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Patterns of Soil Erosion and Redeposition on Lucky Hills Watershed, Walnut Gulch Experimental Watershed, Arizona

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Abstract

Degradation of semiarid and arid rangelands is a major concern and is usually described in terms of soil movement and changing plant communities. The purpose of this paper was to determine the patterns and rates of soil erosion and redistribution from measurement of the distribution of fallout ^{137}Cesium on the Lucky Hills Watershed, a semiarid rangeland watershed in southeastern Arizona. Soil redistribution ranged from a loss of -9.8 t ha^{-1} yr^{-1} to the deposition of $+7.0$ t ha^{-1} yr^{-1}. Net soil loss occurred at 54 of the 74 sample sites or approximately 73% of the watershed. Soil erosion rates were significantly correlated to the percent of rock fragments in the surface 25-cm soil layer with erosion decreasing as rock fragments increased. Soil redistribution was not significantly related to vegetation cover at the sample sites. This study supports earlier research on Walnut Gulch Watershed that showed the importance of rock fragments in estimating soil loss.
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Keywords: Soil erosion; ^{137}Cesium; Deposition; Sediment

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1. Introduction

Degradation of semiarid and arid rangelands is a major concern and is usually described in terms of soil movement/erosion and changing plant communities (Tongway et al., 2003; de Soyza et al., 2000; Herrick and Whitford, 1995). A National Research Council Report (1994) cited a need to develop methodologies to monitor and assess this degradation and its impact on rangelands and rangeland health. Understanding the patterns of soil erosion and soil redistribution are key factors for monitoring and assessing soil quality, rangeland health, and managing semiarid rangelands (Whitford et al., 1998). Maintaining or improving soil quality or rangeland health requires managing soil erosion and soil organic carbon (SOC) movement and loss at the field and watershed level (Whitford et al., 1998; Lal et al., 1998; Ritchie and McCarty, 2003). Recent studies indicate that soil erosion and subsequent redeposition of this eroded material within the same field play a significant role in understanding SOC patterns and therefore soil quality at field and landscape levels (Ritchie and McCarty, 2003; McCarty and Ritchie, 2002). The stability of semiarid rangeland systems has been defined as the capability of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Schlesinger et al., 1990; Ritchie et al., 2003). This study used radioactive fallout ^{137}Cesium (^{137}Cs) to determine patterns of soil erosion patterns and soil redistribution on Lucky Hill Watershed, a semiarid watershed in the Walnut Gulch Experimental Watershed near Tombstone, Arizona. The Lucky Hills Watershed had been chosen by the Global Change and Terrestrial Ecosystems–Soil Erosion Network (GCTE-SEN) group as a watershed to be used to test erosion models. This study was designed to measure rates and patterns of erosion and redeposition in the field.

2. Methods

The study site is in the Southeastern Arizona Basin and Range province on the Lucky Hills watershed that is a subwatershed of the United States Department of Agriculture (USDA), Agriculture Research Service (ARS) Walnut Gulch Experimental Watershed near Tombstone, Arizona. Active research and monitoring began in 1961 on the Lucky Hills watershed with monitoring of rainfall and runoff (Canfield and Goodrich, 2003). The elevation of the Lucky Hills watershed ranges from 1363 to 1375 m. Mean annual temperature is 17 °C ranging from 1 °C in January to 35 °C in June. The annual precipitation in this region ranges from 250 to 500 mm yr^{-1}, with approximately two thirds of the rainfall occurring in the monsoon season (July–August). Mean annual rainfall for the Lucky Hills Watershed is approximately 356 mm (Nichols et al., 2002; Emmerich, 2003). The soils are mapped as Luckyhills–McNeal Sandy Loam (Ustochreptic Calciorthids) and are mainly sandy loam with high fraction of fragmented rocks (Breckenfeld et al., 1995; Simanton and Toy, 1994; Simanton et al., 1994). The vegetation on the Lucky Hills watershed is a shrub-dominated ecosystem with Acacia [*Acacia constricta* Benth.], Tarbush [*Flourensia cernua* DC], and Creosote [*Larrea divaricata* Cav.]). A sparse understory of grasses and forb is also found (Weltz et al., 1994). The shrubs are about 0.6 m height and cover about 26% of the surface. The surface leaf area

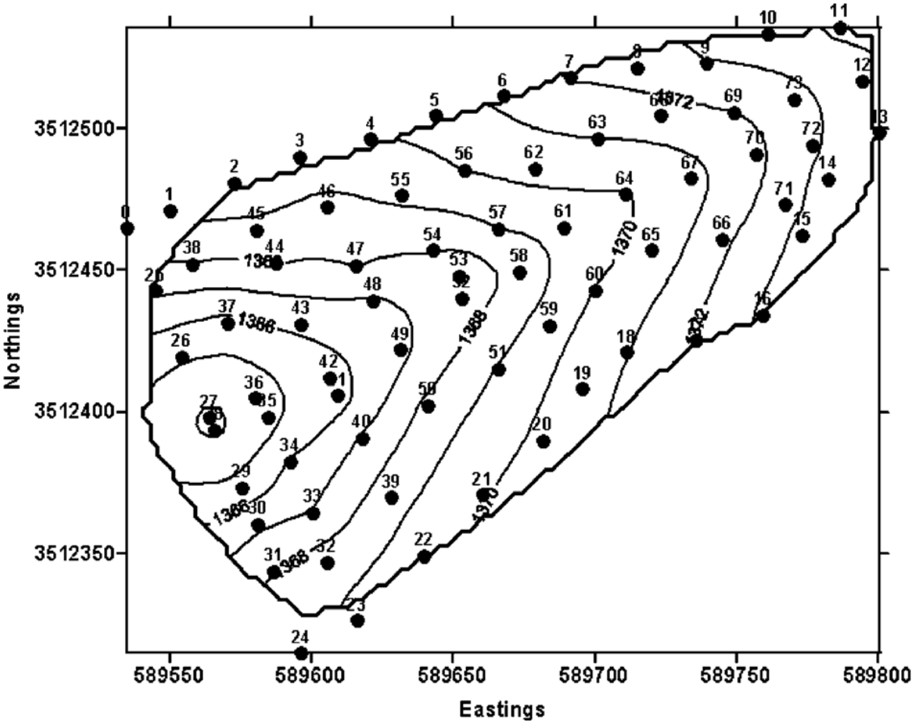

Fig. 1. Map of Lucky Hill Watershed showing the sample sites and the elevation.

index is about 0.3–0.4, which implies that the clump leaf area index of the shrubs ranged between 1.15 and 1.54 (Weltz et al., 1994). The watershed was fenced in 1963 limiting the grazing by domestic livestock (Osborn and Simanton, 1983).

Soil samples were collected on approximately a 25-m grid pattern on the watershed. Soil samples were collected at 74 sites (Fig. 1). A differential GPS was used to determine the coordinates and elevation of each sample site. Cover (i.e., vegetation, bare) was noted for each site. Bulk soil samples were collected for the 0–25 cm soil layer. Soil samples were dried at 80 °C and sieved to pass through a 2-mm screen. Weights of soil (<2 mm) and rock fragment (>2 mm) fractions were determined. The soil fraction (<2 mm) was placed into Marinelli beakers and sealed for ^{137}Cs analyses. Analyses for ^{137}Cs were made by gamma-ray spectrometry using a Canberra Genie-2000 Spectroscopy System[1] that receives input from three Canberra high purity coaxial germanium crystals (HpC>30% efficiency) into three 8192-channel analyzers. The system is calibrated and efficiency determined using an Analytic[1] mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Measurement precision for ^{137}Cs is ±4% to 6% (Ritchie, 2000).

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[1] Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

Radioactive ^{137}Cs was globally distributed by the deposition of fallout material from atmospheric nuclear weapon tests from the mid 1950s to the mid 1970s mostly by rainfall (Playford et al., 1993; Cambray et al., 1989; Carter and Moghissi, 1977). While rainfall may be patchy in arid and semiarid landscapes, the assumption is that over the 20-year period of radioactive fallout, all areas would have approximately uniform rain and fallout deposition (Ritchie et al., 2003). Once ^{137}Cs reaches the soil surface it is strongly and quickly adsorbed on the exchange sites of the soil particles and is essentially nonexchangeable in most environments (Tamura, 1964; Cremers et al., 1988). Chemical and biological processes move little ^{137}Cs once it reaches the soil surface except where there is significant animal activity (i.e., badger borrows, kangaroo rat mounds), thus physical processes of water and wind erosion are the dominant factors moving ^{137}Cs-tagged soil particles between and within landscape compartments (Ritchie and McHenry, 1990). Thus patterns of ^{137}Cs concentration can be used to estimate soil erosion and redistribution rates and patterns based on the measurement of ^{137}Cs concentrations in the eroding or depositing soil and comparing it to measurement of ^{137}Cs concentration in a reference soil (site) where soil erosion has not occurred (Walling, 2003, Ritchie and McHenry, 1990).

Sixteen soil samples were collected at sites with little evidence of physical disturbance of the surface for use as reference soil sites. The mean ^{137}Cs concentration in theses samples was 1839∀792 Bq m^{-2}. This variability in reference samples is similar to variability measured in other studies (Sutherland, 1996; Wallbrink et al., 1994). We assumed that this ^{137}Cs concentration represented the ^{137}Cs input to the watershed area and used it with the models developed that relate soil and ^{137}Cs movement. The Diffusion and Migration Model for Erosion and Deposition on Undisturbed Soil was used. This model accounts for differences in yearly input of ^{137}Cs and for diffusion of ^{137}Cs in the soil profile (Walling and He, 1999; Ritchie and McHenry, 1990).

3. Results and discussion

The range in rock fragments (>2 mm) for the 0–25 cm soil layer ranged from 18% to 59% with a mean of 37.4∀9.9% for the 74 sample sites. These values are similar to earlier studies of rock fragments on the soil surface of the Walnut Gulch watershed (Simanton and Toy, 1994; Simanton et al., 1994). The percent rock fragment increase with increasing elevation with a concurrent decrease in soil particles (<2 mm) with increasing elevation (Fig. 2). The spatial pattern (Fig. 3) of soil particles shows higher percent of soil particles at the lower areas and in areas of deposition. This is consistent with water erosion moving the lighter soil particles down slope while leaving the larger rock fragments near their site of origin. Studies of rock fragments at Walnut Gulch Watershed (Simanton and Toy, 1994; Simanton et al., 1994) and other sites (Cousins et al., 2003; Poesen et al., 1999) have reached similar conclusions. All these studies recommend the inclusion of information related to rock fragments in any effort to model soil erosion in semiarid landscapes.

^{137}Cs concentrations ranged from 0 to 7372 Bq m^{-2} for the 74 samples. One site had ^{137}Cs concentration (7372 Bq m^{-2}) that was more than double the next highest concentration (3239 Bq m^{-2}) measured. We have no explanation for this high ^{137}Cs

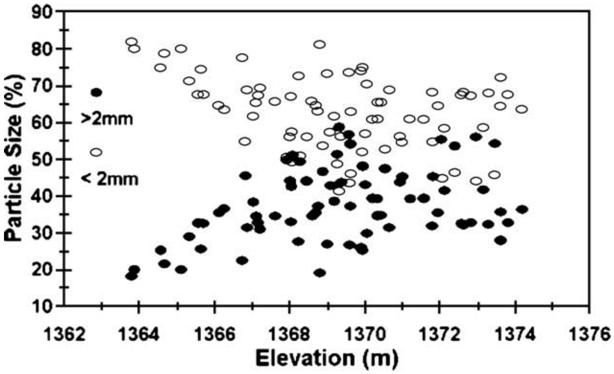

Fig. 2. The relationship between percent rock fragments and percent soil particles and elevation.

concentration and have chosen not to use it in further analyses. The mean of the 73 remaining sites was 1092∀870 Bq m^{-2}, which is similar to that measured (1184 Bq m^{-2}) at the USDA ARS Jornada Experimental in Southern New Mexico, which has similar climatic conditions (Ritchie et al., 2003). There were eight sites where no ^{137}Cs was detected. These eight sites were near or on the bank of a channel or gully scar, so we assume that all the surface soil and ^{137}Cs had been removed by erosion. At these eight sites

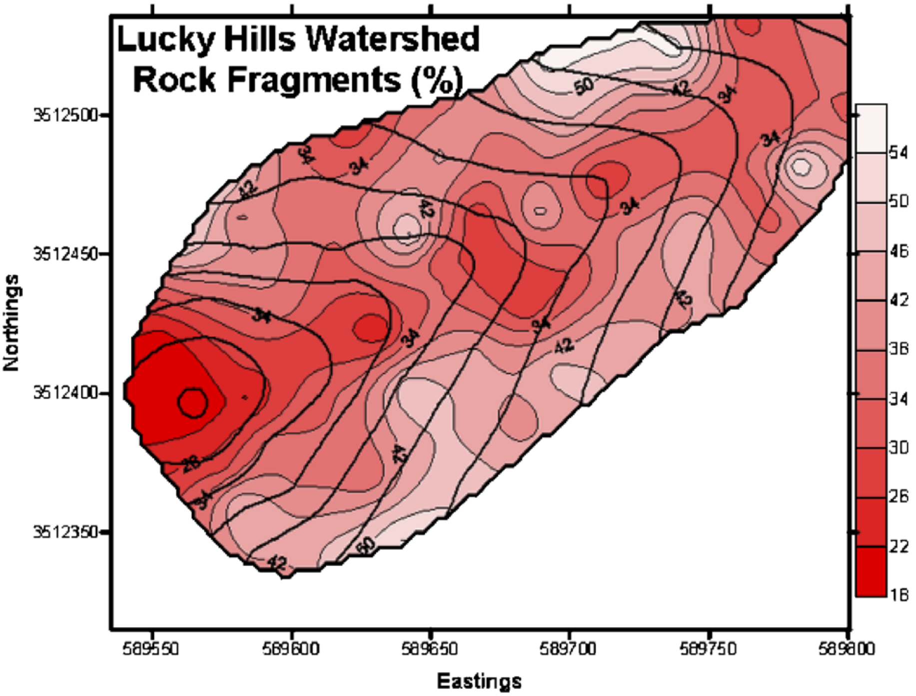

Fig. 3. Map of Lucky Hill Watershed showing the distribution of rock fragments (%) in the 0–25 cm soil horizon. Range of rock fragment is from 18% to 59%.

the percent (73%) of soil particles (<2 mm) was significantly greater than the percent (61%) of soil particles at the other sample sites. This supports the concept of erosion of surface soil and the exposure of the C horizon of the soil profile with higher clay and less rock fragments. There was a significant ($F=12.92$, $p=0.0006$, $R^2=0.15$) positive linear relationship between ^{137}Cs concentrations per square meter and the percent rock fragments. This would indicate that as the percent rock fragments increased there was less ^{137}Cs loss from a site and less soil movement since ^{137}Cs movements is associated with the soil movement.

Erosion and deposition rates ranged from a soil loss of −9.8 t ha^{-1} year^{-1} (metric tons per hectare per year) to the deposition of +7.0 t ha^{-1} year^{-1} with an average of −3.8∀4.5 t ha^{-1} year^{-1}soil loss for the total watershed. However these rates may be low since there were 8 samples sites where no ^{137}Cs was found. Assigning these sites a ^{137}Cs concentration of 1 Bq m^{-2} allows the model to estimate an erosion rate of −9.8 t ha^{-1} year^{-1}. However, this rate could be greater since we have no way to determine an erosion rate for these 8 sample sites based on the ^{137}Cs concentration. Soil redistribution is shown in Fig. 4. 73% of the sample sites (54 out of 74) were found to have a net loss of soil. Soil loss was usually on the higher elevation with the areas of deposition being in the low areas.

A significant ($F=13.6$, $p=0.0004$, $R^2=0.16$) positive linear relationship was found between soil redistribution and increasing rock fragments. As the percent rock fragments

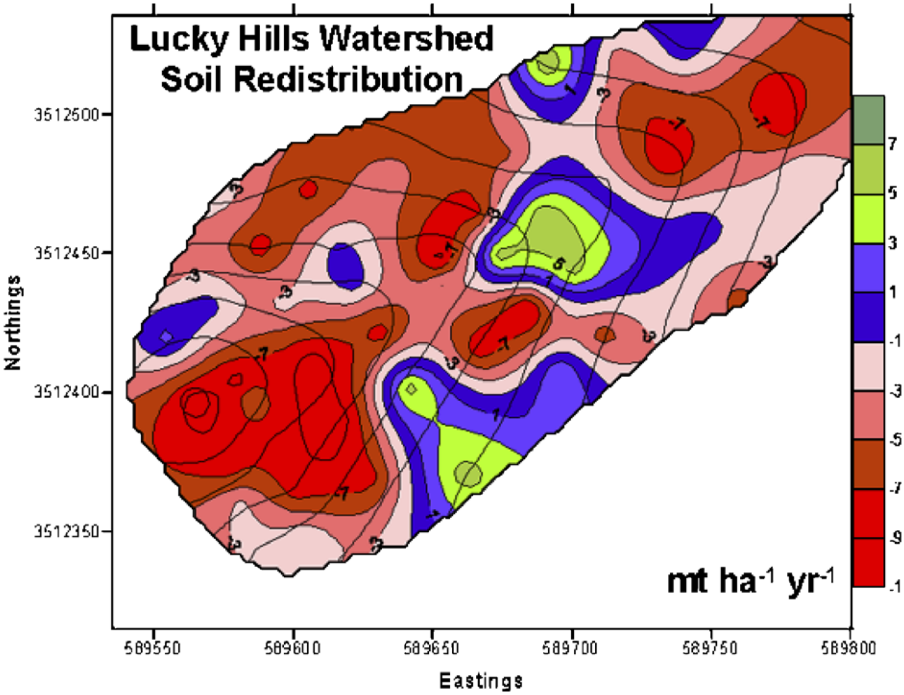

Fig. 4. Map of Lucky Hill Watershed showing the soil redistribution pattern. Range of redistribution is from a soil loss of −9.8 t ha^{-1} year^{-1} to a deposition of +7.0 t ha^{-1} year^{-1}.

Table 1
Soil redistribution rates and rock fragments related to sample site location relative to a cover (shrub)

Cover	Number of samples	Soil redistribution, t ha^{-1} year^{-1}	Rock fragments, %
Near or under a shrub	20	−3.9∀4.7a	35.7∀9.2a
Between shrubs	38	−2.3∀4.1a	41.0∀9.5b
Near erosion scar	12	−8.4∀2.1b	28.6∀7.2c

Values with different letter (a, b, c) are different at the 0.05 level of probability.

increased, the soil loss decreased. Sites with rock fragment less that 40% had an average erosion rate of −5.0 t ha^{-1} year^{-1}, while site with rock fragments greater than 40% had an average erosion rate of −1.6 t ha^{-1} year^{-1}. This is consistent with observation of water erosion in other studies of rock fragments at Walnut Gulch Watershed (Simanton and Toy, 1994; Simanton et al., 1994) and other sites (Cousins et al., 2003; Poesen et al., 1999).

Location of the sample site in relationship to vegetation did not have a major effect on soil redistribution (Table 1). While soil sites near or under a shrub had greater soil loss rates they were not significantly different from site collected between shrubs. This is in contrast to a study at the USDA ARS Jornada Experimental Range in southern New Mexico where sample collected under shrubs showed deposition and sites between shrubs showed erosion (Ritchie et al., 2003). The shrubs on the Lucky Hill Watershed are about 0.6 m height and cover only about 26% of the surface with a Leaf Area Index is about 0.3–0.4 (Weltz et al., 1994). This small coverage and area does not appear to capture much of the moving soils. The large shrubs (Mesquite [*Prosopis glandulosa* Torr.]) on the Jornada capture the wind blown eroding soils and probably contributed to the difference. Rock fragments were greater in between shrubs (41%) versus near or under shrubs. The rock fragment would tend to armor the surface between the shrubs to reduce soil loss.

4. Conclusions

Soil erosion rates and patterns were estimated on the Lucky Hills Watershed from measurements of the distribution of fallout ^{137}Cs. Net soil loss had occurred at 54 of the 74 sites or approximately 73% of the watershed. Soil erosion rates were significantly correlated to the percent of rock fragments in the surface 25-cm soil layer but were not related to vegetation cover at the sample site. This study supports earlier research on Walnut Gulch Watershed that showed the importance of rock fragments in estimating soil loss (Simanton and Toy, 1994; Simanton et al., 1994). Vegetation cover at the sample site was not related to soil redistribution. This is probably due to the low vegetation cover (26% of the surface) that would not impede raindrop impact on the soil surface.

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