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Soil infiltration, runoff and sediment yield from a shallow soil with varied stone cover and intensity of rain

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Summary

Stones on the surface of the soil enhance infiltration and protect the soil against erosion. They are often removed in modern mechanized agriculture, with unfortunate side-effects. We evaluated experimentally the influence of surface stones on infiltration, runoff and erosion under field conditions using a portable rainfall simulator on bare natural soil in semi-arid tropical India, because modernization and mechanization often lead to removal of these stones in this region. Four fields with varied cover of stones from 3 to 65% were exposed to three rainfall intensities (48.5, 89.2 and 136.8 mm hour^{-1}). Surface stones retarded surface runoff, increased final infiltration rates, and diminished sediment concentration and soil loss. The final infiltration ranged from 26 to 83% of rainfall when the rainfall intensity was 136.8 mm hour^{-1}. The reduction in runoff and soil erosion and increase in infiltration were more pronounced where stones rested on the soil surface than where they were buried in the surface layer. The sediment yield increased from 2 g l^{-1} for 64.7% stone cover with rainfall of 48.5 mm hour^{-1} to 70 g l^{-1} for 3.5% stone cover with rain falling at 136.8 mm hour^{-1}. The soil loss rate was less than 2 t ha^{-1} hour^{-1} for the field with stone cover of 64.7% even when the rainfall intensity was increased to 136.8 mm hour^{-1}. The effects of stones on soil loss under the varied rainfall intensities were expressed mathematically. The particles in the sediment that ran off were mostly of silt size.

Introduction

Large amounts of water are lost as runoff in arid and semi-arid regions. Surface sealing, a common feature in most soils of these regions and formed during rain storms, is a major cause of reduced infiltration and increase in runoff and erosion. However, many of the soils in such regions frequently have stones, typically angular rock fragments at the surface, so that covered portions are protected from the action of rain drops and therefore from surface sealing. Much attention has been paid to the role played by the finest particles, i.e. the clay fraction, in conditioning a soil's behaviour (Poesen & Lavee, 1994). Much less has been devoted to the effects of the coarsest materials, i.e. stones. Stone cover is widespread, particularly around the Mediterranean Sea where it often occupies more than 60% of the land (Poesen & Lavee, 1994). It also covers significant areas of land in other countries, including the USA (Miller & Guthrie, 1984) and China (Gale *et al.*, 1993).

Stones also cover a large portion of the red soils (Alfisols, Inceptisols and Entisols in the USDA classification; Luvisols, Lixisols and Regosols are the closest equivalents in the FAO classification) of the semi-arid tropics of India. We need to know what their effect is on these soils, because of their potential benefits, and limitations, for land use. We need more quantitative information on their effects on hydrological and soil degradation processes so that we can improve models to predict the effects of land-use changes on these soils. Cultivation of fields containing stones is a tradition that is still practised in semi-arid India. But these coarse fragments cause excessive wear, breakage and down-time of modern field machinery, and they restrict root growth and the pegging of groundnuts, which is one of the major crops in this region. Common practice is to remove the stones for commercial production. Unfortunately, this significantly retards water infiltration and increases surface runoff and erosion (Chow *et al.*, 1992; Nyssen *et al.*, 2001). Coarse fragments resting on the surface have the same effect as other mulching materials: they protect the soil against the impact of rain drops and so prevent to some extent surface sealing and the detachment of soil particles.

Though it seems obvious that stones influence the hydrological behaviour of soil, little investigation of that behaviour

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on the soils of semi-arid tropical India has been reported. These soils are shallow, coarse in texture, contain little organic matter and are prone to severe erosion. Yields of crops are small, partly because of the dry climate and partly because the soils are shallow (Littleboy *et al.*, 1996). Variation in rainfall also limits the productivity of these soils. Some of the rain events are of short duration and very intense, and this combination aggravates the erosion. Also, knowledge of sediment sizes in runoff is essential to soil erosion research because the size of the particles is one of the major factors that affect the transport and deposition of sediment (Rhoton & Meyer, 1987). But studies of size distributions of sediment in runoff are difficult and time-consuming.

The most widely used method for studying the effects of stones on soil erosion has been with simulated rain under laboratory conditions on disturbed soils. Few experiments have been done under natural conditions (Cerdà, 2001). Simulation experiments are more rapid, efficient, controlled and adaptable than research under natural rainfall (Meyer, 1994), and they are suitable for the study of infrequent heavy precipitation events such as those that occur under semi-arid conditions (Cerdà, 1996).

We have evaluated the effect of stone cover on the hydrological and erosional behaviour of a shallow soil in the semi-arid tropics in India under varied intensities of rain. We have also studied how rain intensity affects particle-size distribution of the sediments. We developed a mathematical relation to quantify the effect of stone cover on soil erosion under the various rainfall intensities for planning soil conservation.

Materials and methods

Quantification of stone cover

Though there are different size classes (gravel, cobble, stone) of the mineral particles greater than 2 mm in diameter, we use 'stone' as a general term for all the coarse fragments having diameters larger than 2 mm. Three variables are commonly used to express the quantities of stones in the topsoil: they are surface cover, volume and mass per cent of stone cover of soil. We used stone cover of the soil surface to characterize our experimental plots. The stone cover was measured on vertical photographs of the surface for each plot with a digital camera. It was mapped from the photograph and enlarged, and later its area was measured with a planimeter (Tamaya Digitizing Area-Line Meter, Tokyo). We also calculated the percentages of stones by mass of the soil by removing the soil from one square metre to 0–5 cm depth and separating the stones on a 2-mm sieve.

Study area

Our experiment was done on the Hayatnagar Research Farm (17°18′N, 78°36′E, 515 m above mean sea level) of the Central Research Institute for Dryland Agriculture, Hyderabad, during April 2002. The climate is semi-arid, with hot summers and mild winters. The mean maximum air temperature during summer (March, April and May) varies from 35.6 to 38.6°C. Mean minimum temperature during winter (December, January and February) ranges from 13.5 to 16.8°C, and the mean annual temperature is 25.7°C. Mean annual rainfall is 746.2 mm and accounts for approximately 42% of annual potential evapotranspiration (1754 mm). Nearly 70% of the total precipitation is received during the southwest monsoon season (June to September). The soil is a medium-textured, red soil (Typic Haplustalf in the USDA soil classification; Haplic Luvisols is the closest equivalent in the FAO scheme). In general, slope varies between 1 and 4% with some divergent and complex slopes conducive to considerable erosion hazard. The surface soil is rapidly permeable and readily drains. The soil is slightly acid to neutral in reaction and holds little water. The soil varies from 25 to 60 cm deep, and becomes heavier and more compact from the surface downwards. Surface crusting and hardsetting are recurring problems in this soil. We chose four fields for our experiment based on the proportions of stone cover. These are sparse cover (S_1), medium cover (S_2), intense cover (S_3) and very intense cover (S_4) of the soil surface. The per cent cover of stones (Figure 1) measured by planimeter was 3.5, 17.6, 41.7 and 64.7 for the S_1, S_2, S_3 and S_4 fields, respectively. But as per cent mass of soil in the 0–5 cm layer of soil the percentages were 5.5, 40.1, 45.9 and 69.3 in S_1, S_2, S_3 and S_4 fields, respectively. On our experimental plots, most stones rested on the soil surface, and few were partly or completely embedded within the soil except in field S_2. The moisture content at saturation (by mass) of stone is negligible and varies between 0.71 and 1.23%. Most of the fragments have diameters between 2 and 3.8 cm and are irregular in shape. There were a few larger fragments of 5.6–8 cm diameter.

Rainfall simulation experiment and soil and sediment analysis

Before using the rainfall simulator (Figure 2) (manufactured by Department of Natural Resource in Toowoomba, Queensland, Australia) in the experimental plots we calibrated it with a rain gauge. We chose three constant rates of rain of 48.5 mm hour^{-1} (I_1), 89.2 mm hour^{-1} (I_2) and 136.8 mm hour^{-1} (I_3) for the experiment, knowing that these would divide the range of natural rainfall intensity in the region. The kinetic energy of I_1, I_2 and I_3 rainfall intensities were 13.17, 25.65 and 39.64 MJ ha^{-1} hour^{-1}, respectively. The return period of intensity I_1 is common in every year, for I_2 it is once in 2 years, and for I_3 it is once in 20 years. For our simulation study, we isolated two plots, each of 2 m × 0.75 m, hydrologically from overland flow, using galvanized sheet metal borders. We ensured that the sides of the galvanized sheets were parallel and that their fronts were perpendicular to the insides. The down-slope border consisted of an outflow lip to channel runoff water into a steel collecting trough located directly beneath the lip. We ensured that the runoff flowed smoothly into the fronts without

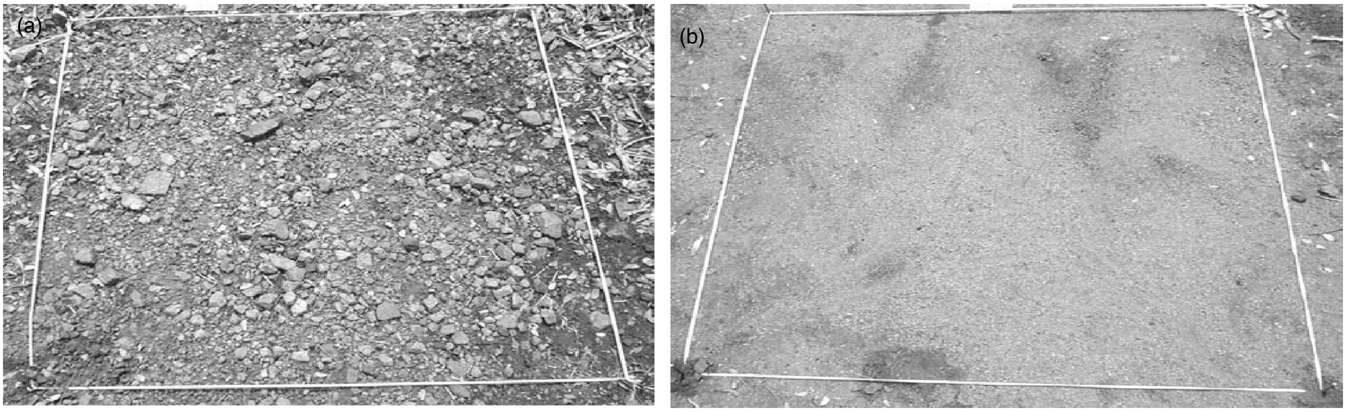

Figure 1 View of two stone cover fields: (a) very intense (64.7%) cover; (b) field with sparse (3.5%) cover (in colour online).

moving sideward or accumulating just before the fronts. Three nozzles (specification: 80100) were mounted 1.10 m apart to a frame and raised at a height of 3 m and oscillated laterally across slope. The drop size determined by the flour pellet method varied between 2.9 and 3.4 mm for all the three intensities (Mishra *et al.*, 2003). We set the intensities by regulating the frequency of oscillation of the nozzles. A vacuum arrangement was used to suck the runoff and sediment from the collecting trough into one of the graduated drums.

Three variables were measured: time to ponding from the start of the rain, time to surface runoff and time to runoff reaching the outlet. Time to ponding was measured when 40% of the surface showed ponds on flat or concave microsurfaces, following Cerdà (2001). Runoff occurred without previous ponding on the steeper microsurfaces, though it could be detected as a shine on such areas before runoff started. Such visual determinations identify where the top few millimetres of the soil are saturated. To ensure uniformity one person made these assessments for the whole set of experiments. The runoff discharge from the plots was measured at 5-minute intervals. Runoff was also sampled for every 5-minute interval for determination of sediment load. The simulated rain was terminated when the rate of runoff became constant. Generally it took 45–50 minutes for each plot to achieve a constant runoff rate. The rain simulator was run for 50 minutes on each plot for each intensity. We determined the sediment load for each

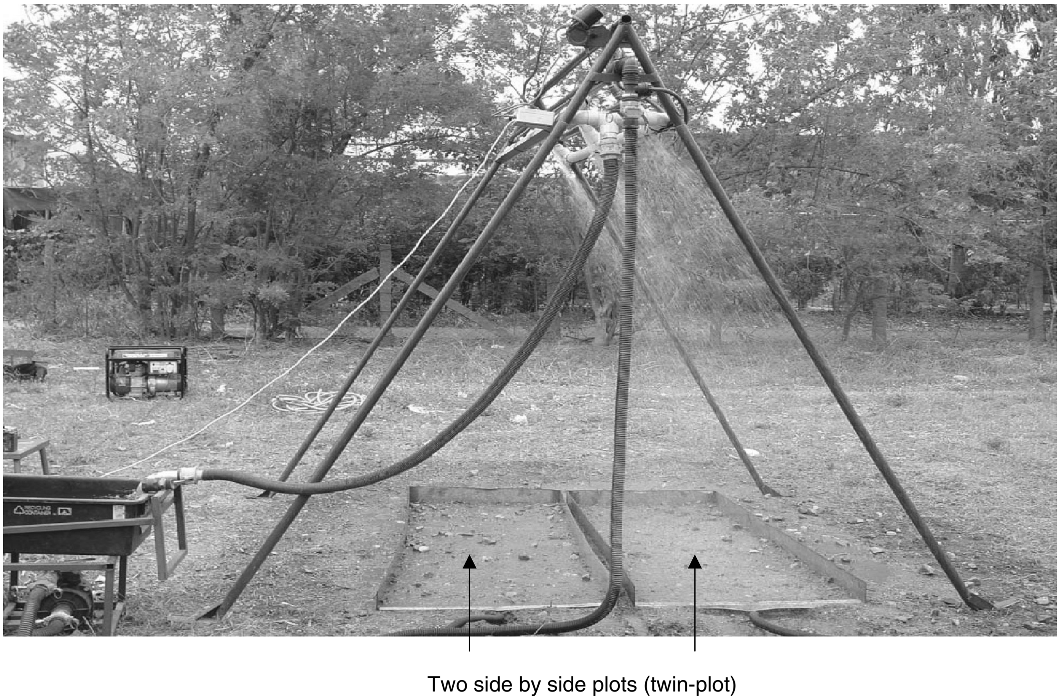

Figure 2 Portable twin-plot rainfall simulator installed in the field (in colour online).

collected sample gravimetrically by drying the entire sample at 105°C. The infiltration rate was calculated as the difference between measured rain intensity and the corresponding runoff rate. The infiltration rate decreased to a constant denoted commonly as final infiltration rate, which varies with rainfall intensity and antecedent water content of the soil.

Surface soil samples of 0–10 cm depth were collected for the analysis of soil physical properties and organic carbon. Bulk density and soil texture were measured by the core method (Blake & Hartge, 1986) and bouyoucos hydrometer method (Gee & Bauder, 1986), respectively. A part of the representative soil samples was dried in air, powdered and passed through a 0.2-mm sieve for determination of organic carbon by Walkley and Black's method (Jackson, 1967, pp. 205–225). The texture of the experimental plots was sandy clay loam (Table 1). There was no significant difference in bulk density and organic matter content between the four plots. All the soils were very dry before the experiment.

Particle-size analysis of sediment

We used laser diffraction for determining the particle-size distribution of sediment. A Malvern Mastersizer S (Malvern Instruments Ltd, UK) with minimum 2 mW helium–neon (633 nm wavelength) 18-mm beam diameter laser of monochromatic light was used. Our principal concern was to determine the proportion of sand, silt and clay within the range of 0.05–2000 μm. Two range lenses, 300RF (0.05–880 μm range) and 1000F (4.2–3480 μm), were used. The results measured by the two range lenses were blended to produce a result with a broader size range. The software generates distributions by volume based on a standard lognormal model. The output was converted to US Department of Agriculture (USDA) textural classes by particle size, namely $< 2\,\mu$m (clay), 2–50 μm (silt), 50–100 μm (very fine sand), 100–250 μm (fine sand), 250–500 μm (medium sand), 500–1000 μm (coarse sand), and 1000–2000 μm (very coarse sand). Tap water was used as the suspension medium with 1-minute ultrasonic action (Chappell, 1998). The sample was sieved through a 2000-μm sieve to obtain a sample within the range of 0.05–2000 μm before it was put into the sizer. The sample retained in a 2000-μm sieve was separately weighted and converted into per cent distribution by weight. The results were divided by 2.65 (the density of the stones is about 2.65 g cm^{-3}) to convert them into volume distribution.

Let us denote the per cent distribution for the USDA particle-size classes as $d_1, d_2, \ldots, d_7$ in ascending order of the size from clay to sand and d_8 for $> 2000\,\mu$m. A weighted mean diameter (MD) in μm was calculated as

$$\mathrm{MD} = \frac{1.025d_1+26d_2+75d_3+175d_4+375d_5+750d_6+1500d_7+3000d_8}{\sum_{i=1}^{8} d_i}.$$

Data analysis

We had four fields, and so four stone covers and three rainfall intensities; this gave 12 treatment combinations. Four sets of observations and analysis were recorded as replication for each treatment. The rainfall simulator was run twice for each field with each rainfall intensity as the simulator covers two side-by-side plots (twin plots) simultaneously in each time. The data for variables were analysed by analysis of variance (ANOVA) with two factors, stone cover and rainfall intensity. We also fitted a non-linear regression for the soil loss on stone cover for each rain intensity.

Results and discussion

Time to ponding, runoff initiation and runoff outlet

The greater the cover of stones the longer is the delay in the generation of runoff. During rain, the first surface change is the onset of ponding. When the intensity decreases, time to ponding as well as time for initiation of runoff increase. The time to ponding ranged from 118 to 475 s. At all the rainfall intensities runoff was fastest on the plots with the least cover of stones (Table 2). In field S_1 runoff started in less than 3 minutes when the rain intensity was 136.8 mm hour^{-1}. Both surface runoff and runoff in the outlet started later as the

Table 1 Initial soil properties of the field under four levels of stone cover

Property	3.5% stone cover (S_1)	17.6% stone cover (S_2)	41.7% stone cover (S_3)	64.7% stone cover (S_4)
Stone /% mass of soil	5.5	40.2	45.9	69.3
Sand (2–0.05 mm) /%	52.9	57.7	59.9	54.9
Silt (0.05–0.002 mm) /%	12.5	9.6	13.7	11.6
Clay (< 0.002 mm) /%	34.6	32.7	26.4	33.5
Soil texture (ISSS)	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Bulk density /g cm^{-3}	1.56	1.59	1.62	1.62
Organic carbon /%	0.63	0.61	0.57	0.63
Soil moisture at the time of experiment /% by weight	3.1	2.6	1.6	2.0
Slope /%	1.2	1.7	1.9	1.6

Table 2 Effect of different stone covers on time to ponding, runoff initiation and runoff in outlet under three rainfall intensities

	Time to ponding /s Rainfall intensity /mm hour^{-1}				Time to runoff initiation /s Rainfall intensity /mm hour^{-1}				Time to runoff in outlet /s Rainfall intensity /mm hour^{-1}			
Stone cover /%	48.5	89.2	136.8	Mean	48.5	89.2	136.8	Mean	48.5	89.2	136.8	Mean
3.5 (S_1)	306	172	118	199	409	271	155	278	445	314	167	309
17.6 (S_2)	331	198	149	226	419	329	247	332	479	390	289	386
41.7 (S_3)	409	244	205	286	469	302	248	340	534	344	311	396
64.7 (S_4)	475	262	224	320	521	478	406	468	569	509	450	509
Mean	380	219	174		455	345	264		507	389	304	
Standard errors:												
Stone cover (S)		6				6				6		
Rainfall intensity (I)		5				5				5		
S × I		11				10				10		

amount of cover increased. For all the cases, it took less than 1 minute from time to runoff initiation to time to runoff in outlet. A stony surface increases hydraulic roughness, and that favours more rapid infiltration and deeper penetration of applied water (Poesen *et al.*, 1990; Poesen & Ingelmo-Sánchez, 1992), which ultimately delays time to ponding and runoff.

Runoff and final infiltration rate

The runoff rate (or simply runoff) generally increased up to 30–40 minutes for each amount of cover at all rainfall intensities (Figure 3). After that, runoff was maintained at steady state. In field S_4 (64.7% cover) runoff was negligible (less than 1 mm hour^{-1}) when the rain intensity was only 48.5 mm hour^{-1}. The steady state runoff was also only 2.5 mm hour^{-1} for field S_3 with cover of 41.7% with the same rainfall intensity. Approximately 26% of the rainfall ran off when the rainfall intensity was 48.5 mm hour^{-1} on field S_2 (17.6% cover) and 51% on field S_1 (3.5% cover). The final infiltration rates were 26, 39, 62 and 83% of rainfall for fields S_1, S_2, S_3 and S_4 when the rainfall intensity was 136.8 mm hour^{-1} (Table 3). It was 31,

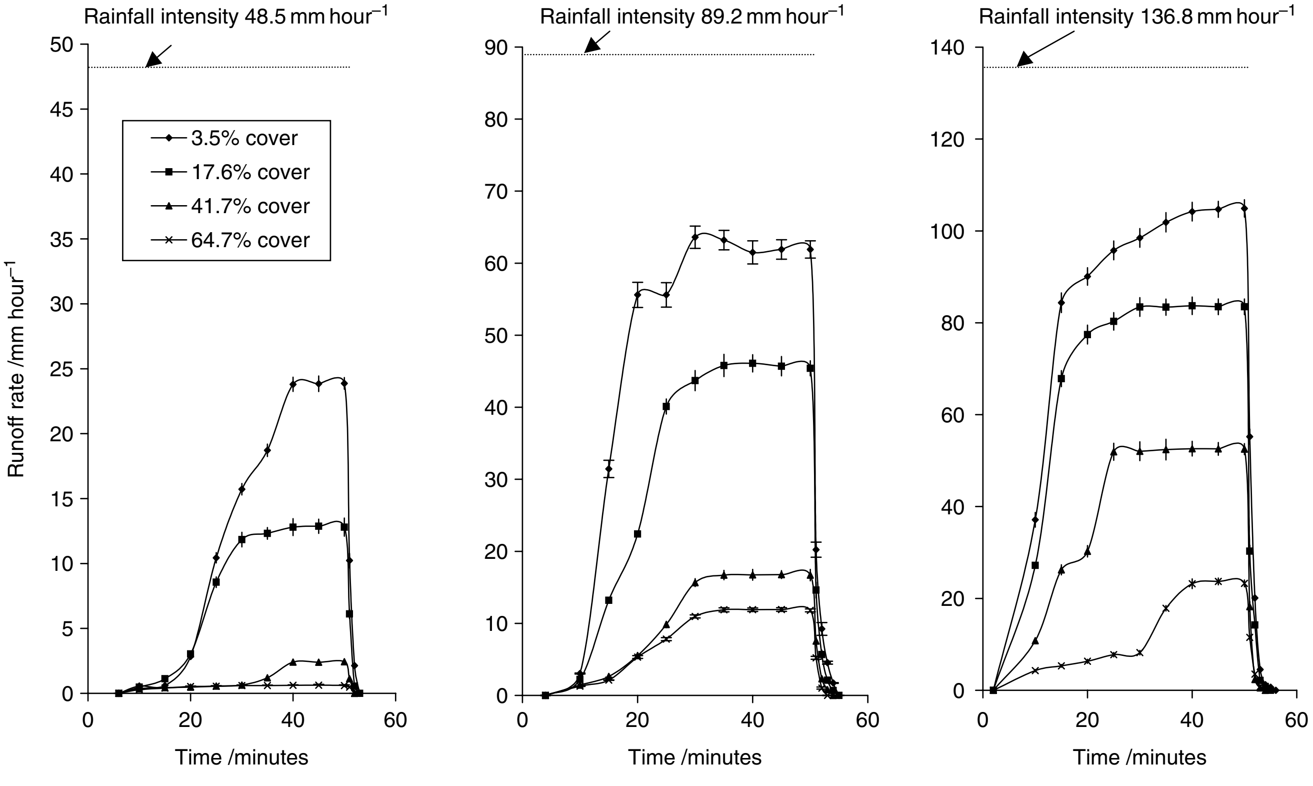

Figure 3 Runoff hydrograph under different stone cover fields with different intensities of rainfall (error bars are ± 1 standard error about means; some error bars are not visible because they are shorter than the symbol size).

Table 3 Effect of different stone covers on final infiltration and soil loss under three rainfall intensities

	Final infiltration /mm hour^{-1} Rainfall intensity /mm hour^{-1}				Soil loss rate /t ha^{-1} hour^{-1} Rainfall intensity /mm hour^{-1}			
Stone cover /%	48.5	89.2	136.8	Mean	48.5	89.2	136.8	Mean
3.5 (S_1)	23.63	27.70	35.60	28.98	1.991	28.717	81.627	37.445
17.6 (S_2)	35.66	43.40	53.01	44.02	0.987	13.273	27.101	13.787
41.7 (S_3)	46.10	72.50	84.83	67.81	0.061	1.831	9.043	3.645
64.7 (S_4)	47.92	77.40	113.57	79.63	0.027	0.868	1.931	0.942
Mean	38.33	55.25	71.75		0.767	11.172	29.926	
Standard errors:								
Stone cover (S)		2.40				0.438		
Rainfall intensity (I)		2.08				0.380		
S × I		4.17				0.769		

49, 81 and 87% of rainfall for rainfall intensity of 89.2 mm hour^{-1} and 49, 74, 95 and 99% of rainfall for rainfall intensity of 48.5 mm hour^{-1} for fields S_1, S_2, S_3 and S_4, respectively.

The positions of the stones is also important in controlling the generation of overland flow. In field S_2 a large proportion of the fragments are embedded in the soil; they comprise more than 50% than the surface stone cover. The runoff in this field was considerably larger than in fields S_3 and S_4. Poesen & Ingelmo-Sánchez (1992) reported similar results when fragments were well embedded in a surface seal. As our experimental plots were very small (2 m × 0.75 m), runoff ceased within 3, 5 and 6 minutes after the end of rain in all the fields when the rainfall intensity was 48.5, 89.2 and 136.8 mm hour^{-1}, respectively.

Sediment and soil loss

The cover of stones determines the amount of sediment detached because it protects the soil surface against the impact of rain drops. This is shown by the reduction of the sediment removed by the runoff as stone cover increases. The sediment concentration increased during the first 20 minutes of rainfall (Figure 4), after which there was a steady decrease of sediment

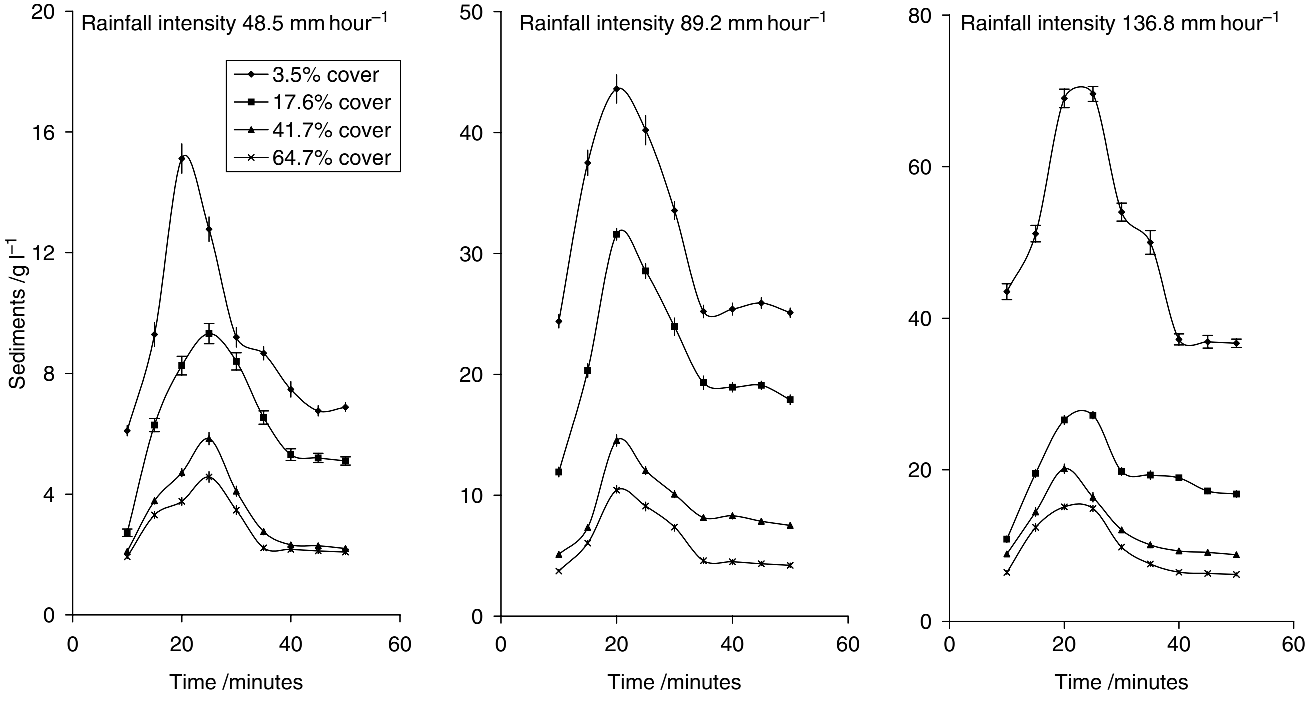

Figure 4 Sediment concentration under different stone cover fields with different intensities of rainfall (error bars are ± 1 standard error about means; some error bars are not visible because they are shorter than the symbol size).

concentration to the end of the experiment. However, Cerdà (2001) reported the sediment concentration was greater at the time of runoff initiation and diminished gradually until the end of a 60-minute application of rain. The accumulated sediment yield increased linearly initially because it took time for the soil to wet as well as for the particles to detach. Sediment yield reached a peak then gradually decreased to remain fairly constant. Evidently, stones protect the soil from erosion. The sediment yield increased from 2 g l^{-1} for 64.7% stone cover with rainfall of 48.5 mm hour^{-1} to 70 g l^{-1} for 3.5% stone cover with 136.8 mm hour^{-1} of rain. Sediment concentration was generally less than 5 g l^{-1} for fields S_4 and S_3 with stone cover of 64.7 and 41.7% and rain falling at 48.5 mm hour^{-1}. But in most instances it exceeded 5 g l^{-1} for covers of 17.6 and 3.5% (fields S_2 and S_1). We calculated the soil loss by multiplying sediment concentration and volume of runoff. Soil loss was less than 1 kg when the rainfall intensity was 48.5 mm hour^{-1} for 50 minutes for all the fields. It was also less than 1 kg in field S_4 with 64.7% cover even when the rainfall intensity was increased to 136.8 mm hour^{-1} for the same duration. Average soil loss rate (Table 3) was less than 2 t ha^{-1} hour^{-1} for all fields even within field S_1 with the least cover of 3.5% when rain fell at 48.5 mm hour^{-1}. Also, the soil loss rate was less than 2 t ha^{-1} hour^{-1} for field S_4 with 64.7% stone cover even when the rainfall intensity was increased to 136.8 mm hour^{-1}. The soil loss was exceptionally large (81.6 t ha^{-1} hour^{-1}) when the rain fell at 136.8 mm hour^{-1} in field S_1 with only 3.5% cover. As the plot was only 2 m × 0.75 m there was little scope of redistribution of sediments within it.

The results of non-linear regression analysis for the effects of stone content on soil loss are presented in Figure 5. The best fitting equation is

$$y = a \exp(-bx),$$

where y is the soil loss rate, x is the per cent cover of stones and a and b are empirical coefficients. Similar equations have also been reported by Chow & Rees (1995). With this equation, the effect of stones on soil loss may be readily incorporated into existing models for predicting soil loss, which helps in conservation planning.

Particle-size distribution

The proportion of clay was very small in the sediment under all combinations of cover and rain intensities (Table 4). Silt (2–50 μm) dominates in all the sediments and contributes more than 50%. Silt-size particles are mostly responsible for the crusting. When the runoff water containing particles of this size deposits its load in the low land a crust is left on drying. Sediment with particles >2 mm was noted in four cases, namely, cover 41.7% + 136.8 mm hour^{-1} intensity, cover 17.6% + 136.8 mm hour^{-1} intensity, cover 3.5% + 89.2 mm hour^{-1} intensity and 136.8 mm hour^{-1} intensity. The weighted mean diameter also varied between 99.5 and 300.7 μm in the various combinations of stone cover and rainfall intensity.

Conclusion

Surface stones retarded ponding and surface runoff, increased final infiltration rates and diminished runoff discharge, sediment concentration and soil loss. The reduction of runoff and soil erosion and increase in infiltration is more effective where stones rest on the soil surface than where they are embedded in the surface seal. Stones enhanced the water percolation and reduced erosion by curbing erodibility and runoff. For the soil under investigation, the reduction in soil loss with stone cover under varying rainfall intensities was expressed by a mathematical relation with a high degree of reliability. These findings

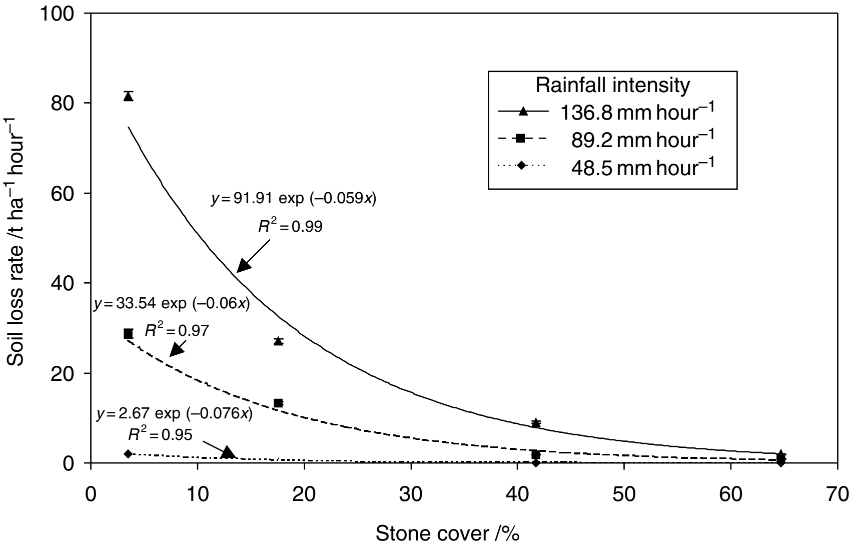

Figure 5 Relation between soil loss y and content of stones x, under three intensities of rainfall (error bars are ±1 standard error about means; some error bars are not visible because they are shorter than the symbol size).

Table 4 Effect of different stone covers (S) on particle-size distribution of sediment under three rainfall intensities (I)

Treatment	Particle-size distribution /%								Weighted mean diameter /μm
	0.05–2 μm	2–50 μm	50–100 μm	100–250 μm	250–500 μm	500–1000 μm	1000–2000 μm	2000–4000 μm	
S_1I_1	1.28 (0.89–1.54)	68.32 (58.24–74.54)	9.90 (8.42–10.96)	4.33 (2.68–6.53)	6.66 (5.63–7.98)	8.22 (7.02–9.66)	1.29 (1.01–2.23)	0	138.75
S_1I_2	1.26 (1.01–1.32)	63.35 (58.34–69.22)	11.98 (7.87–13.16)	10.86 (8.41–12.89)	3.64 (3.07–5.24)	3.56 (3.05–4.51)	4.51 (3.22–6.01)	0.84 (0.69–1.03)	177.67
S_1I_3	1.77 (1.18–2.32)	54.91 (44.75–59.61)	6.77 (5.30–8.25)	10.54 (8.54–11.40)	5.44 (4.21–6.72)	12.87 (10.11–13.98)	5.47 (5.04–6.11)	2.23 (2.01–2.43)	303.69
S_2I_1	1.17 (0.98–1.62)	73.89 (66.31–76.09)	7.33 (6.31–9.01)	3.11 (2.32–5.13)	6.71 (5.22–8.39)	7.04 (6.18–8.19)	0.75 (0.61–1.03)	0	119.38
S_2I_2	1.54 (0.79–2.67)	60.87 (55.64–64.22)	14.28 (10.32–15.28)	8.75 (5.77–9.71)	4.73 (3.58–5.32)	8.75 (7.73–9.11)	1.08 (0.99–1.19)	0	141.43
S_2I_3	1.25 (0.88–1.52)	68.44 (52.25–71.73)	12.2 (11.34–14.79)	2.59 (2.10–4.33)	2.11 (1.51–4.03)	7.87 (6.17–9.33)	3.87 (3.51–4.03)	1.67 (1.51–1.78)	206.58
S_3I_1	0.61 (0.46–0.74)	63.75 (59.14–69.11)	12.89 (7.18–14.47)	12.14 (8.14–14.21)	5.84 (3.26–8.03)	4.77 (1.01–5.45)	0	0	105.17
S_3I_2	1.21 (0.48–1.58)	59.02 (51.61–66.32)	9.87 (8.23–11.04)	12.7 (6.77–14.38)	7.79 (6.03–8.91)	8.82 (4.33–10.71)	0.59 (0.44–0.79)	0	149.20
S_3I_3	0.65 (0.17–0.83)	56.31 (45.11–66.50)	11.9 (6.46–14.27)	10.77 (8.27–12.12)	10.01 (9.27–12.02)	7.67 (5.87–10.63)	2.11 (2.01–2.47)	0.58 (0.45–0.61)	186.53
S_4I_1	0.48 (0.42–0.54)	70.38 (59.14–74.11)	9.34 (8.03–12.72)	8.93 (7.37–10.52)	6.15 (3.44–8.84)	4.72 (3.72–5.73)	0	0	99.40
S_4I_2	0.4 (0–0.69)	70.89 (66.27–72.81)	8.93 (6.65–10.46)	9.48 (7.22–10.31)	4.22 (3.21–6.31)	6.01 (5.42–7.03)	0	0	102.62
S_4I_3	0.55 (0–0.67)	72.54 (62.12–75.26)	9.19 (7.80–11.93)	6.07 (4.91–7.13)	4.64 (2.50–6.64)	6.47 (4.77–8.21)	0.54 (0.48–0.67)	0	110.41
Standard errors:									
Stone cover (S)									7.257
Rainfall intensity (I)									6.077
S × I									12.603

S_1, S_2, S_3, $S_4 = 3.5$, 17.6, 41.7, 64.7% stone cover; I_1, I_2, $I_3 = 48.5$, 89.2, 136.8 mm hour^{-1} rainfall intensity.
Values in parentheses are the range.

have implications for erosion modelling and soil conservation under semi-arid climatic conditions.

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