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Potential use of synthetic color-contrast aggregates and a digital image processing technique in soil splash measurements

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Abstract A digital computer-based method for measuring soil splash was evaluated in the present study. Accordingly, Synthetic Color-Contrast Aggregates (SCCA), having the same size, shape and specific gravity as those of natural soil aggregates were used as tracers for detecting particle movement. Subsequently, the amount and intensity of sheet erosion was inferred with the help of Digital Image Processing (DIP) techniques using MATLAB. The present study was conducted under laboratory conditions with a simulated rainfall intensity of some 90 mm h^{-1} and a slope of 30%, using sandy-loam soils taken from a summer rangeland in the Alborz Mountains, northern Iran. Soil erosion was mapped based on the DIP technique and finally compared with the density distribution of SCCA to evaluate the accuracy of the approach. The results show that the method can be used for measuring soil splashed downslope, and for estimating the amount and intensity of splash.

Key words Alborz Mountains, Iran; digital image processing; erosion tracers; sheet erosion; soil splash; synthetic color-contrast aggregates

INTRODUCTION

The initial stage of splash-induced soil erosion is highly destructive and entails the dispersion and subsequent breakdown of soil aggregates. Splash also plays a synergistic role in soil erosion by decreasing surface infiltration rates and increasing runoff coefficients. The extent of splash erosion is a function of raindrop impact energy in conjunction with the stability of soil aggregates (Kukal & Sarkar, 2011). Although the bulk of eroded soils measured/sampled at the outlets of plots, slopes and watersheds are suspended sediments, splash-induced sheet erosion may contribute to a significant proportion of soil loss as a non-suspended type of soil movement that usually is ignored in soil erosion and sediment studies. The main reason for this may be due to the difficulties associated with sampling and measuring non-suspended particles at appropriate locations. To overcome this problem, a new, simple, innovative method with the potential for application in large-scale surveys is required. Computer-based methods, especially using the remote-sensing aspects of these techniques, may have the desired properties of both simplicity and large-scale application. Accordingly, a digital computer-based method for measuring soil splash has been developed for the present study. Synthetic Color-Contrast Aggregates (SCCA) having the same size, shape and density to actual soil aggregates (Ventura *et al.*, 2002) were used to evaluate this approach. A detailed review of the current literature has indicated no similar study has yet been attempted.

MATERIALS AND METHODS

The present study was conducted under controlled laboratory conditions with a simulated rainfall intensity of 90 mm h^{-1}, an optimized rainfall duration of 10 min, and a 30% slope, using sandy-loam soils (14% clay, 24% silt and 62% sand) taken from the top layer (0–20 cm) of some summer rangelands in the Alborz Mountains in Northern Iran. The natural values for the bulk density, pH, EC, and organic content of the soil used in this study are 1.376 g cm^{-3}, 7.95, 75.5 µmohs cm^{-1}, and 2.167%, respectively. The soil was prepared for lab simulation following the methods of Kukal and Sarkar (2011).

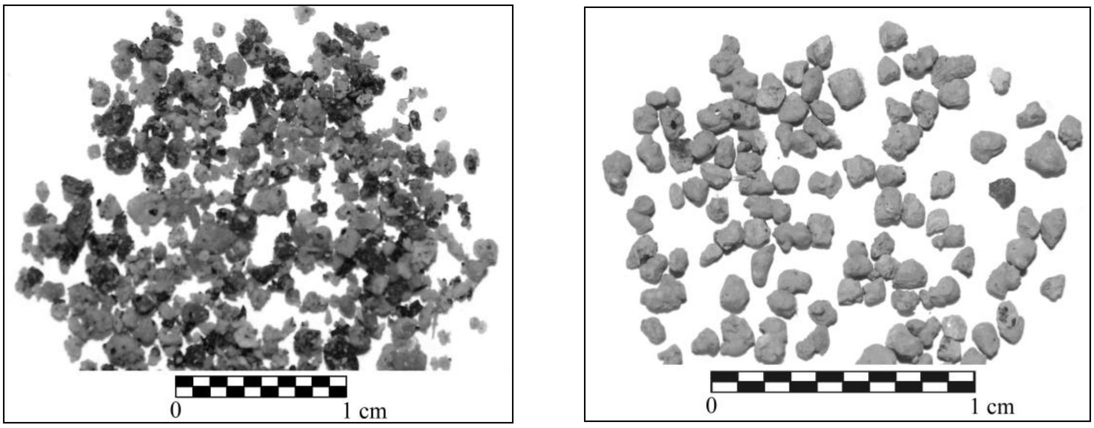


Fig. 1 Fine mineral pumice (left) and SCCA grains (right).

The SCCAs are made using fine mineral pumice as a base material that subsequently was aggregated with white cement, and then coloured with yellow pigment powder (Lanxess Brand) using optimal ratios of 200:100:15 fine pumice to white cement powder to yellow pigment powder, respectively (Fig. 1).

Three splash cups (Morgan, 1978; Nanko *et al*., 2008) were placed at the upper, middle and lower parts of each experimental plot to measure the amount of splash erosion induced by raindrop impacts. The SCCAs were distributed over the three square frames (Mertens & Elsen, 2006) adjacent to each splash cup to facilitate photography and consequent image processing. It is very important that the SCCAs should be located within the upper 1 mm surface soil layer; a small roller is used to improve their adhesion and resistance to simulate actual soil aggregates (Torri & Poesen, 1992). The general view of the experimental setup is shown in Fig. 2.

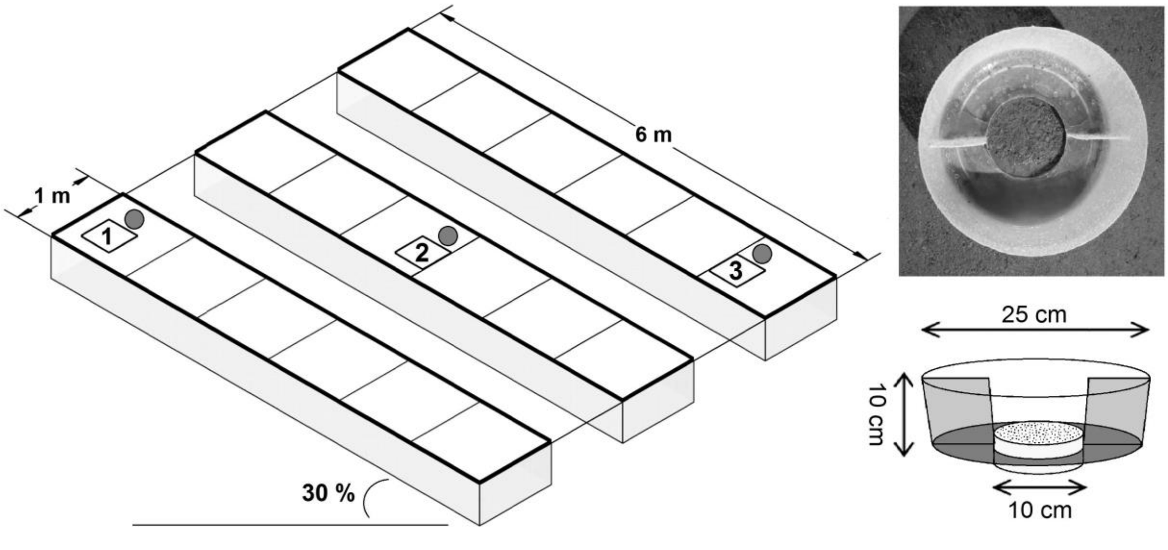
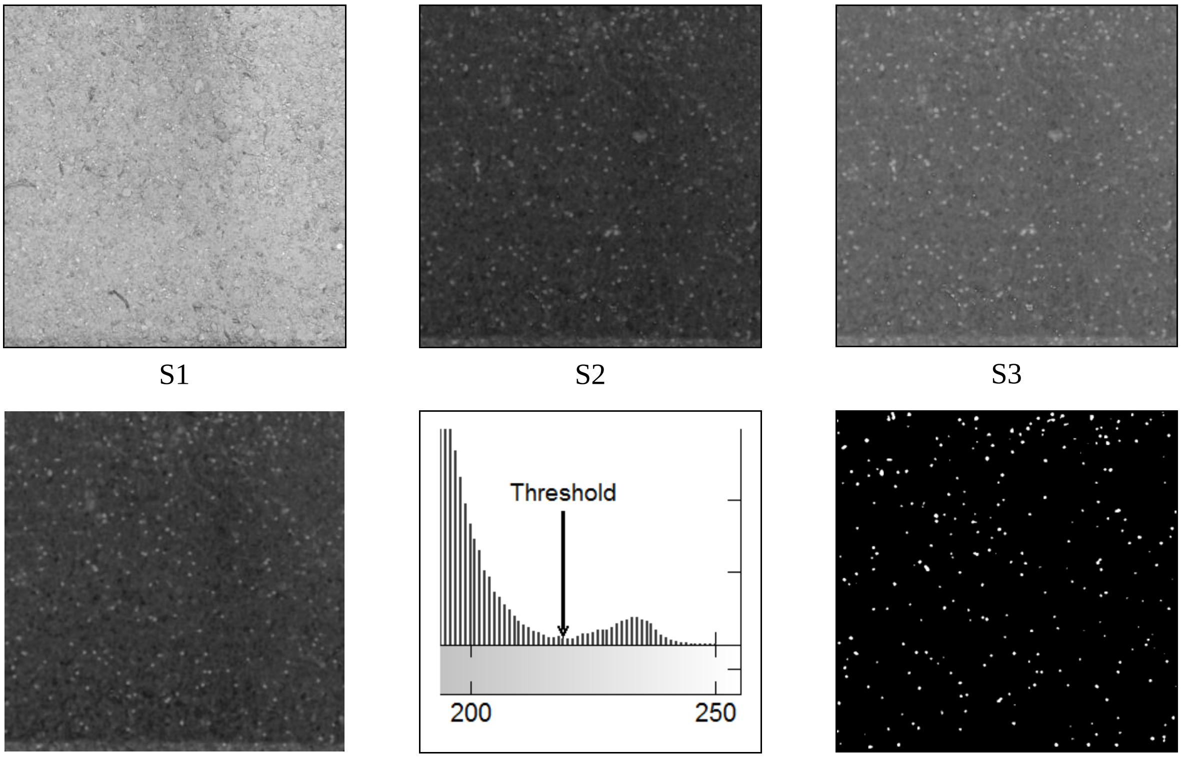


Fig. 2 Installation of three 6 m^2 plots, three 1600 cm^2 imaging square frames, and three designed splash cups located at different parts of the slope.

RESULTS

In the present study, an attempt was made to assess the applicability of SCCAs in quantifying splash erosion under laboratory conditions. The results of the application of SCCAs and the corresponding photos and image processing stages are shown in Fig. 3.



S1 S2 S3

S4 S5 S6

Fig. 3 The results from the most important steps in digital image processing using MATLAB. This analysis is for images taken from frame 1 before rainfall simulation. S1: reading original image, S2: converting to an HSV colormap, S3: converting to greyscale (Gonzalez & Woods, 2007), S4: 2-D median filtering to reduce "salt and pepper" noise (Gonzalez & Woods, 2007), S5: visual detection of the threshold using a grey level histogram, S6: converting the image to binary form based on the threshold of brightness between SCCAs and background (Ören *et al.*, 2006).

The pixel threshold between the SCCAs and the background soil particles was determined using a grey-level histogram (Fig. 4). The threshold for the sample histogram (Fig. 4) is about 217, which means that all the pixels with a grey level ≥ 217 are SCCAs and all the others are natural background soil particles. In some images, because of light and contrast conditions, the threshold could not simply be determined using the histogram, and some of the filter and limitation quantities used during steps S3 and S4 had to be changed to increase the contrast between SCCAs and the background particles (Parker, 1997; Butler *et al.*, 2002; Ören *et al.*, 2006; Bogrekci & Godwin, 2007; Gonzalez & Woods, 2007).

The final steps in the image processing procedure entail determining the optical density of the SCCAs in each frame, and then linking these densities to the volume of non-suspended soil particles displaying downslope movement, by comparing them with the results obtained from the three splash cups installed in each plot. The results of SCCAs density (no. m^{-2}) and conversions to eroded weight (g m^{-2}) and the average weights of soil eroded by downslope splash (Leguédois *et al.*, 2005) are shown in Table 1. The entire calculation was made by following the steps used for Frame 1.

$$\text{SCCAs reduction ratio} = (\text{SCCA density before simulation} - \text{SCCA density after simulation})/(\text{SCCA density before simulation}) = 0.8134 \tag{1}$$

$$\text{Eroded area (per square metre)} = (\text{SCCAs reduction ratio})(1\ \text{m}^2) = 8134\ \text{cm}^2\ \text{m}^{-2} \tag{2}$$

$$\text{Eroded volume} = (\text{eroded area})(\text{mean soil aggregate diameter 1 mm}) = 813.4\ \text{cm}^3\ \text{m}^{-2} \tag{3}$$

$$\text{Eroded mass} = (\text{eroded volume})(1.376\ \text{g cm}^{-3}) = 1119.28\ \text{g m}^{-2} \tag{4}$$

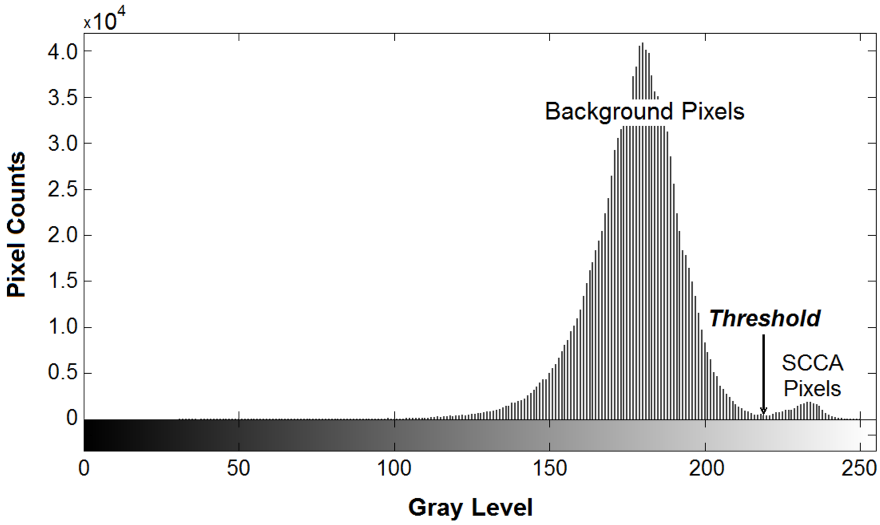


Fig. 4 Histogram of processed images and the threshold of grey level between SCCAs and background used for the analysis of images taken from frame 1 and before rainfall simulation. The final result of the processing is an image with just two brightness degrees. The black pixels indicate the SCCAs, and the white pixels indicate background (Fig. 5).

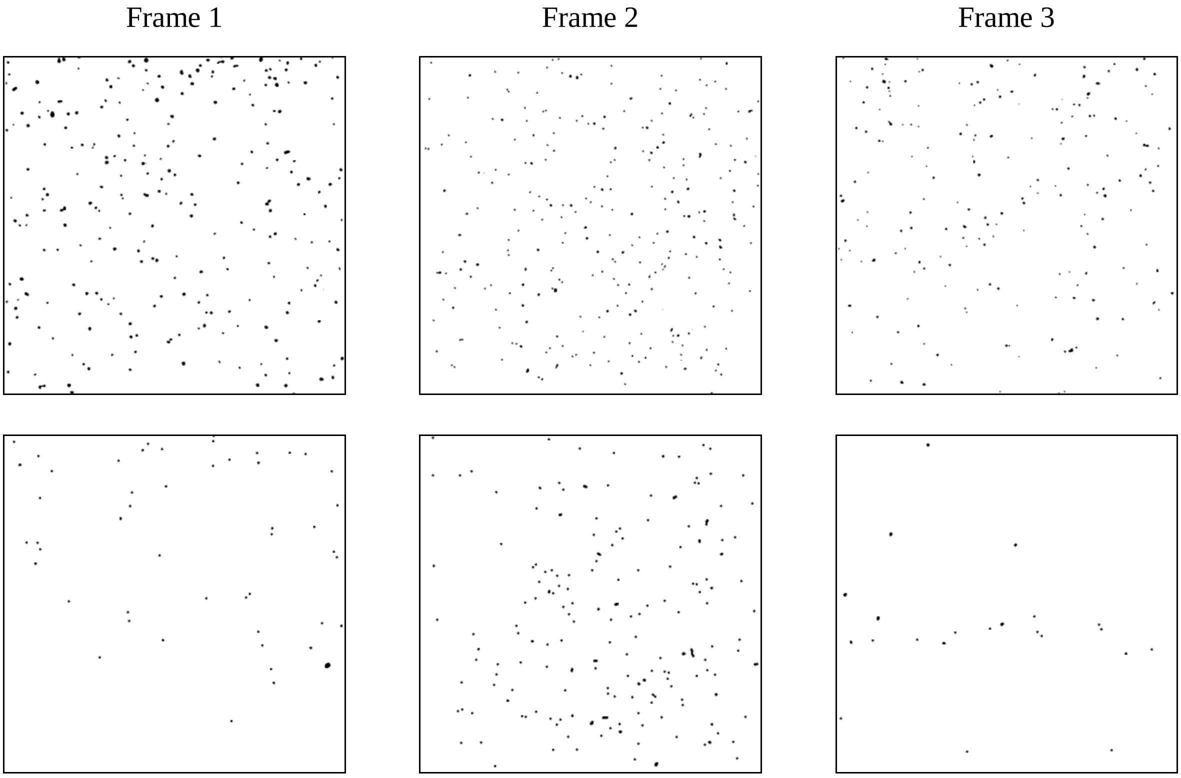


Fig. 5 Processed images before (upper three images) and after (lower three images) rainfall simulation in the three study frames.

The main assumption is that the ratio between eroded soil area and total frame area is equal to the SCCAs reduction ratio. Then, the available thickness of the soil surface layer to splash and movement by raindrop impacts and runoff is assumed to be the mean soil aggregate diameter (about 1 mm) because of the remaining percentage of SCCAs after rainfall simulation.

Table 1 Density of SCCAs and conversions to average weights of soil eroded with splash.

Imaging frames	SCCA density (no. m^{-2})		SCCAs reduction ratio (%)	Splash erosion (g m^{-2})	
	Before simulation	After simulation		SCCA	Cup
1	2978	556	81.34	1119.28	186.20
2	3156	2033	35.56	489.35	184.42
3	2244	244	89.11	1226.14	162.68

DISCUSSION AND CONCLUSION

At the longitudinal middle of the plots, the intensity of soil splash induced by raindrops is low because the depth of the runoff is about 1 mm and that is sufficient to protect the soil surface from impact. This effect generates an interesting visual result in the processed images (Fig. 5). In other words, the locations of the three frames relative to the depth of surface runoff leads to different dominant processes in each frame. Hence, in Frame 1 the splash effect of rain is intense because the depth of the runoff is small and only composed of some shattered drops, whereas the dominant process in Frame 3 is the inverse of Frame 1 because the depth of the runoff is more than 2 mm, and has a speed of about 0.7 m s^{-1}. Therefore, the dominant forces that separate and mobilize the SCCAs as well as natural soil particles in Frames 1 and 3 are not the same; whereas both forces (splash and runoff) act with relatively low intensity in Frame 2.

The prioritization effects of relatively intense splash, medium splash-runoff, and relatively intense runoff on downslope soil particle movement can be shown as:

Intense Splash ≈ Intense Runoff > combined effects of Splash and Runoff

The amount of soil particles moved as a result of intense splash in Frame 1 seems to be less than the amount of particles moved as a result of intense runoff in Frame 3. The relatively simple reason for this observation is that splash erosion can move the soil particles both up- and downslope whereas runoff erosion only can move the soil particles downslope.

Although the displaced soil volumes that were measured separately using splash cups were determined in both an upslope and a downslope direction, the comparison between SCCA and splash cup data only was performed on material that moved downslope. Unfortunately, the results show little or no agreement between the measurement methods. This may reflect the substantial differences associated with the two measurement techniques. However, additional evaluations of the actual measurement techniques employed in each method, under different conditions, may be required before any final conclusions can be drawn.

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