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SOIL MANAGEMENT OF ALFISOLS FOR WATER CONSERVATION AND UTILIZATION

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ABSTRACT

Alfisols are abundant soils used for rainfed agriculture but have a wide range of problems due to low infiltration rates. We studied a range of soil and crop management options (tillage and mulching for annual crops, and perennial crops) to increase infiltration during 1989 and 1990. With annual crops straw mulch and FYM mulch reduced runoff by 52% and 17% respectively compared to bare treatments but tillage had small and inconsistent effects. Perennial crops produced high runoff during the establishment period in 1988 and subsequently a wide range of response depending on the foliage structure of the crop. Tall growing perennial pigeon pea did not reduce runoff compared to crops with no surface amendment but the dense, short, spreading stylosanthes hamata reduced runoff more than straw mulch. Reduction in runoff will decrease soil erosion and may increase drainage by up to 200 mm per year. This drainage is a massive potential resource for deep rooted crops or irrigation from groundwater. Sustainable agricultural production at a watershed scale will involve soil management to increase infiltration in rainfed areas and exploitation of consequent increases in groundwater resources by irrigation or deep rooted crops.

INTRODUCTION

Alfisols are an abundant soil order in India covering over 33% of the agricultural area (Kampen and Burford 1980) and often occur in the upper sections of watersheds. Due to this topography, Alfisols are typically used for dryland agriculture but crop production is limited by high runoff, high erosion and poor crop establishment and growth. These problems are all linked to low infiltration rates. Soil management, particularly the use of straw mulches when combined with zero tillage and the use of ley pastures, has dramatically increased in filtration of an Alfisol at ICRISAT (Yule et al, 1990).

These authors reported that in 1989 straw mulches increased infiltration throughout the year including during the crop growth period when a full crop canopy cover was present, and during the summer and the pre-monsoon storm periods nine to eleven months after the mulch was applied. They also found that tillage produced variable responses; for a short period following tillage infiltration was greatly enhanced but during the subsequent cropping period infiltration in tilled plots was less than in zero-tilled plots. A short, dense and spreading pasture legume, Stylosanthes hamata produced the highest infiltration but only 10 mm more than the zero tillage plus straw mulch treatment.

Increasing infiltration can increase cro production and decrease soil erosion. Crop production will be increased if the increased infiltration improves crop water availability during the growing season. Soil water balance, derived at ICRISAT (El-Swaify et al. 1987) indicate that both runofff and drainage are significant water balance components in the Alfisols at Patancheru (annual rainfall 760 mm). Consequently soil management to increase infiltration will both improve crop water availability and reduce losses as unoff. However the already significant drainage component will increase. Some consequences of this result for watershed management are discussed in this paper. In addition the associated decrease in runoff will decrease soil erosion directly and probably due to a complementary reduction in sediment concentration. Consequently management to increase infiltration is considered generally beneficial.

Perennial species increase infiltration by protecting the soil surface from raindrop impact, by increasing the soil water deficit, by increasing soil organic matter and consequently surface soil structural stability, by encouraging soil faunal activity and by producing root channels through relatively impermeable soil horizons. A short, dense spreading plant such as a legume or a stoloniferous grass may exhibit these benefits very well and also impede runoff by the stems. Tufted grasses may produce high infiltration in the tufts but low infiltration in bare areas between tufts. Trees and shrubs with little or no understorey may offer little protection to the soil surface since drops falling from leaves may attain considerable kinetic energy before striking the soil. This paper reports and compares the runoff and consequent infiltration produced by a range of tillage and mulching management treatments and from various perrenial vegetation types.

MATERIALS AND METHODS

The experiment is located at ICRISAT Centre, near Hyderabad, Andhra Pradesh on an Alfisol of variable depth to a murrum or weathered parent material (30 cm -100 cm) using plots 28 m long (down slope) and 5 m wide. The land slope is 2%. There are 15 treatments and 3 replications

Annual crops are grown in 9 treatments involving 3 tillage options (zero, 10 cm deep, 20 cm deep) and 3 amendments (nil, 15 t ha^{-1}) farm yard manure, 5 t ha^{-1} rice straw). The remaining treatments are perennial pigeonpea, Cenchrus ciliaris and Stylosanthes hamata alone or in combination. These treatments will be removed after four years and all treatments will have annual crops for a further two years.

The experiment was established in 1988. Tillage treatments were imposed in July, just before sowing of millet. The amendments were applied soon after sowing. The treatments involving perennial species were sown in July 1988. In 1989, the treatments in the annual crop plots were imposed in late June early July and sorghum sown in mid July. Tillage plots received a shallow (7 cm) cultivation to break the crust, and then about a week later a tyne cultivation (50 cm spacing) to the treatment depth. Amendments were added in three equal increments after each tillage operation and after planting. In 1990, tillage and amendments were applied in the same way from mid June to early July. Sorghum was sown on 12 July.

Rainfall at the site was recorded each minute in a tipping bucket pluviometer. Runoff from each plot was collected in a trough and directed through calibrated tipping buckets with electrical sensors (Smith and Thomas, 1990). The output from the sensors was recorded in a data logger at one minute intervals. Daily values of rainfall and runoff were calculated and analyzed statistically using analysis of variance by GENSTAT Version 4 package.

RESULTS AND DISCUSSION

Monthly rainfalls from June 1988 to November 1990 are presented in Table 1. Rainfall in 1988 was below the median (June to November) while in 1989 and 1990 it was above the median. The monthly distribution varied across the years. In 1988 distribution was unimodel with most rain in late August-early September. In 1989, most rain fell during the land preparation and crop establishment period (late June and July) and during the main crop growth period in September.

Table 1. Monthly rainfall in 1988, 1989 and 1990 and ICRISAT long term median monthly rainfall.

Month	Mediam	1988	1989	1990
March	6	-	66	0
April	17	-	0	0
May	21	-	46	141
June	107	42	74	101
July	169	163	397	75
August	156	211	98	238
September	154	163	239	88
October	53	0	21	163
November	13	0	0	2
Total	696	578	941	808

In 1990 the land preparation and crop establishment period had low rainfall but considerable rain fell during the main crop growth period (August) and during crop maturity (October). The automatic data logging equipment broke down for three days in July 1989 (rainfall of 157 mm and associated runoff were lost) and for one day in August, 1990 (rainfall of 92 mm and associated runoff were lost). Consequently the total rainfalls discussed in this paper are 800 mm in 1989 and 716 mm in 1990.

The annual runoffs for each treatment in 1988, 1989 and 1990 are presented in Table 2. Runoff was much lower in 1990 (8% of rainfall) than in 1988 (29% of rainfall), than in 1989 (22% of rainfall). This result was due to the rainfal distribution in respective years. In 1988 there was a high proporation of runoff from continued heavy rain late in the growing season; in 1989 high rainfall fell before crop establishment and produced high runoffs, in 1990 most rain fell late in the growing season when plant cover and soil water deficit reduced runoff. Also the rainfall intensities in 1990 were generally lower than in 1989, particularly in the preplanting period.

Table 2. Runoff and ranking (1 = highest, 15 = lowest) for all treatments in 1988, 1989 and 1990.

Treatment		1988		1989		1990	
		Runoff (mm)	Ranking	Runoff (mm)	Ranking	Runoff (mm)	Ranking
T_0	B	126	7	270	1	93	3
	F	110	11	213	5	66	5
	S	64	15	108	14	36	10
T_{10}	B	116	9	265	2	98	1
	F	124	8	220	4	60	8
	S	74	13	125	11	26	14
T_{20}	B	116	10	209	6	76	4
	F	94	12	178	8	66	6
	S	73	14	117	13	34	11
PP 1		30	5	257	3	95	2
PP+ S		127	6	118	12	24	15
PP+ S+C		133	3	130	10	26	12
C		147	2	142	9	66	7
C + S		153	1	180	7	51	9
S 133		4	96	15	26	13	
Mean S.E		18.8		17.2		12.0	

T0, T10, T20 = depth of tillage
B = bare, F = farm yard manure, S = rice straw
PP = perennial pigeonpea, S = Stylosanthes hamata
C = Cenchrus ciliaris

The response to treatment among the tillage x amendment treatments was very silmilar in all years. Straw mulch treatments produced the lowest runoff for each tillage option while FYM produced a small and generally consistent reduction in runofff compared to the bare treatments. Compared to the bare treatments, straw mulch produced on average 52% less runoff and FYM mulch produced 17% less runoff. The differences across tillage treatments were small and not consistent. It is quite unexpected that tillage would produce similar runoff to zero tillage but Yule et al (1990) showed that tillage reduces runoff for a short period after the tillage operation but subsequently produces more runoff, presumably due to structural degradation. The 1990 results support the conclusions made by Yule et al (1990).

The treatments with perennial crops produced more runoff in 1988 than the treatments with annual crops. This was in marked contrast to the general response in 1989 and 1990 when perennial crops, except sole piceon pea, produced low runoff.

We suggest that this response were due to the relatively long period required by these species to develop foliage cover. In 1989 and 1990 the treatments with perennial crops produced surprisingly almost as wide a range in runoff as the tillage x amendment treatments. In both years, the Stylosanthes hamata produced the lowest runoff and perennial pigeonpea produced the highest runoff. Perennial pigeonpea had generally similar runoff amounts to the mean of the bare mulch treatments in annual crop plots. An understorey of Stylosanthes or Cenchrus reduced runoff on average by 78% in pigeonpea plots. The Cenchrus and Cenchrus + Stylosanthes plots produced quite high runoff and also higher than when in combination with perennial pigeonpea. These responses appear to reflect the growth habits of the perennial plots. Stylosanthes hamata is a dense, short spreading legume that provides total ground cover against raindrop impact and considerable resistance to overland flow, as evidenced by small residue dams that build up within the plots. Cenchrus ciliaris is a medium height tufted grass that can provide total ground cover but after harvests large areas of bare soil between tufts are exposed. It is also likely that these bare areas have low infiltration capacities. When grown with Cenchrus, the Stylosanthes is more upright, provides less cover and less resistance to overland flow, presumably due to competition for light with the grass. Perennial pigeonpea produces a dense canopy between 1 and 3 m above ground due to regular pruning. Consequently the soil surface underneath perennial pigeonpea is exposed to drops falling from the canopy. Since runoff from the sole pigeonpea plots is similar to runoff from bare tillage plots, the data suggest that a pigeonpea canopy provides little effective protection for the soil surface. Since the soil is kept free of weeds, there is also no resistance to overland flow. As expected therefore, an understorey of Stylosanthes or Cenchrus with the pigeonpea greatly reduces runoff.

The total infiltration for the treatments in 1989 adn 1990 is presfented in Table 3. 1988 was not included because of the slow establishment responses previously noted for the treatments with perreenial crops. Table 3 shows that the straw and Stylosanthes plots had remarkably similar responses in each year, about 670-700 mm. The differences across the two years were greater for treatments with high runoff because of the smaller differences in total runoff in 1990, as already discussed. Preliminary water balance estimates, assuming a soil water holding capacity of 100 mm, indicate annual evapotranspiration could be about 500 mm. We will caluculate better water balance estimates when all parameters have been determined from our data. However these preliminary estimates suggest the drainage term could be 50-200 mm per year depending on annual rainfall quantity
and variability. This value is similar to data presented in ICRISAT (1991). In addition soil managements which decrease runoff will probably produce more drainage since we expect little difference in evapotranspiration. Simplistically these improved managements, which decrease runoff, will convert it to increased drainage. This will recharge the subsoil below the depth of annual crops and/or enter the groundwater. If straw management can increase groundwater accessions by 100 mm, this amounts to an enormous resource at a watershed scale. In a 500 ha watershed, the accession would be 500,000 m^3, enough to irrigate 100 ha with 500 mm or 200 ha with 250 mm in the post rainy season. Yule et al (1990) estimated a potential to increase grain production by 50m tonnes in India. We fully recognize that there are many constraints and limitations to the achievement of this potential, however the potential is too great to be ignored. Soil management to increase infiltration, specifically a reduction in tillage and retention or application of crop residues or straw as a surface mulch, will in addition improve or stabilize crop yields in dryland areas by reducing crop water stress, and decrease soil erosion by reducing runoff. These responses combine to form a key and essential role in sustainable agricultural development.

Table 3. Annual infiltration (rainfall minus runoff) for all treatments in 1989 and 1990.

Treatment			Infiltration
		1989 (mm)	1990 (mm)
T_0	B	530	623
	F	587	650
	S	692	680
T_{10}	B	535	618
	F	580	656
	S	675	690
T_{20}	B	591	640
	F	622	650
	S	683	682
PP		543	621
PP +	S	682	692
PP +	S + C	670	690
C		658	650
C + S		620	665
S		704	690

* See Table 2 for treatment identification.

CONCLUSION

The soil management options studied in this experiment have produced large effects on runoff and infiltration, and have indicated principles to apply to management of Alfisols. The most important consideration is the protection of the soil surface from rain drop impact, either direct impact or drips from foliage. This can be best achieved by straw mulches or a dense short spreading perennial crop. In cropped areas, reduction in tillage is also beneficial for soil structure and necessary to maintain the mulch cover. It is necessary to provide surface soil cover under tall crops such as perennial pigeon pea. Reduction in runoff will decrease soil erosion but increase drainage, which can become a massive resource for exploitation by irrigation from groundwater or by deep rooted crops. Sustainable agricultural production at a watershed scale will involve soil management to increase infiltration in rainfed areas and exploitation of consequent groundwater resources by irrigation or by deep rooted crops.

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