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RUNOFF AND EROSION FROM VERTISOLS UNDER DIFFERENT MANAGEMENT PRACTICES

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ABSTRACT

Vertisols exposed to rains is highly prone to runoff and erosion resulting in loss of productive surface soil and vegetation supporting rainwater. Persistent research efforts are therefore underway to develop/ identify and improve management practices those are more effective to minimize these losses. In line with such efforts, the reported field study evaluated effects of tillage, mulch and amendments on runoff and erosion losses from vertisols at ICAR-Indian Institute of Soil Science (IISS), Bhopal. A mini rainfall simulator was used to generate rains. Results revealed that runoff was6.9% less under no-tillage compared to tilled soil when a pre-monsoon dry soil was exposed to rain of intensity 6mm min^{-1} for 3-minute. Further, results exhibited that tilled soils with deeper tillage tend to reduce runoff. However, summer tillage with 15 cm depth is desirable to reduce bypass flow in vertisol. Runoff reduced to 1.7, 1.1 and 0.8% with application of Mulch$_{50,}$ Mulch$_{100,}$ and Mulch$_{200,}$ respectively. Amendments such as FYM and gypsum both caused marked reduction in runoff compared to control observed for different durations and amounts of rainfall. Surface mulch, FYM and gypsum reduced runoff and erosion and in general higher rate was more effective. Covering surface completely, applying stem/ stick mulch material across slope and gypsum @ 16 t ha^{-1}were significantly effective.

Key words: Sediment loss, tillage, rainfall simulator, mulch, FYM, gypsum

INTRODUCTION

Land degradation due to water erosion is a serious concern in India (Sehgal and Abrol, 1994). Against the permissible limit of around 3 to 5 t ha^{-1} the estimated annual erosion rate in India is about16.35 t ha^{-1} (Dhruva Narayana and Ram Babu, 1983). Soil erosion with time not only causes irreversible damage to fertile land but also add to various environmental problems including decline in quality of surface water as well as of air (FAO, 2001). As discussed by Lobb (2011) and similar views expressed by many other researchers' erosion and emission of greenhouse gases are positively related. Therefore, erosion is also a contributing factor in climate change process. Vertisols and associated soils occupy nearly 73 M ha of geographical area in India. These soils exhibit wide range in infiltration rate (Bharambe and Shelke, 2001, Choudhary *et al.,* 2015). However, in general infiltration in vertisols is characteristically low due to prominent swelling and consequent reduced number of water conducting pores as well as in number of instances due to presence of hard and compacted subsurface layer (Gupta *et al.,*, 1976). Low infiltration, low organic carbon content, high swelling, undulating topography, mild slope but extending over long distance, sparse vegetation, mainly rainfed cultivation, etc. all contribute to high runoff (40% or more) and erosion losses on these soils (Dhruva Narayana and Ram Babu, 1983). In view of recognized importance of reduced runoff and erosion losses for realizing climate resilient agriculture and the research findings broadly revealing that influence of tillage and crop residues on soil erosion was highly location specific, persistent research efforts are going on to evaluate and develop various site specific management options to minimize these losses (Bhardwaj and Sindhwal, 1998; Ramajayam *et al.,*, 2007; Singh *et al.,*, 2007). The reported work, with objective to evaluate tillage, mulch and amendments vis-à-vis runoff and erosion on vertisols of central India had these considerations in view.

MATERIALS AND METHODS

Rainfall simulator and operation

Description of the simulator and the procedure on measurement of runoff and soil loss as described by Kamphorst (1987). The characteristics of simulated rain using simulator are presented in Table 1.

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Table 1: Specifications of the rainfall simulator (after Kamphorst, 1987*)*

Magnitude of the rain-shower	18mm
Duration of rain-shower	3min
Intensity of rain-shower	6mm min^{-1}
Fall height of drops at top of slope	375 mm
Fall height of drops at bottom of slope	425 mm
Average fall height of drops	400 mm
Diameter of drops	5.9 mm
Mass of drops	0.106 g
Number of capillary tubes	49
Kinetic energy of shower	35.4 J mm^{-1}
Surface area of test plot	0.0625 m^{-2}
Slope of test plot	20%

The runoff and soil - loss test is carried out at moisture content near to field capacity. To achieve this moisture water is applied on test area carefully enough to avoid splash and slowly enough to prevent water saturation of the soil surface resulting in runoff. For this operation a small plastic container with a perforated lid is used. The water discharge from this container is regulated by pushing with the thumbs on the bottom of soft plastic while holding the perforated lid close to the soil surface. The amount of water to be applied for pre-wetting (ml) is estimated by multiplying the difference between the moisture content at pF=2 and the actual moisture (both as volume fractions) by a factor 5 (cm) and a factor 625 (cm^2). Subsequently the test area is sloped to 20%. During 20% slope making some smearing of soil may occur. To open up the natural soil pores below the smeared surface, a thin layer of soil material is removed with the point of a knife. The loose material produced by this operation is carefully removed with a soft brush. The slope length is kept at least 0.4m to accommodate both the test plot and the gutter. At the bottom of the slope a small trench is made in which the container for sample collection of runoff and soil-loss is placed. During the simulation the sprinkling head is moved sideways in all horizontal directions to make sure that the drops emerging from the capillaries are equally and randomly distributed over the test plot. This is done by hand as the sprinkling head slides easily on the upper rim of the support over predetermined distances. After three minutes the simulation is stopped and sediment left behind in the gutter is added to the contents of the sample container with the aid of a wiper. The sample container is taken to the laboratory, where the amounts of runoff and sediment loss (erosion) are determined by a standard procedure of weighing and drying.

Soil

The study was conducted at the Nabibagh experimental farm of ICAR - IISS, Bhopal. Some important properties of the soil are presented in Table 2.

Table 2: Characteristics of the 0-5 and 5-15 cm soil layers of study sites

Soil characteristics	Soil depth (cm)	
	0-5	5-15
Sand (%)	28	28
Silt (%)	23	23
Clay (%)	49	49
Texture	Heavy clay	Heavy clay
Dispersion ratio	0.31	0.32
pH (1:2 soil:water)	8.2	8.1
EC (dS m^{-1})	0.163	0.163
Gravimetric moisture at 1/3 bar (%)	32.6	32.5
Gravimetric moisture at 15 bar (%)	19.8	19.4
Plastic limit (%)	19	20
Liquid limit (%)	58	56
Plasticity index (%)	39	36
COLE rod (%)	14.3	14.7
Bulk density 1/3 bar (Mg m^{-3})	1.52	1.59
Saturated hydraulic conductivity (cm d^{-1})	13.7	14.0
$CaCO_3$ (%)	2.3	2.3

Management

The following management options were evaluated:

Tillage

Four depths of tillage (0.0, 7.5, 15.0 and 22.5 cm) were uniformly imparted to the test area manually with a *khurpi* to simulate no (zero) to deep tillage. For all the treatments three replications were used in this as well as the following studies. Due to large difference between the replicated values of the recorded runoff and sediment loss parameters geometric mean of the replications was used for comparison. For statistical treatment t-test was followed (Topping, 1955; Walpole, 1974).

Mulch:

Leftover residues after threshing of soybean, wheat and mustard as well as the stem of mustard and wheat were used as mulch materials. These were evaluated at four rates namely no (zero) application ($Mulch_0$), 50% of the amount to cover surface of the test area completely ($Mulch_{50}$), 100% of the amount to cover surface of the test area completely ($Mulch_{100}$) and 200% of the amount to cover surface of the test area completely ($Mulch_{200}$). Mustard and wheat stems were evaluated for orientation effects too by placing across as well as along the slope at rate $Mulch_{100}$ (Table 3).

Table 3: Mulch materials and their features

Mulch material	Fineness rating	Length (cm)	Amount to cover100% surface 0.062 m^2 test area (g)
Mustard fine (MF)	2[A]	-	21.68 (3.45[C])
Mustard stem (MS)	5 (Least)	20.7[B]	58.99 (9.44)
Soybean fine (SF)	3	-	29.40 (4.70)
Wheat fine (WF)	1 (Most)	-	14.07 (2.25)
Wheat stem (WS)	4	6.4	20.83 (3.33)

A= By visual observation and feel, B= Geometric mean, C= t ha^{-1}

Amendment

FYM and gypsum at three rates (4, 8 and 16 t ha^{-1}) were evaluated. Required amount of the amendment was mixed thoroughly in 10cm surface layer and imparted four wetting and drying cycles. Mixing was repeated prior to each wetting and drying cycle to achieve improved uniformity in application.

RESULTS AND DISCUSSION

Tillage

Runoff was significantly less in zero tilled (6.9%) compared to tilled soil where it ranged from 22.1% for 7.5cm tilled depth to 14.4% for 22.5cm (Table 4). This may be attributed to the fact that soil was highly cracked due to intense summer drying and the cracks had not closed completely even after pre-wetting of soil and slope making as part of the standard procedure. The existing deep cracks in zero tilled condition had allowed preferred rapid passage to water to deeper depths. However, this phenomenon called also “by pass flow” is not considered desirable because the water moved to deeper depths is normally not available to the plants and causes also loss of nutrients (Smaling and Bouma, 1992). The results have exhibited that for tilled soils runoff had reduced with deeper tillage. This may be attributed to more closing of cracks and loosening of soil to deeper depth resulting in increased water retaining capacity of the soil (Verma *et al.*,, 1979). According to Singh *et al.,* (2014) summer ploughing plays very crucial role in improving the rainfall receptivity of the fields and should be done along contours to check runoff.

Table 4: Effect of tillage on runoff, sediment and sediment concentration from 0.062 m^2 test area

Tillage depth (cm)	Runoff (%)	Sediment (g)	Sediment concentration (g l^{-1})
0.0	6.9[a]	2.4[a]	31.3[a]
7.5	22.1[b]	16.9[b]	67.8[a]
15.0	20.3[b]	8.0[a]	34.7[a]
22.5	14.4[b]	3.8[a]	23.2[a]
Significance level	$P\leq0.05$	$P\leq0.20$	$P\leq0.20$

Values with same letter in a column are statistically at par

Sediment loss was significantly higher for tillage depth 7.5 cm (16.9 g per 0.062m^2test area/ 2.72 t ha^{-1}) compared to all other treatments, which were statistically at par. Sediment loss had decreased with deeper tillage, but was numerically least for no-tilled soil. Free and Bay (1969) reported similar results on runoff and erosion. They reported less runoff as well as soil loss under zero/ no- tillage compared to conventional tillage. Higher erosion under tilled compared to no-tilled condition may be attributed to relatively easy detachment of loosened soil particles from the surface of aggregates under rain impact. Sediment concentration was statistically at par for all the treatments and the trend was reflection of runoff and sediment loss. Taking into consideration depths and corresponding values of the recorded parameters it is suggested that tillage may be practiced to around 15 cm depth.

Mulch

In the reported study the trend for influence of all the mulch materials on runoff, sediment loss and sediment concentration was similar and the difference between any of the two mulch materials was not marked hence the data under all the materials have been pooled together. Results revealed that runoff decreased with mulch and became significant when surface was covered completely (Table 5). Doubling the amount further reduced runoff but not significantly compared to$Mulch_{100.}$ Sediment loss decreased significantly with mulch and decrease was more at higher rates. The difference between the rates was also significant. Sediment concentration decreased with mulch and was negatively related to mulch rate. $Mulch_0$ and$Mulch_{50}$ were statistically at par but significantly higher to both $Mulch_{100}$and$Mulch_{200,}$ later two were statistically at par. Taking into consideration all the three parameters $Mulch_{100}$ is suggested as best option.

Table 5: Effect of mulch amount pooled over all mulch materials on runoff, sediment and sediment concentration from 0.062 m^2test area

Treatment	Runoff (%)	Sediment (g)	Sediment concentration (g l^{-1})
$Mulch_0$	3.0^a	1.8^a	51.7^a
$Mulch_{50}$	1.7^a	0.7^b	35.8^a
$Mulch_{100}$	1.1^b	0.2^c	13.1^b
$Mulch_{200}$	0.8^b	0.1^c	8.2^b
Significance level	$P\leq0.20$	$P\leq0.05$	$P\leq0.05$

Values with same letter in a column are statistically at par

The effect of mulch on runoff could be attributed to impeded flow/ movement of water and consequent longer time/ more opportunity to water for absorption in soil. Since mulch prevented/ reduced direct beating of soil by rain drops and higher amount of mulch provided more cushioning effect, therefore sediment loss was less with mulch and at its higher amount. Among various researchers, Hadda (1983) under natural rainfall and Singh (1992) under simulated rainfall reported similar findings i.e. reduced runoff and less erosion with mulch and more effect at higher rates of mulch.

Table 6: Effect of orientation of mustard stems on runoff, sediment and sediment concentration from 0.062 m^2 test area

Treatment	Runoff (%)	Sediment (g)	Sediment concentration (g l^{-1})
No mulch	3.0^a	1.8^a	51.7^a
MS_{100} across slope	1.3^a	0.2^b	12.7^b
MS_{100} along slope	7.5^b	0.8^{ab}	11.5^b
Significance level	$P\leq0.05$	$P\leq0.10$	$P\leq0.10$

Values with same letter in a column are statistically at par

Mulch material in stem/ stick form may be placed along or across the slope. In this study significantly higher runoff was recorded for orientation of mustard stem along the slope (7.5%), while runoff for no-mulch and across the slope was statistically at par (Table 6). Sediment loss was least for mulch applied across slope. It was significantly less to no-mulch application but at par to along slope application. Along slope application and no-mulch were at par. Sediment concentration for no-mulch was significantly higher to both across and along applications; later two were statistically at par. Maximum runoff for along the slope orientation could be attributed to rapid favored movement of water on the non-absorbing surface of mustard stem, while less runoff for across slope could be attributed to obstacle slowed movement and thus greater opportunity for water absorption by soil. Sediment concentration varied in agreement to sediment and runoff amounts. Accordingly, maximum sediment concentration was for no-mulch followed by mulch across and along the slope, respectively. Because mulch reduced erosion, therefore even though runoff was higher for mulch placed along slope compared to no-mulch, sediment loss was less in previous case. Taking into consideration all the parameters, mulch material in stem/stick form should be applied across the slope.

Amendment

FYM and gypsum both caused marked reduction in runoff compared to control observed for different durations and amounts of rainfall (Table 7). However, the decrease was statistically significant for gypsum 16t ha^{-1} only. The decrease in runoff by FYM and gypsum may be attributed to faster intake of water in the soil consequent to improved aggregates stability resulting from organic matter in FYM and Calcium in gypsum. Improved aggregate stability was supported by water stable aggregate (WSA) > 0.425mm measured by standard wet sieving procedure. WSA was 25, 26, 28 and 29 % for control, 16t ha^{-1} FYM, 4t ha^{-1} gypsum and 16t ha^{-1} gypsum respectively. Runoff data for FYM 4- and 8- t ha^{-1} and gypsum 8t ha^{-1} are not shown for brevity but their effects were also statistically non-significant. Data for FYM 4 t ha^{-1} is included to show that gypsum even at 4 t ha^{-1} is invariably more effective than FYM 16 t ha^{-1}. Positive effect of FYM on reducing runoff has been reported by various researchers (Rao *et al.,*, 1998). For same duration and amount of rain runoff was more at later stage.

Table 7: Effect of amendment on runoff from 0.062 m^2 test area for different durations and amounts of rain

Rain-shower		Runoff (%)				Significance level
Duration (minute)	Amount (mm)	Control	FYM 16 t ha^{-1}	Gypsum 4 t ha^{-1}	Gypsum 16 t ha^{-1}	
2 (0-2)^A	12	4.4^a	2.6^a	0.7^a	0.5^a	$P \leq 0.20$
2 (2-4)	12	13.3^a	7.7^{ab}	3.4^{ab}	1.2^b	$P \leq 0.20$
4 (4-8)	24	25.1^a	18.2^{ab}	10.3^b	8.5^b	$P \leq 0.20$
4 (8-12)	24	26.9^a	26.9^a	24.7^a	16.2^a	$P \leq 0.20$

A= Since initiation of rain event
Values with same letter in a row are statistically at par

In conformity with less runoff, sediment loss was less in amended soil and as expected from the trend of runoff and sediment losses, sediment concentration in general declined with time (For brevity data is not reported). Positive relation between runoff and soil loss has been reported by various researchers (Singh *et al.,*, 2002; Bansal *et al.,*, 2007). From the findings described under this section both FYM and gypsum can be used to reduce runoff and soil loss, but the change is significant only for gypsum @16 t ha^{-1}.

From the simulated rainfall study it is concluded that to reduce significantly runoff and sediment loss on a vertisol it should be: i) tilled to 15 cm depth, it is also desirable to prevent the by-pass flow and ii) surface mulch should be applied to cover completely the surface area and mulch material if in stem/stick form should be applied across the slope. Application of FYM and gypsum reduces runoff and sediment loss.

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