by soil and vegetation properties and processes (Herrick et al., 2002). The variations due to climatic events and/or management actions that are associated with each ecological site are typically depicted using State-and-Transition Models (STM) (Fig. 1). These models consist of states, transitions, and thresholds. The states, represented by the boxes in Fig. 1, are relatively stable and able to absorb disturbance and stresses to retain their ecological structure, up to a threshold point. The movement from one state to another is referred to as a transition and can be triggered by natural events and/or management actions. These transitions can occur over long or short periods of time and represent a change in site function. Once a threshold is crossed, restoration of the state to a previous or more desirable state can no longer be reached through natural events or a simple change in management. Significant inputs of management resources (e.g.

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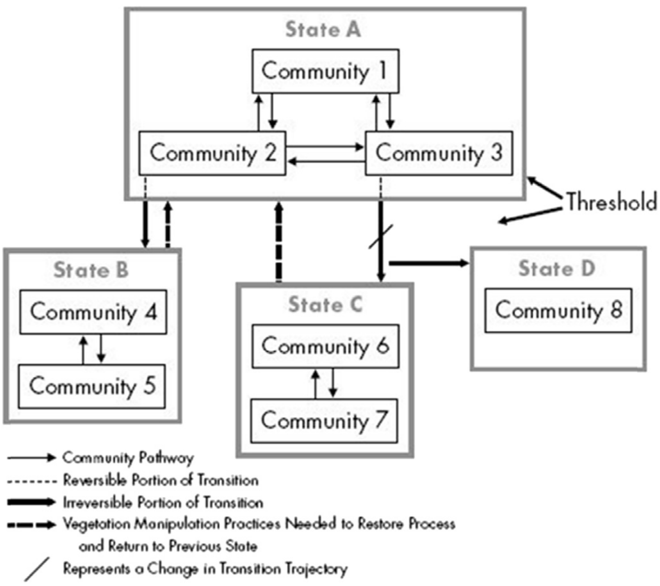

Fig. 1. State-and-transition model diagram for an ecological site (USDI BLM, 2001).

brush management and range planting) and energy are required, otherwise the transition becomes irreversible (USDI BLM, 2001).

STMs are currently used to provide information about past vegetation changes to aid in anticipating and interpreting future change (Thacker et al., 2008; Chartier and Rostagno, 2006; Papanastasis and Chouvardas, 2005; Bestelmeyer et al., 2004) with the goal towards maintaining healthy and sustainable rangelands. The health of a rangeland is defined by “the degree to which the integrity of the soil and the ecological processes are sustained” (National Research Council, 1994). This is determined through ecological site level assessment of three main attributes: soil and site stability, hydrologic function, and biotic integrity. The first two attributes of soil and site stability and hydrologic function respectively represent the capacity of a site to limit redistribution and loss of soil resources by wind and water; and capture, store, and safely release water from rainfall and run-on while maintaining the ability to recover when a reduction in resources occurs. Biotic integrity describes the capacity of the biotic community (plants, animals, and microorganisms above and below the ground) to support ecological processes within the normal range of variability expected for the site, resist a loss in the ability to support these processes, and recover when losses do occur. These attributes are ecosystem components that cannot be directly measured, but can be approximated by a set of observable indicators of the component. There are a total of 17 indicators used to evaluate the three attributes. These indicators may be associated with single, two, or all three attributes (Pyke et al., 2002; Pellant et al., 2005). Utilizing several of these indicators (e.g. the formation of rills, litter dams and terracettes, bare ground patch size, plant community composition, or soil surface stability) to signal the approach of particular transitions, can aid managers by indicating the operation of processes that may be altered to inhibit or encourage these transitions to obtain or maintain the desired rangeland system (Bestelmeyer et al., 2003).

Soil degradation through accelerated erosion is extremely detrimental to rangeland health. This degradation damages not only the soil itself, but also disrupts nutrient cycling, seed germination, water infiltration, seedling development, and other ecological processes that are important components of rangeland ecosystems (National Research Council, 1994). On undisturbed rangelands, the dominant erosion process is primarily raindrop detachment with the detached soil particles being transported over a short distance and deposited on-site (Parsons et al., 2006). After a disturbance such as a prolonged drought, fire, overgrazing, or a combination of factors, the dominant process can change to sheet and/or concentrated flow detachment (generally referred to as “accelerated” erosion) that transports soil off-site (Pierson et al., 2009; Tongway and Ludwig, 1997).

One method of evaluating the soil's resistance to erosion is by measuring soil aggregate stability (AS). Surface AS, which is measured using a soil stability kit, is positively related to a soil's resistance to erosion (Pyke et al., 2002). The soil stability kit uses a slake test to assess the resistance of the soil surface to erosion. The slake test determines the stability of a soil ped by immersing it in water and applying a ranking ranging from one (unstable) to six (stable) based on the percent of soil remaining following immersion and/or wet sieving (Herrick et al., 2001). Although the slake test provides a measure of the likelihood erosion will occur, it does not provide any information regarding the amount of erosion that can or will occur.

Thus far, the slake test has not been widely validated on rangelands with runoff and erosion data. Two studies have measured soil AS using the soil stability kit and runoff and sediment generated using a rainfall simulator (Michaelides et al., 2009; Pierson et al., 2010). These studies focused on species specific responses, rather than a broader ecological site perspective. This study is approached from an ecological site context. Rainfall simulator experiments were conducted on the Reference State (RS) and two alternate states of the Loamy Upland ecological site (R041XC313AZ) (USDA, 2004) in southeastern Arizona. The STM for the Loamy Upland ecological site was developed through quantitative measurements of changes of vegetation composition and cover as a result of climate and management and qualitative observations of the presence or absence of erosional features (ex. rilling, pedestalling, etc). There has not been a systematic test of how hydrological processes are related to the STM or how changes in hydrologic processes are related to changes in AS. It is hypothesized in this paper that as a site moves away from reference state conditions, AS will decrease and runoff and erosion will significantly increase. Further, by pairing rainfall simulator data with vegetation and AS measures, it will be possible to identify the point where hydrological processes change and degradation risk increases as a result of changes in AS levels. Therefore, the objectives of this study were to: 1) quantify changes in runoff, erosion, and AS for vegetative states relative to the RS and 2) test whether changes in runoff and erosion are related to changes in AS.

2. Methods

2.1. Study sites

This study was conducted at seven sites at three locations; the Empire Ranch, the San Rafael Valley, and the Walnut Gulch Experimental Watershed (WGEW) (Table 1). All of the locations lie within Major Land Resource Area (MLRA) 41-3 Southeastern Arizona Basin and Range (USDA, 2006). Elevation ranges from 975 to 1525 m and the average annual precipitation ranges from 304 to 406 mm with 60% of the rainfall occurring between July and September. The study sites represent the reference state (RS) and two alternate states, Mesquite, Natives (MN) and Mesquite, Lehmann (ML), within the Loamy Upland 12–16” precipitation zone ecological site (R041XC313AZ) (USDA, 2004). A simplified depiction of the STM for Loamy Uplands is shown in Fig. 2.

The Empire Ranch, which is operated by Bureau of Land

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