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Improved rainfed farming for semiarid tropics—implications for soil and water conservation

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Alfisols and Vertisols are major soil orders found in the semiarid tropics. In most semiarid regions, the average annual rainfall would seem to be enough to produce one or two crops per year; however, rainfall patterns are erratic with frequent dry periods within the rainy season. The uncertainties have kept farmers from investing substantially in the development of the land resource base and in the use of high yielding varieties, fertilizers, and other inputs (4). Increased population has resulted in a need for fundamental changes in production systems. Shifting cultivation is being replaced by permanent agriculture, and farmers' attempts to further increase production have caused an extension of agriculture to marginal lands subject to frequent crop failure, primarily because of inadequate moisture. Intensified land use under existing systems may become self-defeating because it results in increased runoff and soil erosion, reduced groundwater recharge and downstream flooding of agricultural lands. As a result, the land resource base is shrinking and its productive capacity is diminishing. Thus, a scheme of resource management combining effective conservation and utilization of soil and water with crop production systems that maintain productivity and assure dependable harvest is urgently required (5).

The International Crops Research Institute for the Semi Arid Tropics (ICRISAT) in Hyderabad, India, has studied a wide range of soil and water conservation and cropping management systems in small, natural watersheds on Vertisols and Alfisols. Determinations of runoff, soil erosion, crop production, rainfall use efficiency, labor use efficiency, and

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profitability in operational-scale research have been made using both improved and traditional animal-drawn implements. Results from these Vertisol watersheds have shown several improved management systems to be more effective and profitable than the traditional system of monsoon fallow. Among the improved systems, the broadbed and furrow system of soil and water management was the most effective and profitable on Vertisols (*1*, *2*). In contrast, this system did not show any particular advantage from the standpoint of conservation or profitability over other improved systems on Alfisols. This paper discusses the hydrologic and soil loss consequences of alternative management systems for Vertisols and Alfisols. Likely requirements for effective farming systems management on these two widely contrasting semiarid soils are considered.

Experiments on semiarid soils

Experiments were conducted at the ICRISAT research center near Hyderabad. The mean annual rainfall is about 760 mm (*6*).

Experiments on Vertisols. Five watersheds of 2.4 to 4.2 ha each were studied. The land management systems investigated were (1) a broadbed and furrow system at 0.6 percent slope, (2) a broadbed and furrow system at 0.6 percent slope within existing farmers' field bunds, (3) a broadbed and furrow system at 0.4 percent slope, (4) a flat on grade at 0.6 percent slope, and (5) a traditional flat system. In the first four treatments the improved system of farming—improved varieties and cropping systems, chemical fertilizers, improved farm implements and managements—was used. Intercrops of maize or sorghum with pigeonpea and sequential crops of maize and chickpea were superimposed on these treatments. In the fifth treatment the traditional system of farming—local varieties, farm yard manure, traditional implements and management—was used. Traditional practice was simulated in treatment by keeping the watershed fallow during rainy season and growing sorghum on residual soil moisture in the postrainy season.

The Vertisol belongs to the very fine, clayey, montmorillonitic, calcareous hyperthermic family of Typic Pallusterts (Table 1). The soil is self-mulching and exhibits cracking and becomes hard when dry and sticky when wet. Because of the prevailing 2:1 clay type and the relatively high clay content, the soil is usually imperfectly drained and has a moderate to low hydraulic conductivity.

Experiments on Alfisols. Four watersheds of 1.1 to 2.1 ha each were used to study the following land management systems: (1) flat on grade with graded bunds at 0.6 percent slope, (2) broadbed and furrow system at 0.6 percent slope, (3) traditional flat with contour bunds, and (4) tradi-

Table 1. Vertisol properties (watershed BW1, ICRISAT).*

Depth (cm)	Particle Size Distribution Percent of Total			Coarse Fragments (>2 mm)	Moisture Holding Capacity (%)		Bulk Density (g/cm³)
	Clay (<.002 mm)	Silt (.05 – .002 mm)	Sand (2 – .05 mm)		1/3 bar	15 bar	
0-15	51.7	20.8	21.5	6	31.0	19.5	1.20
15-30	53.9	20.5	19.6	6	32.2	19.7	1.30
30-60	55.5	19.8	18.7	6	33.5	20.2	1.40
60-90	58.0	20.1	15.9	6	34.4	20.0	1.40
90-120	61.2	20.0	11.8	7	34.3	20.0	1.42

*Some data taken from Murty, et al., 1981.

Table 2. Alfisol properties (watershed RW1C, ICRISAT).*

Depth (cm)	Particle Size Distribution Percent of Total			Coarse Fragments (>2 mm)	Moisture Holding Capacity (%)		Bulk Density (g/cm³)
	Clay (<.002 mm)	Silt (.05 – .002 mm)	Sand (2 – .05 mm)		1/3 bar	15 bar	
0-15	13.2	6.1	75.7	5.0	11.2	4.4	1.50
15-30	22.3	9.7	63.0	6.0	14.6	7.2	1.58
30-60	31.1	9.0	51.9	8.0	15.0	8.1	1.59
60-90	38.3	8.8	41.9	12.0	14.8	8.2	1.46

*Some data taken from Murty, et al., 1981.

tional flat with field bunds. In the first three treatments the improved system of farming and in fourth treatment the traditional system of farming was used. The cropping systems superimposed on these treatments were intercrops of pearl millet or sorghum with pigeonpea and sole crops of pearl millet or sorghum.

The soil belongs to the fine, kaolinitic, isohyperthermic member of the family of Udic Rhodustalfs (Table 2). It has an unstable surface structure and a strong tendency to display crusting and hardening when dry. Subsurface layers are very hard and compact and have relatively low hydraulic conductivities. The soil is low in organic matter, nitrogen, and phosphorous. The Alfisols at the research site have depths from 90 to 110 cm and slopes from 1 to 2.9 percent.

Hydrological and soil loss parameters. Rainfall amount and intensity were measured using four recording and eight nonrecording rain gauges. Surface runoff on all watersheds was measured continuously using parshall flumes and water-stage-level recorders. The runoff samples from each storm were manually collected to estimate soil loss. The automatic runoff samplers (3) were used to collect the runoff samples only on two Vertisol watersheds for three years (1977-1979). Runoff samples within the watersheds also were collected for selected storms to estimate the sediment delivery ratios. Particle size analysis of eroded soil also was done on selected storms. Most soil moisture measurements were made by collecting gravimetric soil samples at 0-10, 10-20, 20-30, and 30-50 cm depths. On selected watersheds such measurements were made with a neutron probe 180-cm deep in 15-cm increments.

Results and discussion

Runoff and soil loss on Vertisols. Runoff, soil loss, and peak runoff rate were significantly affected by methods of land management (Table 3). The watersheds under improved systems produced much lower runoff, soil loss, and peak runoff rate than the traditional monsoon fallow system. The broadbed and furrow system was found more efficient in controlling soil and water loss as compared to the flat on grade system. The system of broadbed and furrow with farmers' field bunds was most efficient in reducing the runoff and soil loss. On average, this system reduced annual runoff to one-third, soil loss to one-eleventh, and peak runoff rate to half when compared with traditional systems. Table 4 shows a breakdown of trends for each year. Performance of the broadbed and furrow system is consistently superior to the traditional system in reducing the yearly runoff, soil loss, and peak runoff rate. During the extremely low rainfall of 1977, when moisture conservation was crucial, the broadbed and furrow system conserved most of the annual rainfall with an annual runoff of only 1 mm. In contrast, during the high rainfall of 1975 and 1978, when removal of excess water by drainage was crucial, this system produced substantial runoff amounting to 162 mm and 273 mm, respectively. The traditional system, even in normal rainfall years (1976, 1979, and 1980), resulted in extremely high average soil loss of 7.75 tons/ha compared with 0.88 tons/ha from the broadbed and furrow system. The improvement is a result of good crop cover during the monsoon season, land smoothings, slope adjustment, controlled runoff velocity as it flows through many furrows, and better soil and moisture conditions.

A close examination of soil loss and runoff trends within the season reveals that only a few major storms (>90 mm rainfall) determine the seasonal runoff and soil loss under the broadbed and furrow system. In most years, these storms accounted for 75 to 91 percent of the seasonal runoff and 63 to 91 percent of the seasonal soil loss (Table 5). Similar effects were recorded for other Vertisol watersheds under improved as well as traditional systems. Investigations of storms with maximum weighted mean intensities for various years indicated that these storms were not necessarily those with highest intensities, but those with large amounts of total rainfall, particularly when received while the Vertisols were still saturated from previous storms.

Duncan's multiple range test was used to rank the land management systems in terms of effectiveness in controlling runoff, peak runoff rate,

Table 3. Effects of alternative land management systems on annual runoff, soil loss and peak runoff rate from Vertisol watersheds (average annual values from 1975-1980).

Treatments	Rainfall (mm)	Runoff (mm)	Runoff Percent of Seasonal Rainfall	Peak Runoff Rate* (cu.m/sec/ha)	Soil Loss (tons/ha)
Broadbed and furrow at 0.6% slope	810	116	14.3	0.11	1.17
Broadbed and furrow at 0.6% with farmer's field bunds	808	76	9.4	0.07	0.58
Broadbed and furrow at 0.4% slope†	853	91	10.7	0.07	0.86
Flat on grade at 0.6% slope	812	143	17.6	‡	1.35
Traditional flat, monsoon fallow	806	220	27.3	0.16	6.64

*Maximum peak runoff rate from 1975-1980.

†Watershed monitored only from 1975-1978; the values reported are average of these four years.

‡Problem with water-level recorder.

Table 4. Annual rainfall, runoff, soil loss, and peak runoff rate for a cropped Vertisol with broadbed and furrow system and a traditional monsoon fallow system (1975-1980).

	Broadbed and Furrow at 0.6% Slope, Cropped					*Traditional flat, monsoon fallow*				
		Runoff					*Runoff*			
Year	*Rainfall (mm)*	*(mm)*	*Percent of Seasonal Rainfall*	*Peak Runoff Rate (cu.m/sec/ha)*	*Soil Loss (tons/ha)*	*Rainfall (mm)*	*(mm)*	*Percent of Seasonal Rainfall*	*Peak Runoff Rate (cu.m/sec/ha)*	*Soil Loss (tons/ha)*
1975	1,041	162	15.6	0.06	1.39	1,055	253	24.0	0.15	5.21
1976	687	73	10.6	0.09	0.98	710	238	33.5	0.16	9.20
1977	585	1	0.2	0.01	0.07	586	53	9.0	0.06	1.68
1978	1,125	273	24.3	0.11	2.93	1,117	410	36.7	0.15	9.69
1979	690	73	10.6	0.08	0.70	682	202	29.6	0.15	9.47
1980	730	116	15.9	0.06	0.97	688	166	24.1	0.11	4.58

Table 5. Contribution of major storms (rainfall > 90 mm) to seasonal runoff and soil loss on a cropped Vertisol with broadbed and furrow system at 0.6% slope from 1975 to 1979.

	Rainfall			*Runoff*		*Soil Loss*	
*Rainfall Events and their Date of Occurrence**	*(mm)*	*Percent of Seasonal Rainfall*	*Weighted Mean Intensity (mm/hr)*	*(mm)*	*Percent of Seasonal Runoff*	*(tons/ha)*	*Percent of Seasonal Soil Loss*
September 9, 1975	157	15	10.1	122	75	0.87	63
July 21 and August 19, 1976	246	36	7.6 & 26.0	64	87	0.77	79
August 14 and 22, 1978	281	25	15.8 & 14.3	220	81	2.19	75
September 27, 1979	106	15	35.2	66	91	0.64	91

*No major rainfall event occurred during 1977, unusually low annual runoff of only 1 mm was recorded.

Table 6. Effect of different land and water management systems on runoff, peak runoff rate, and soil loss for small, medium, and large storms on Vertisols at ICRISAT Center (1975-1980).

	Broadbed and Furrow at 0.6% Slope with Field Bunds	*Broadbed and Furrow at 0.4% Slope*	*Broadbed and Furrow at 0.6% Slope*	*Flat on Grade at 0.6% Slope*	*Traditional Flat, Monsoon Fallow*
Mean runoff amount for small storms* (mm)	0.7 d†	1.2 cd	2.2 c	4.7 b	12.9 a
Mean runoff amount for medium storms* (mm)	15 c	17 c	21 c	30 b	58 a
Mean runoff amount for large storms* (mm)	138 cd	130 d	172 bc	193 b	228 a
Peak runoff rate for medium and large storms (liters/sec/ha)	21 c	24 c	34 b	40 b	85 a
Mean soil loss for medium and large storms (kg/ha)	177 b	187 b	312 b	432 b	1,245 a

*Small storms, rainfall amount up to 30 mm; medium storms, above 30 mm and up to 90 mm; large storms, above 90 mm.

†Values in the same row with the same letter not significantly different ($P \leq 0.05$), Duncan's multiple range test.

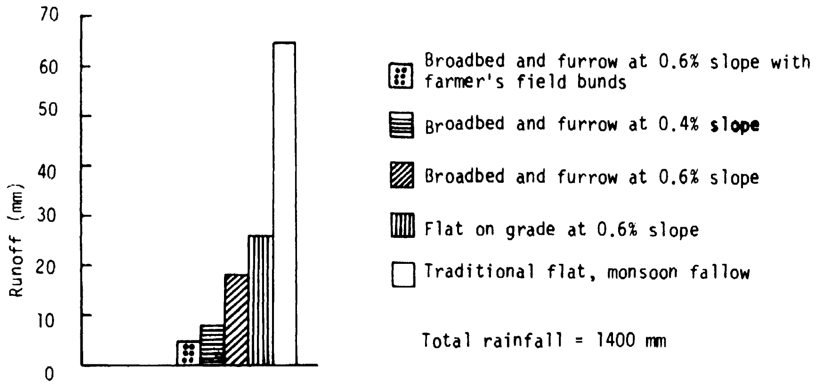

Figure 1. Total runoff during 3 years (1976-1978) when top 30 cm profile moisture was less than its field capacity (Vertisols, ICRISAT).

and soil loss on Vertisols. The test was done on the daily data collected from the various treatments. Three categories of storms were considered: small storms (rainfall ≤30 mm), medium storms (rainfall >30 mm ≤90 mm), and large storms (rainfall >90 mm). For small storms, all the systems with broadbed and furrow were significantly more effective in controlling runoff as compared with the flat on grade system (Table 6). However, there were significant differences among the various broadbed and furrow systems as the broadbed and furrow with farmer's field bunds displayed superior water and soil conservation. For runoff resulting from medium and large storms, the differences among the various improved systems were relatively low (Table 6). However, there was a significant difference between runoff from improved and traditional systems for all storm categories on the Vertisols. There were no significant differences among the various improved systems for soil loss, but a significant difference was found between the improved and traditional systems.

On Vertisols under unsaturated conditions (soil water contents below field capacity for the top 30 cm of soil), all land management systems resulted in extremely low runoff (Figure 1). From 1976 to 1978 1,400 mm rainfall occurred under unsaturated conditions and resulted in a maximum runoff of 65 mm with a narrow range of only 5 to 25 mm from the various improved systems. From these totals, an average annual runoff difference of only 3 mm was observed between the broadbed and furrow system and flat on grade system at 0.6 percent slope. Thus, on monsoon-cropped Vertisols, the benefits of improved land and water management systems to moisture conservation are small under unsaturated soil conditions. The high infiltration and surface retention storage due to a rough soil surface and presence of abundant micro-cracks are responsible for the extremely low runoff in dry soils. As shown in figure 2, however, such benefits are significant for wetter antecedent conditions. The runoff (as percent of rainfall) was also considerably affected by weighted mean intensity of the storms. As expected, effect of storm-weighted mean intensity on runoff was much higher in wet than in dry Vertisols.

The soil erosion hazard associated with runoff occurrence is represented as soil loss per unit of runoff (Figure 3). This was significantly affected by land management systems and crop cover. Relatively high values were sustained in the traditional monsoon fallow system. In improved land management systems the values were gradually reduced as the crop cover increased. This shows the effectiveness of crop cover in reducing soil loss

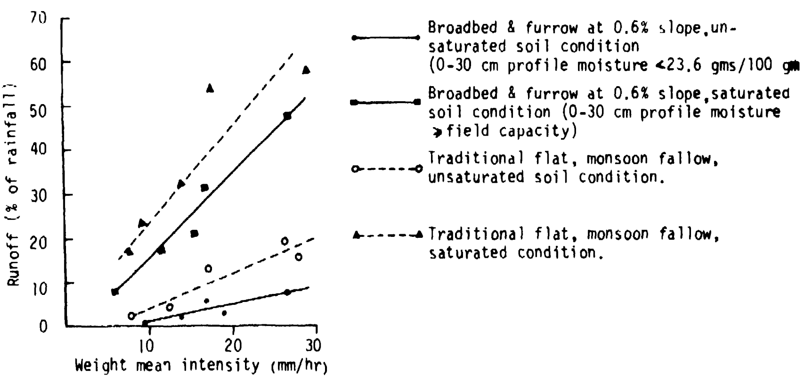

Figure 2. Effect of weighted mean intensity and moisture condition on runoff (percent of rainfall) for two land management systems (1975-1980).

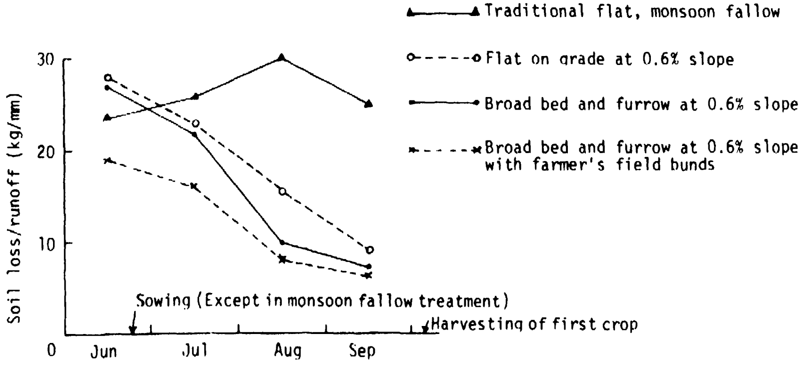

Figure 3. Effect of land management system and crop growth on soil loss per unit of runoff from Vertisol watersheds (monthly average values from 1975-1980).

Table 7. Effects of alternative land management systems on annual runoff, soil loss, and peak runoff rate from Alfisol watersheds (average annual values from 1975-1979).

Treatments	Rainfall (mm)	Runoff (mm)	Runoff Percent of Seasonal Rainfall	Peak Runoff Rate* (cu.m/sec/ha)	Soil Loss (tons/ha)
Flat with graded bunds at 0.6% slope	837	135	16.1	0.14	1.87
Broadbed and furrow at 0.6% slope	831	238	28.6	0.25	3.40
Flat with contour bunds	836	110	13.2	0.10	0.85
Traditional flat with farmers' field bunds†	790	165	20.9	0.15	2.52

*Maximum peak runoff rate from 1975-1979.
†Watershed monitored only from 1976-1979; the values reported are average of these four years.

per unit of runoff. The maximum seasonal runoff was recorded during August when the broadbed and furrow system had lower soil loss per unit of runoff as compared to the flat on grade system (Figure 7). The broadbed and furrow system was better for the disposal of excess water under the high runoff situations on Vertisols, which is desirable under conditions of excess moisture.

Runoff and soil loss on Alfisols. Compared with low runoff and soil loss from contour and graded bund watersheds, there was significantly more runoff and soil loss from other land management systems on Alfisols (Table 7). The flat with contour bund system was most efficient in reducing soil and water loss. In contrast, soil loss from the traditional system (traditional flat with farmer's field bunds) was 2.52 tons/ha compared with 3.40 tons/ha from broadbed and furrow system. In addition, the runoff amount and peak rate were also higher from broadbed and furrow systems despite poor crop cover in the traditional system compared with the broadbed and furrow under the improved system. The graded bund system was consistently more effective than the broadbed and furrow system in reducing runoff, soil loss, and peak runoff rate (Table 8). During the high rainfall of 1975 and 1978, the graded bund system had relatively low average soil losses of 2.45 tons/ha compared with 4.6 tons/ha from the broadbed and furrow system. During the very low rainfall of 1977, the graded bund system conserved most of the annual rainfall with annual runoff of only 29 mm.

Several factors were likely responsible for the poor performance of the broadbed and furrow system on Alfisols in controlling runoff and soil loss.

Table 8. Annual rainfall, runoff, soil loss, and peak runoff rate for an Alfisol watershed with flat, graded bund system and a watershed with broadbed and furrow system (1975-1979).

	Flat with Graded Bunds at 0.6% Slope					*Broadbed and Furrow at 0.6% Slope*				
		Runoff					*Runoff*			
Year	*Rainfall (mm)*	*(mm)*	*Percent of Seasonal Rainfall*	*Peak Runoff Rate (cu.m/sec/ha)*	*Soil Loss (tons/ha)*	*Rainfall (mm)*	*(mm)*	*Percent of Seasonal Rainfall*	*Peak Runoff Rate (cu.m/sec/ha)*	*Soil Loss (tons/ha)*
1975	1,103	165	15.0	0.13	2.10	1,104	308	27.9	0.20	4.20
1976	662	140	21.2	0.14	2.00	684	191	27.9	0.25	2.81
1977	549	29	5.3	0.06	0.56	563	80	14.2	0.10	1.13
1978	1,048	207	19.8	0.13	2.81	1,060	356	33.6	0.17	5.00

Smoothing the soil surface following storms was found to be much quicker than in the flat system, which resulted in small quantities of depression storage. This was undesirable as serious sealing and crusting occurred causing an infiltration rate often less than 7 mm/hr. The broadbed and furrow system also exposed the lower argillic soil horizons during the shaping process, which has an extremely low initial infiltration (Figure 4a and 4b). About 30 to 35 percent of the total area is in furrows (Figure 4a) where the initial infiltration rate is only one-third of the top soil surface. This results in lower overall infiltration from the broadbed and furrow system as compared to the flat system. In a permanent broadbed and furrow system (in which the land form is maintained over several seasons) the compaction in furrows was also found to be partially responsible for higher runoff.

The major share of seasonal runoff and soil loss from Alfisol watersheds under the broadbed and furrow system was induced by only a few major storms, as on the Vertisols (Table 9). In most years these storms accounted for 31 to 66 percent of the seasonal runoff and 24 to 55 percent of the seasonal soil loss. Similar effects of these major storms were also observed from Alfisol watersheds under other land treatments. However, the contributions of these storms to seasonal runoff and soil loss were much less on Alfisols than Vertisols because substantial runoff events and associated soil losses on Alfisols resulted from small and medium storms, which was not true for Vertisols. Analysis of different land management systems in controlling runoff and soil loss from small, medium, and large storms confirmed this. Daily data collected from the various treatments between 1975 and 1979 were used. It was found that small and medium storms contribute significantly to seasonal runoff and soil loss. In broadbed and furrow system, 21 percent of the seasonal runoff and 22 percent of the seasonal soil loss were recorded from small storms, showing the broadbed and furrow system is ineffective in small storms. The flat, graded bund system permitted much lower runoff and soil loss compared with the broadbed and furrow system from small and medium storms. For large storms the runoff differences among the various systems were low. It was also found that runoff and soil loss during the early part of the rainy season were extremely high in broadbed and furrow system compared with flat graded bunds system.

High runoff occurred on Alfisols under the various land management systems even with unsaturated soil moisture conditions (Figure 5). This is typical of the moisture conservation problems in Alfisols even early in the season before the soil has an opportunity to recharge. Differences in runoff between the various systems were also high. An average annual runoff difference of 31 mm was observed between the broadbed and furrow and flat graded bund systems. An annual runoff difference of 7 mm was observed between the broadbed and furrow and the traditional system.

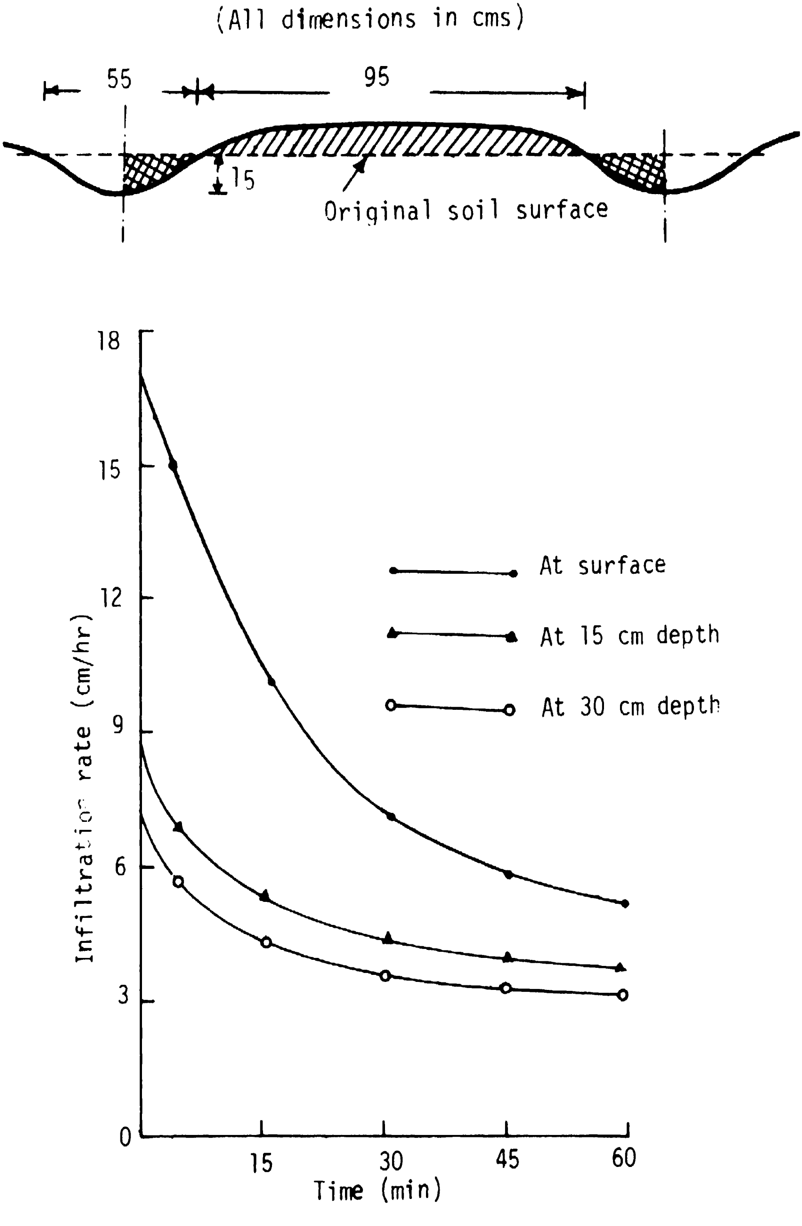

Figure 4. a (above): dimensions of broadbed and furrow. b (below): infiltration characteristics of an Alfisol (watershed, RWIC ICRISAT).

Table 9. Contribution of major storms (rainfall>90 mm) to annual runoff and soil loss on an Alfisol watershed with broadbed and furrow system at 0.6% slope from 1975 to 1979.

	Rainfall			*Runoff*		*Soil Loss*	
*Rainfall Events and their Date of Occurrence**	*(mm)*	*Percent of Seasonal Rainfall*	*Weighted Mean Intensity (mm/hr)*	*(mm)*	*Percent of Seasonal Runoff*	*(tons/ha)*	*Percent of Seasonal Soil Loss*
September 9, 1975	159	14	9.3	132	43	0.35	47
July 21 and August 19, 1976	231	34	8.3 & 27.0	127	66	1.00	55
August 14 and 22, 1978	284	27	15.6 & 14.1	205	58	2.07	41
September 27, 1979	127	17	32.1	78	31	0.97	25

*No major rainfall event occurred during 1977, which was a very low rainfall year.

Different land management systems and crop cover had significant effect on soil loss per unit of runoff (Figure 6). Extremely high values in all systems were observed during the early part of growing season. In all treatments the soil loss per unit of runoff was gradually reduced as the crop cover increased during the growing season. Throughout the growing season the flat contour bund systems had produced the lowest values compared with other systems. On Alfisols the excess runoff under saturated soil condition (frequently occur due to low moisture holding capacity) could be desirable. This excess runoff could be stored in a tank and later

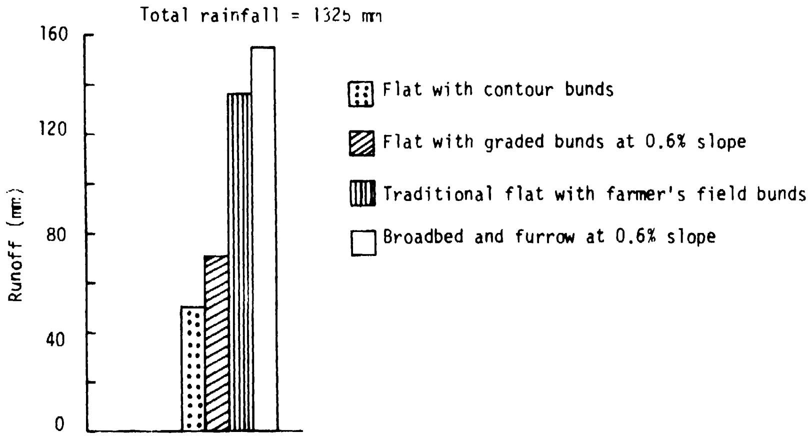

Figure 5. Total runoff during 3 years (1976-1978) when top 30 cm profile moisture was less than its field capacity (Alfisols, ICRISAT).

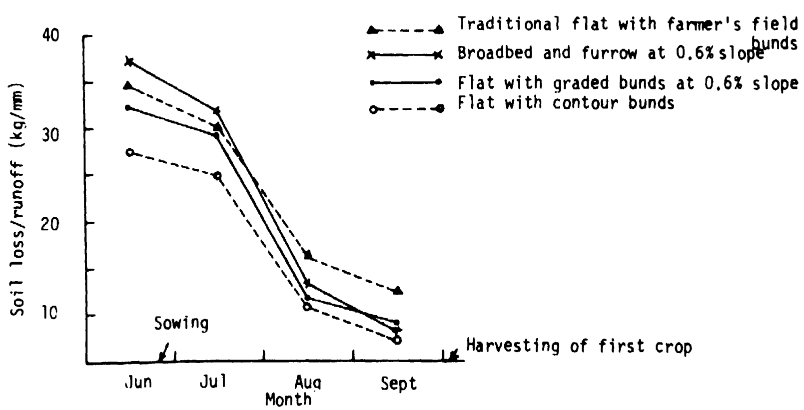

Figure 6. Effect of land management system and crop growth on soil loss per unit of runoff from Alfisol watersheds (monthly average values from 1975-1980).

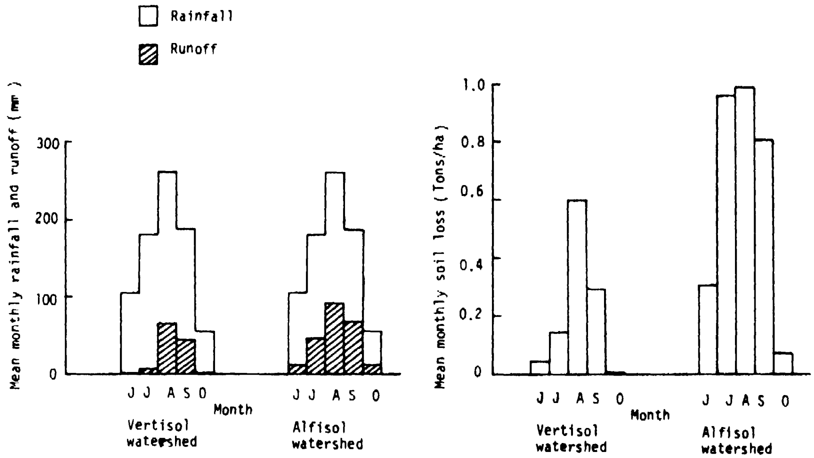

Figure 7. Average monthly rainfall, runoff and soil loss on Alfisol and Vertisol watersheds with broadbed and furrow system at 0.6% slope (1975-1980).

used for supplemental irrigation. Low soil loss per unit of runoff is very crucial.

Summary

Although Alfisols and Vertisols of the semiarid tropics often occur in close association, their management requirements and hydrologic characteristics are very different. The most striking example is that farmers traditionally crop Alfisols during the rainy season and Vertisols during the postrainy season. Their contrasting nature is attributed primarily to differences in types and amount of clay, moisture-holding capacities, drainage characteristics, crusting and sealing tendencies, contrasting properties of different soil layers, and other associated characteristics.

On Vertisols the broadbed and furrow system effectively controlled soil and water loss while the reverse was true with Alfisols. On Alfisols the raised land configurations (narrow ridge, wave type bed and others) that exposes the lower soil layer (relatively less pervious) resulted in higher runoff and soil loss compared with flat on grade system. Such configurations on Alfisols are also very unstable. This results in several operational problems related to sowing at proper depth, intercultivations, etc., are faced during the crop growing season. On Vertisols most of the raised land configurations provide well structured and drained media and also are quite stable.

In spite of the low terminal hydraulic conductivity of the Vertisols, the water intake capacity early in the monsoon season is high due to deep cracks and the high depression storage capacity. The high infiltration rate is further enhanced if the soil management is such that the surface soil is rough and cloddy. The formation of micro-cracks during rainless period provides high infiltration and surface depression storage for the next storms. Their contribution in reducing runoff is quite significant. In contrast, the initially high infiltration rate of Alfisols is often greatly reduced during the early rainy season by surface sealing, caused by the impact of rain drops and fine-particle translocations on the bare soil. Thus, the runoff and soil loss during the early part of the season from cropped Alfisols is much greater than that from cropped Vertisols (Figure 7). It also shows the importance of the early crop cover for Alfisols, which is not so crucial for Vertisols. On Alfisols most years under the extremely dry soil condition the first or the second storm of the season results in extremely high runoff. Improving the infiltration of Alfisols, particularly during the early part of the season, by using some tillage system or by organic/inorganic mulch or by improving the soil structure, is needed.

In contrast, the moisture conservation on Vertisols does not seem to be a problem. Infiltration in unsaturated soil conditions is generally high. However, the Vertisols have a problem of surface drainage.

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