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8th ISCO Conference, 1994, New Delhi, India

Effect of Soil Management Practices on Runoff and Infiltration Processes of Hardsetting Alfisol in Semi-Arid Tropics

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INTRODUCTION

Alfisols of Semi-Arid Tropics (SAT) are often characterised as structurally unstable (EL-Swaify et al., 1985). Under the impact of raindrops the structural instability leads to formation of a seal on the surface. The surface seals reduce infiltration and increase runoff (Moore, 1981). As a result, plant-available water in the profile gets reduced. In most of the SAT Alfisols crop yields are constrained by the plant-available water. Therefore, soil-management practices that reduce losses and increase use of rainwater are needed. Since, reduction in runoff losses can only be achieved by improving infiltration, soil-management practices should aim at maximizing infiltration of rainwater into soil. This in turn is related to the management of surface seals. Various options available to do this are:

(a) breaking the surface seal mechanically,
(b) protecting the surface from raindrop impact.
(c) improving soil structure.

Tillage is by far the most commonly adopted practice to break the surface seal. Protecting the surface from structural degradation is done with application of crop residues as mulches. Practices like addition of farmyard manure (FYM) tend to increase the stability of soil structure. All these options were subjected to a detailed investigation in a long term study at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in collaboration with Queensland Department of Primary Industries (QDPI), Australia. This paper discusses the effect of these management options on runoff and infiltration.

MATERIALS AND METHODS

The experiment was established in 1988 on an Alfisol at ICRISAT Asia Centre, near Hyderabad, Andhra Pradesh, India. The experiment comprised three tillage options and three amendments in a factorial combination. The three tillages were zero tillage (ZT), shallow tillage to 10 cm depth (ST) and deep tillage to 20 cm depth (DT). The amendments were no amendment (B), FYM @ 15t ha^{-1} y^{-1} (F) and rice straw @ 5t ha^{-1} y^{-1} (S). Runoff plots, 28 m long and 5 m wide, with an approximate slope of 2 per cent were used (Smith et al., 1992).

Tillage to the depth and application of amendments as per the treatment were done every year after the onset of monsoon in the second fortnight of June. The test crop was sorghum (variety CSH 9) during 1989, 1990 and 1993 and maize (variety proagro 3448) during 1991 and 1992. Rainfall at the site was measured with tipping bucket pluviometer. Runoff from the plot was measured through tipping buckets with electrical sensors (Smith and Thomas, 1990). The output from the sensors was recorded in a data logger at one-minute intervals. A total of 3658 mm rainfall was recorded over 162 rainy days between 1989 and 1993 at the experimental site. More than 75 per cent of these storms were of size <30 mm. The rainfall and runoff hydrographs were used to study the changes in runoff and infiltration under different management options.

RESULTS AND DISCUSSION

Average annual runoff for different treatments is summarized in Table 1. On average about 28 per cent of rainfall was lost as runoff from untilled, unamended (ZTB) control plots. Significant differences in runoff were observed with different management options. There was no significant difference in runoff due to tillage. Amendments produced significant reduction in annual runoff. The effectivenes of amendments was found to increase over the years. Application of FYM reduced runoff by 25 per cent of control during the second year and gradually increased to 65 per cent of control in the sixth year. Reduction in runoff was 55 per cent in 1989 with the addition of rice straw and increased to 70 per cent in 1993.

Table 1. Annual rainfall and runoff under different soil management options.

Management Option	Runoff (mm) during 1989	1990	1991	1992	1993
Rainfall	941	805	755	557	600
ZTB	284 (100)	105 (100)	217 (100)	272 (100)	153 (100)
STB	272 (96)	107 (102)	217 (100)	232 (85)	121 (79)
DTB	210 (74)	83 (79)	194 (89)	224 (82)	125 (82)
ZTF	205 (74)	77 (73)	127 (59)	134 (49)	50 (33)
STF	218 (77)	68 (65)	101 (47)	103 (38)	57 (37)
DTF	191 (67)	64 (61)	106 (49)	120 (44)	55 (36)
ZTS	121 (43)	35 (33)	52 (24)	52 (19)	44 (29)
STS	135 (48)	43 (41)	53 (24)	62 (23)	48 (31)
DTS	124 (44)	37 (35)	47 (22)	61 (22)	56 (37)
LSD 0.05	36	22	45	35	21

Legend:
ZT: Zero tillage; ST: Shallow tillage to 10 cm depth;
DT: Deep tillage to 20 cm depth; B: Bare surface;
F: Farmyard manure @ 15t $ha^{-1}y^{-1}$;
S: Rice straw @ 5 t $ha^{-1}y^{-1}$;
Figures in parentheses are runoff as per cent of ZTB.

Tillage

Normally tillage increases infiltration and reduces runoff by breaking the surface crust. Data from this experiment suggests that the increase in infiltration had no effect on the annual runoff and the differences across tillage treatments were small and inconsistent (Table 1). Yule et al. (1990) studied the responses over time and showed that tillage reduces runoff, for a short period after the tillage operation but subsequently produces more runoff presumably due to structural degradation and formation of crust at the surface.

Freebairn and Gupta (1990) reported rainfall-since-tillage as a simple measure of the energy input from rainfall required to develop a crust. Runoff from STB and DTB as per cent of ZTB were plotted against rainfall-since-tillage to follow the changes in runoff infiltration process (Fig. 1). The relations clearly show an increasing trend in runoff with increasing rainfall since tillage. There is considerable noise in the obeserved relations and the same is attributed to the variations in soil and climatic conditions. Runoff during a storm was found to be influenced by amount and intensity of rainfall, soil cover and antecedent moisture conditions (Rao et al., 1994).

Intially, runoff from tilled plots was very low (Fig. 1). There was a sharp reduction in infiltration and runoff increased to more than 60 per cent of the control by the time antecedent rainfall since tillage increased to 70 mm. Most of the tillage benefits were lost and runoff was reverted to pre-tillage levels with about 350 mm rainfall since tillage. Runoff patterns under ST and DT are very similar indicating that, the process of structural

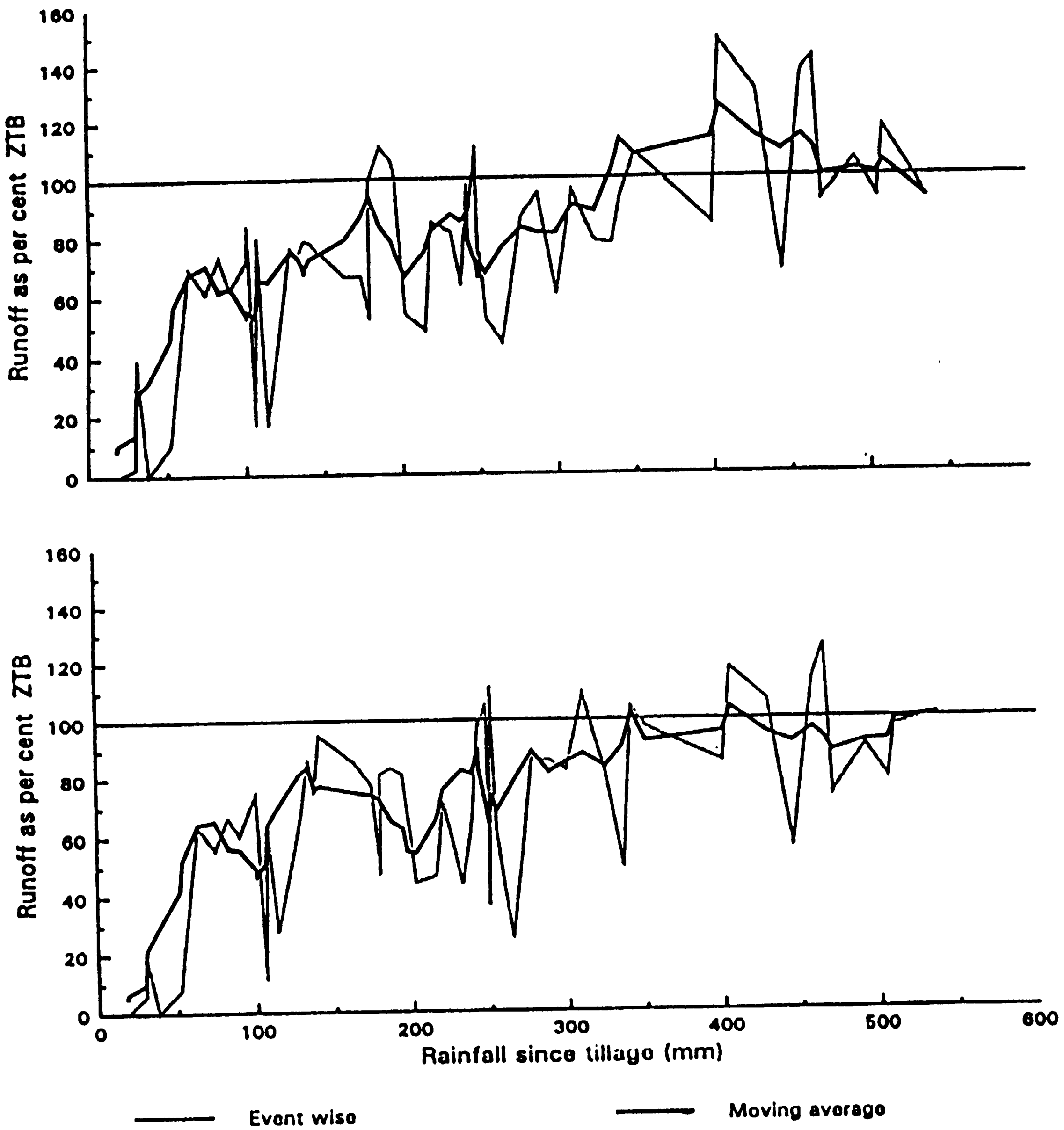

Fig. 1. Effect of rainfall since tillage on runoff: a. Shallow tillage b. Deep tillage.

degradation and formation of surface seal is the same and has no relation to the depth of tillage. We tried to quantify the infiltration rates by matching the rainfall and runoff hydrographs for a few events at different times after tillage. Initially, infiltration rates were very high and there was no runoff from tilled plots with a rainfall of 45 mm (Table 2). After about 100 mm rainfall-since-tillage, infiltration rate was 40 mm h^{-1} with ST and was reduced to 11 mm h^{-1} after about 180 mm rainfall-since-tillage. Thereafter, changes in infiltration rates were marginal. Slightly higher infiltration rates were observed under DT compared to ST but the trends in reduction were similar.

The results clearly demonstrate that, the benefit of increased infiltration rates achieved by mechanically breaking the surface seal persist for a short

period. The sealing of surface pores and reduction in surface roughness with subsequent rainfall sharply reduced infiltration. Frequent shallow tillages may help maintain high infiltration rates, but they are reported to make the soil susceptible for structural degradation by reducing the organic matter content of the soil (Dalal and Mayer, 1986).

Table 2. Effect of rainfall since tillage on infiltration of rainwater.

Date	Rainfall (mm)	Rainfall since tillage (mm)	Infiltration rates (mm h^{-1}) with			
			Shallow tillage		Deep tillage	
			Initial	Final	Initial	Final
10.6.90	45	52	no runoff	no runoff	no runoff	no runoff
2.7.92	70	101	40.2	3.9	43.2	5.3
10.7.91	51	179	11.1	3.5	11.2	4.1
7.8.91	42	288	9.0	3.1	9.8	3.6
11.9.89	37	405	9.3	2.6	9.4	2.9

Mulching

Surface mulches help reduce structural degradation by dissipating the impact of raindrops in short term and by increasing faunal activity in longer term. Surface mulches are now considered as an essential aspect of soil management to increase infiltration (Parr et al., 1990). Runoff was significantly reduced under all tillages when surface was covered with rice straw (Table 1). Runoff from mulched plots had no relation with rainfall-since-tillage. Since effect of mulching depends on the time for which the mulch stays on the surface, runoff as per cent of bare was plotted against time (Fig. 2). Initially, runoff was less than 60 per cent of the bare and decreased further in the following years. Runoff was higher for a short period during off-season. This was mainly due to very little cover left after degradation by termites and other soil animals (Rao et al., 1994). Long-term improvement in infiltration rates can be seen from the reduction in runoff over years. The option to protect the soil surface with residue cover is highly effective in reducing runoff and increasing infiltration. There was no significant difference in runoff due to tillage when surface mulch was supplied. This indicated that the infiltration rates under mulch were higher than those obtained with tillage and the tillage effects were masked by the cover effects.

Surface cover seems to be the most important factor for maximizing infiltration. However, application of mulch is constrained by the availability of residues and their requirement for other competitive uses like fuel and fodder. Research efforts need to be made to identify the ways and means to improve soil cover through suitable changes in cropping systems.

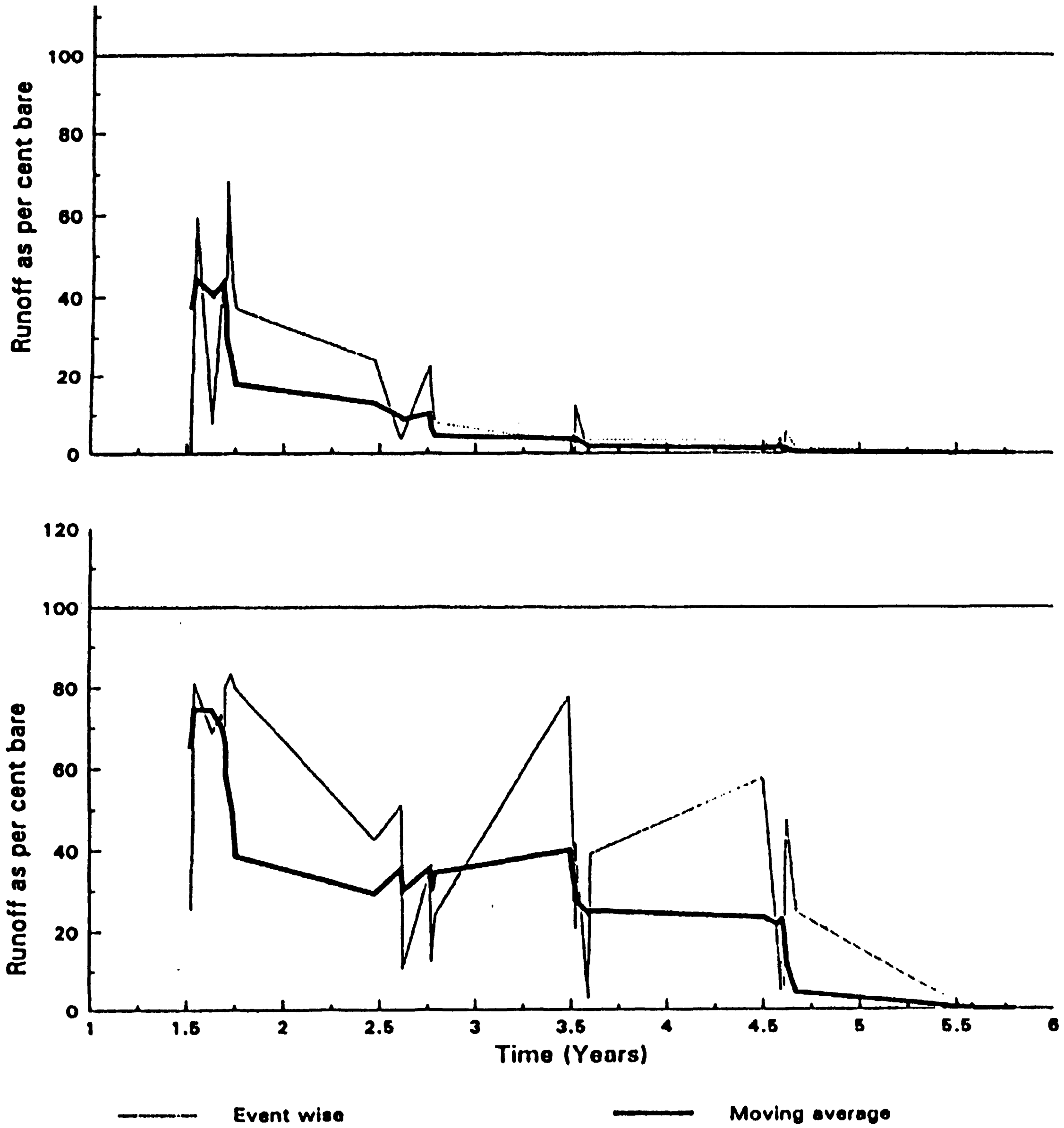

Fig. 2. Cumulative of: (a) straw mulching and (b) FYM application on runoff

Organic Amendments

Addition of organics like FYM was reported to increase and/or stabilise soil structure which in turn increase infiltration and reduce runoff (Biswas et al., 1964; Venkateswarlu, 1987). Runoff from FYM -amended plots was significantly lower than control and tillage had no significant effect on runoff when supplied with 15 t $ha^{-1}y^{-1}$ of FYM (Table 1). It is interesting to see that runoff from tilled plots is higher than that of untilled plots but amended with FYM. This shows that tillage is not important as a soil and water conservation measure. The relation between runoff as per cent bare and time showed a gradual decline in runoff over the years (Fig. 2). The reduction was higher in events during crop season compared to off-season events. The high peaks in the graph represent events during off-season. It was observed that crop establishment and crop growth were faster and better in FYM plots compared to unamended plots. This might have contributed additionally to the direct effects of structural amelioration.

Loss of soil organic matter in soils of SAT regions is identified as a major cause for degradation (Pimental, 1993). Results from this study clearly show the potential of organic additions in reducing runoff and increasing infiltration.

CONCLUSION

Soil-management practices have large effects on runoff and infiltration. The two important aspects of soil management are protection of soil surface from raindrop impact and improving soil structure by addition of organics. In this study crop residues were used to achieve this. In view of the large demand for crop residues across SAT regions, there is a need to identify practices that can improve ground cover and organic matter content. The general practice of tillage is not beneficial. The big reduction in runoff with mulching and organic additions may result in higher drainage and creation of a groundwater resource. In these areas ground water is an important resource. Sustainable agricultural production to a great extent in SAT depends on the management of soil for efficient utilization of rainwater and effective management options need to be developed using the strategic information now available.

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CP 964

Soil and Water Conservation through Crop Cover and Residue Manegement

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INTRODUCTION

Soil erosion by water is a serious hazard in the submontane tract of Punjab which is locally known as " Kandi" area. It lies in the north-eastern part of the state in the form of a long narrow strip of 10–20 km width and is located between 30°40' to 32°30' N latitude and 75°30' to 76°48' E longitude. Out of total area of 0.5 million hectares about 30 per cent is under forest and 1.1 per cent under permanent pasture. Of the 52 per cent cultivated ares, about 60 per cent is rainfed. The area represents Siwalik deposits alluvial detritus derived from subaerial wastes of mountains, swept down by rivers and streams (Wadia, 1976). Soils of the area are generally light-textural with loamy sand and sandy loam as dominant textural classes. They are low in organic matter content (< 0.4%). Most of the soils are represented by Ustifluvents, Ustipsamments and Ustochrepts with local Haplustalfs and Fluvaquents (Sehgal and Sys, 1970).

Rainfall constitutes the major water resource with an average annual value of 949 ± 304 mm, increasing towards the nothwest and south-west to about 1700 m. The coefficient of variation averages 0.35 with values ranging from 0.24 to 0.47 implying high interannual variability. Rain during *kharif* season is of major concern as it constitutes the major portion of annual rain and causes soil erosion. Success in increasing production and improving conditions in the area depends mainly on better rainwater management. Summer monsoon rains are received in 20–30 rainstorms, out of which 10–12 cause overland flow. Two to three of the rainstorms are of rain intensity greater than 120 mm h^{-1} (Fig. 1). Rainstorms with maximum 30-minute intensity of more than 240 mm h^{-1} have also been