Open Access Repository
International Crops Research Institute for Semi-Arid Tropics

Hydrological behavior of Alfisols and Vertisols in the semi-arid zone: Implications for soil and water management

P. Pathak, , R. Sudi, S.P. Wani, K.L. Sahrawat

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

Agricultural Water Management
Volume 118, February 2013, Pages 12–21

DOI: http://dx.doi.org/10.1016/j.agwat.2012.11.012

This is author version post print archived in the official Institutional Repository of ICRISAT www.icrisat.org

---

Hydrological behaviour of Alfisols and Vertisols in the Semi-arid zone: Implications for soil and water management

Prabhakar Pathak*, R Sudi and Suhas P Wani
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT),
P.O. Patanchru 502 324, Andhra Pradesh, India

Abstract

An understanding of hydrological behavior of soils is a prerequisite for developing appropriate soil and water management practices. Such information for the Alfisols and Vertisols, the two major soils

* Corresponding author: Tel.: +91-40-30713337; fax: +91-40-30713074/30713075
E-mail address: p.pathak@cgiar.org (P.Pathak)

in the semi and tropics (SAT), is scanty especially from a long-term perspective. Long-term hydrological studies were conducted on small agricultural watersheds from 1976 to 2008 at the ICRISAT Center, Patancheru, India. We discuss the behavior of Alfisols and Vertisols based on long-term results on runoff volume, peak runoff rate, number of runoff events, soil loss, sediment concentration and deep drainage loss under different rainfall, crop cover and soil conditions. The results on the influence of annual and monthly rainfall on the hydrological behavior of these soils in different rainfall regions are described. The use of long-term hydrological data for extrapolating the results to regions with different rainfall is demonstrated. It is brought out that the Alfisols and Vertisols in the SAT regions have very contrasting hydrological behavior. Several findings emerge from our research that are on unexpected lines. For example, the sandy Alfisols with higher saturated hydrological conductivity generated higher runoff and soil loss compared to the clayey Vertisols with extremely low saturated hydraulic conductivity. On the other hand, the peak runoff rate was higher on the Vertisols compared to the Alfisols. The highly undesirable early season runoff from the Alfisols was substantially higher compared to that from the Vertisols. On Alfisols even under relatively dry soil conditions substantial runoff was recorded. The contributions of 1-2 big storms to annual runoff and soil loss were high on both soils. The contrasting hydrological behavior of these two soils is attributed primarily to their typical characteristics viz. crusting, sealing and low structural stability, leading to fast decline in surface roughness in Alfisols and the presence of large cracks during the early season, formation of micro-cracks during rainless periods and better structural stability, resulting in higher surface roughness in the Vertisols. The results suggest that the information from the long-term hydrological studies can be utilized for developing appropriate effective soil and water management practices and strategies for these soils in different rainfall regions.

Keywords: Alfisols; Vertisols; Semi Arid Tropics; Hydrological behaviour; Agricultural watersheds; Soil and water management

---

1. Introduction

Alfisols and Vertisols are the major soil orders in the semi-arid tropics (SAT). Alfisols, the most abundant soils in the semi-arid tropics, cover nearly 33% of the SAT region. They occur extensively in southern Asia, western and central Africa, and many parts of the South America, particularly northeast Brazil. Vertisols are the deep black soils, generally called black cotton soils, which are abundant in India, Sudan, Ethiopia, Australia and several other countries (El-Swaify et al., 1985). In most semi-arid regions, the average annual rainfall seem enough to produce one or two crops per year; however, rainfall pattern are highly erratic with frequent dry periods within the rainy season (Virmani et al., 1991). The soil related constraints combined with SAT environment results in uncertainties and considerable risk to agricultural systems. This has 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. Due to these, the current agricultural productivity on these soils in most SAT regions remains low (Wani et al., 2009). Also with the current land use system, the rainfall use efficiency of the production systems are low, ranging from 35-55%, thus annually a large percentage of annual rainfall is lost as surface runoff, evaporation and deep drainage (Pathak et al., 2009; Pathak et al., 1989). Groundwater levels are depleting fast, and most rural rainfed areas are facing general water scarcity (Rockstrom et al., 2007). Though the problem of water shortages and land degradation has been in the past, the pace of natural resource degradation has greatly increased in recent times. Thus, on these SAT soils, new strategies and more appropriate soil and water management systems which combine the effective conservation and utilization of soil and water resources with crop production systems that increase productivity and assure dependable harvest is required.

To develop appropriate and more effective soil and water management strategies and practices, a better understanding of the hydrological behavior of soils is extremely important (Purandara and Kumar, 2003; Pathak et al., 2004). Such information from the SAT Alfisols and Vertisols are scanty particularly from the long term hydrological studies. At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) research station in Patancheru, India, long-term hydrological studies have been conducted on small agricultural watersheds on both Vertisols and Alfisols. Based on the results from these long-term studies, this paper discusses the hydrological behavior of the widely contrasting Alfisols and Vertisols. The influence of rainfall, crop cover and typical characteristics of Alfisols and Vertisols on their hydrological behaviours is explained. The use of long term hydrological data for extrapolating the results to regions with different rainfall is demonstrated. The hydrological behavior of these two soils and the implications for developing effective soil and water management strategies and practices for water management in different rainfall regions of the SAT are also discussed.

2. Materials and methods

2.1 Description of research sites and measurements

The long-term hydrological studies were conducted on three small Vertisols watersheds (BW1, BW3A and BW5A) and three small Alfisols watersheds (RW2, RW1C and RW3C) at the ICRISAT center, near Hyderabad India (17° 36' N 78° 16' E, 545m altitude). In all the six watersheds, the BBF systems of land and water management along with improved crop production technologies were used. Except for the difference in the soil type, other parameters remained similar.

Rainfall amount and intensity were measured using recording rain gauges. Surface runoff in all watersheds was measured continuously using hydraulic structures and water-stage-level recorders. The runoff samples from each storm were collected using sediment samplers (Pathak et al., 2002) to estimate soil loss. On selected watersheds soil moisture measurements were also made up to180 cm depth using a neutron probe. During the past few years, the soil moisture measurements are being made using the Time Domain Reflectrometer (TDR).

The mean annual rainfall at the experimental area is about 890 mm; the average minimum temperature is 17°C and maximum temperature is 32°C. Rainfall is variable spatially and temporally and occurs in high intensity. During the experimental period (1976-2008), the annual rainfall ranged from 558 mm to 1473 mm with a co-efficient of variation of 25% (Fig. 1). Such erratic rainfall results in spells of excess moisture and drought during the crop growing period. About 80% of the annual rainfall that occurs during four months (June-September) is called rainy season also known as monsoon in which rainfed crops are grown. The post-rainy winter-season (October-January) is dry and the days are cool and short. A feature of the climate at this location is the high annual potential evaporation, the highest rates occurring in the hot months prior to the onset of the rainy season.

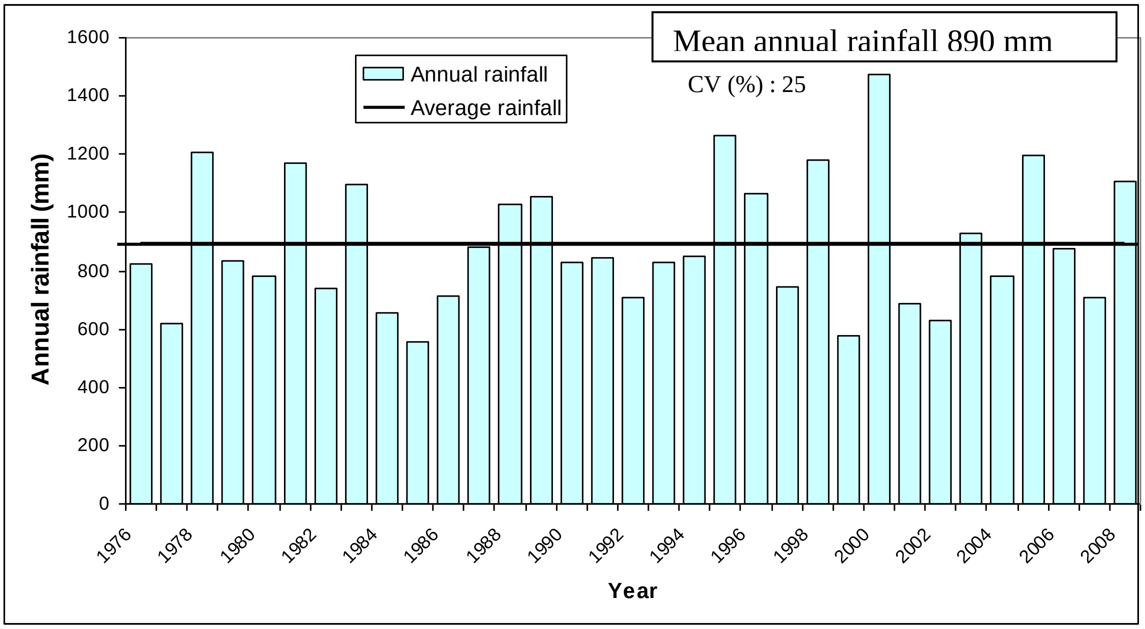

Fig. 1. Annual rainfall during the study period (1976-2008) at the ICRISAT center, Patancheru, India.

Soils at the experimental site: Important physical characteristics of the soils used for hydrological studies are briefly described below:

Vertisols

The Vertisols at the experimental watersheds are the deep black soils and belonging to the very fine, clayey, montmorillonitic, calcareous hyperthermia family of typic Pellusterts (Virmani et al., 1991). Some of the key physical properties of the soils at the experimental sites are summarized in Table 1. The soil is self-mulching and exhibits cracking and swelling; and they become hard when dry and sticky when wet. Because of the prevailing 2:1 clay type and the relatively high clay content, the soils are usually imperfectly drained during the wet periods in the rainy season and they have a very low saturated hydraulic conductivity (Table 2).

Table 1
Physical properties of Vertisol watershed at the ICRISAT farm in Patancheru, India

Soil depth (cm)	Particle size distribution percent of total				Moisture holding capacity (%)		Bulk density (g cm^{-3})
	Clay (<.002mm)	Silt (.050-.002mm)	Sand (2-.05mm)	Coarse fragments (>2mm)	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

Table 2
Saturated hydraulic conductivities of Alfisols and Vertisols at the experimental watersheds ICRISAT Center, Patancheru, India

Soil depth (cm)	Alfisols ($mm\ hr^{-1}$)	Vertisols ($mm\ hr^{-1}$)
0 – 15	17.1	0.60
15 – 30	6.7	0.35
30 – 60	6.1	0.33
60 – 90	8.3	0.21
90 – 120	-	0.22

Alfisols

The Alfisols at the experimental watersheds are medium deep red soils and belong to the fine, kaolinitic, isohyperthermic member of the family of Udic Rhodustalfs (El-Swaify et al., 1987). Some of the important physical properties of the soils at the experimental site are given in Table 3. The soil has very low water retention characteristics and it has mechanical impedance-related problems in the soil profile that restrict crop root development and proliferation. This soil has an unstable structure and a tendency to display crusting and hardening when dry. Sub-surface layers are very hard and compact and possess relatively lower hydraulic conductivities (Table 2). The soils are very low in organic matter; and the depth of these soils in the experimental watersheds range from 90 to 110 cm.

Table 3
Physical properties of Alfisol watershed at the ICRISART farm in Patancheru, India

Soil depth (cm)	Particle size distribution percent of total				Moisture holding capacity		Bulk density
	Clay (<.002mm)	Silt (.05-.002mm)	Sand (2-.05mm)	Coarse Fragments (>2mm)	1/3 bar	15 bar	(g cm^{-3})
0-15	13.2	6.1	75.7	5.0	11	4.4	1.50
15-30	22.3	9.7	63.0	6.0	14	7.2	1.58
30-60	31.1	9.0	51.9	8.0	15	8.1	1.59
60-90	38.3	8.8	41.9	12.0	14	8.2	1.46

3. Results and discussions

3.1 Runoff behaviour of Alfisols and Vertisols

Annual runoff and peak runoff rate: A large differences in the mean annual runoff volume between the Alfisol and Vertisol watersheds were recorded (Table 4). The mean annual runoff volume in Alfisol watersheds is 69% higher compared to those in the Vertisol watersheds. However, the peak runoff is slightly higher in the Vertisol watersheds compared to that in the Alfisol watersheds. The mean annual runoff volume recorded from the Alfisol and Vertisol watersheds are on the unexpected lines. It is usually expected that Alfisols being realtively sandy in texture with higher saturated hydraulic conductivity (Table 2) compared to the Vertisols, will generate much lower runoff volumes compared to Vertisols high in clay and very low saturated hydraulic conductivity (Table 2).

Several factors are likely responsible for the relatively higher runoff from the Alfisols compared to Vertisols. The Alfisols have non-stable soil structure, which enhances the soil’s tendency to develop surface seals that reduce infiltration and profile recharge even under moderate or mild rains. The surface seal hardens into crusts during intermittent dry periods, which further influence the runoff behaviour of the Alfisols. Also because of low structural stability, the smoothing of the soil surface roughness following rainfall events was found to much quicker in the Alfisols. This contributed to fast decline in the surface depression storage, resulting in a relatively higher runoff. On the other hand, the Vertisols have much better structural stability, resulting in a slow and gradual decline in surface depression storage capacity due to rains. The presence of large cracks during the early part of the rainy season and formation of micro-cracks during rainless period (within rainy season) in the Vertisols leads to high infiltration and surface depression storage for the subsequent rains. These typical soil properties contribute significantly to reducing runoff on the Vertisols.

Table 4
Mean annual rainfall, runoff, soil loss and peak runoff rate from the Alfisol and Vertisol watersheds at the ICRISAT Center, Patancheru, India (1976-2008)

Soil type and watersheds	Mean annual rainfall (mm)	Mean annual runoff		Peak runoff rate (m^3s^{-1} ha^{-1})	Mean annual soil loss (t ha^{-1})
		Runoff (mm)	Runoff as % of rainfall		
Alfisol watersheds with BBF system	881	196.5	22.3	0.21	4.62
Vertisol watersheds with BBF system	892	116.9	13.1	0.25	1.63

Monthly and daily runoff: The mean monthly runoff from Alfisols and Vertisols shows a very contrasting trend (Fig. 2). During all the months, the mean monthly runoff from the Alfisols was higher compared to that in the Vertisols. However, in the first two months viz. June and July, the mean monthly runoff from Alfisols was relatively much higher compared to the Vertisols. For example in the month of June, the mean monthly runoff from the Vertisols was only 1% compared to 12% in the Alfisols. The monthly runoff trend clearly shows that the early runoff in the Alfisol watersheds is much higher compared to that in the Vertisol watersheds. However, with progress in the rainy season, the relative difference in the runoff between the Alfisols and the Vertisols gradually declines. The high early season runoff is undesirable because during these periods the soil moisture in soil profile is not full. In the case of Vertisols, the early season runoff is low and most of the runoff occurs during the months of August and September when the soil profile is adequately full.

The contrasting behavior of individual runoff events from Alfisols and Vertisols during the early part of rainy season is shown in Figure 3. Clearly, the runoff from the Alfisols is much higher compare to that in the Vertisols. This reconfirms the monthly runoff trend, that the early season runoff from the Alfisols is higher compared to that in the Vertisols. On the Alfisols, the problems of crusting and sealing are encountered more during the early part of the crop growing season when the crop canopy is not fully established or developed. This reduces the infiltration considerably, leading to higher runoff in the Alfisols particularly during the early part of the season. However, the reverse trend in the runoff can be seen from the events, which occurs under extremely wet soil conditions during the later part of the rainy season. Under such conditions, the runoff from the Vertisol watersheds was significantly higher compared to that in the Alfisol watersheds (Fig. 4). The runoff on the Vertisols under extremely wet soil conditions is mainly governed by their very low saturated hydraulic conductivity (Table 2).

This leads to extremely high runoff on the Vertisols under such moisture conditions. Due to this runoff behaviour of the Vertisols, the monthly runoff during August and September are substantially higher and the runoff gap between the Alfisols and Vertisols is considerably reduced (Fig. 2). This supports the monthly runoff trend recorded from the Alfisols and Vertisols.

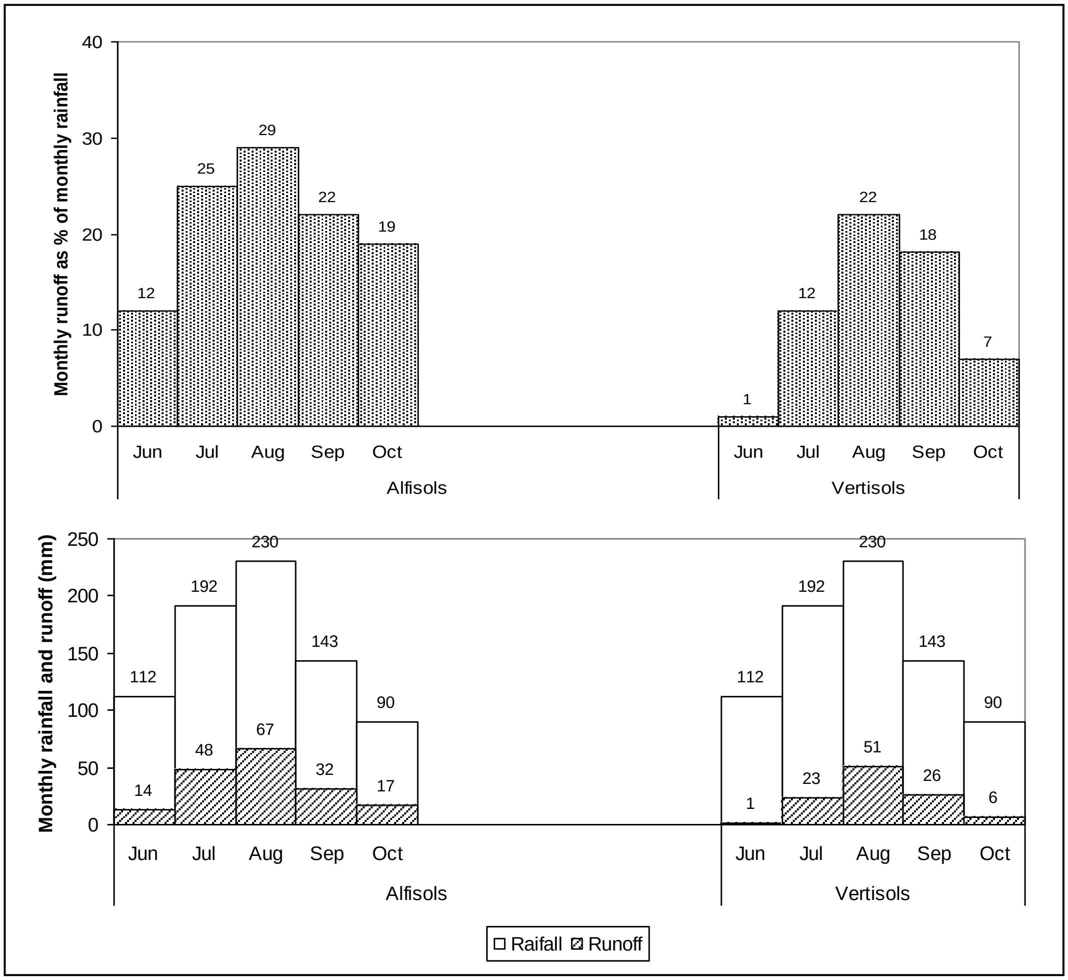

Fig. 2. Mean monthly runoff characteristics of the Vertisol and Alfisol watersheds (1976-2008).

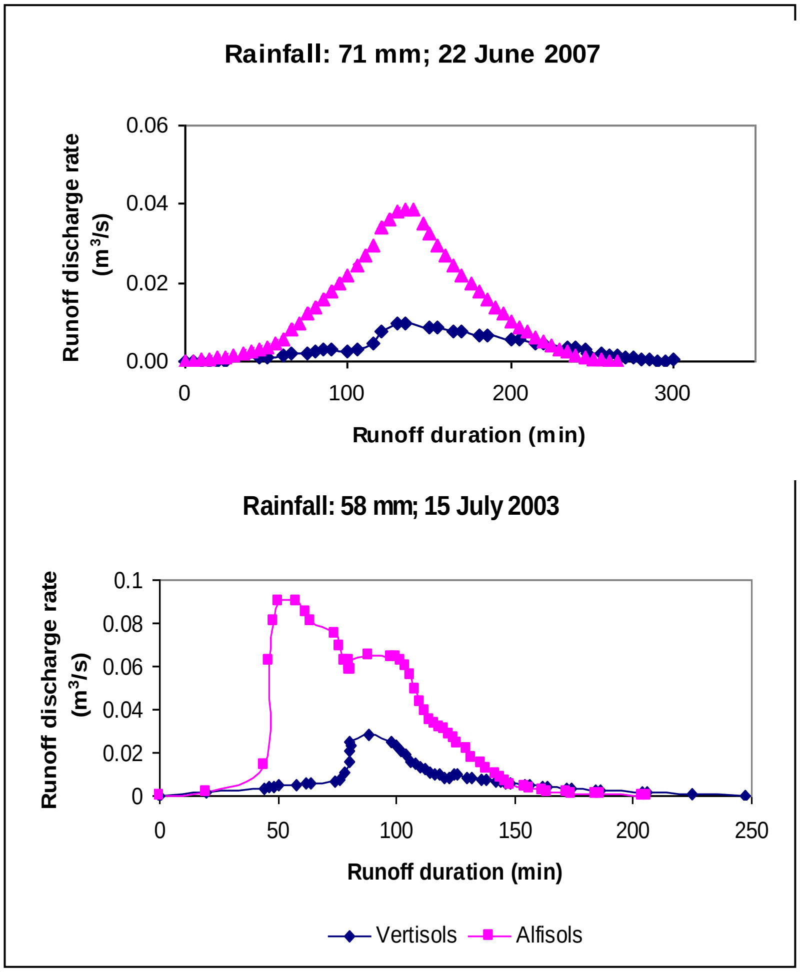

Fig. 3. Runoff events under dry soil conditions during the early part of the rainy season in the Alfisol watershed (RW2), Vertisol watershed (BW1) at the ICRISAT Center, Patancheru, India.

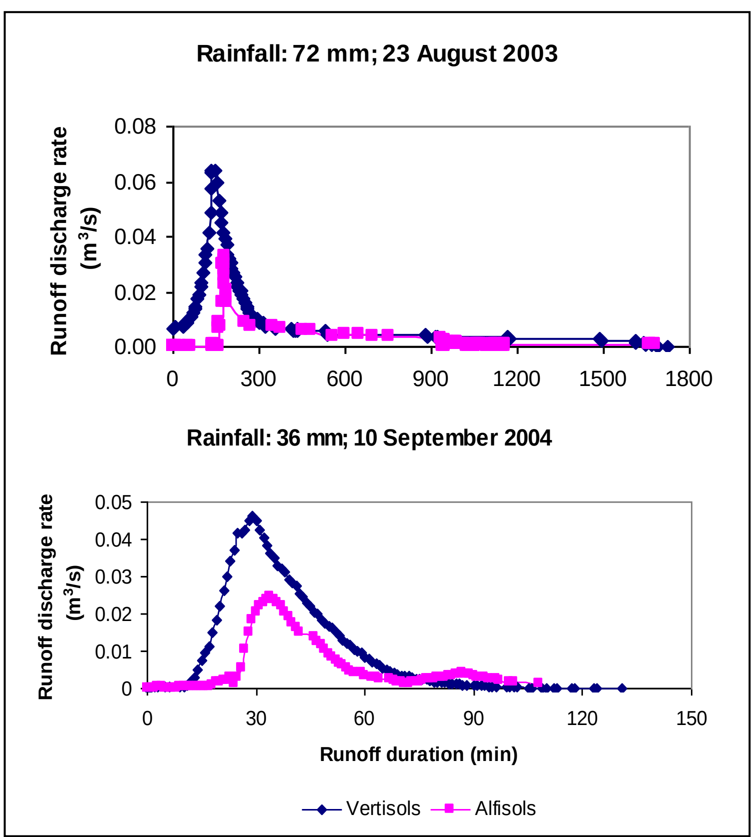

Fig. 4. Runoff events under extremely wet soil conditions during the later part of the rainy season in the Alfisol watershed (RW2) and Vertisol watershed (BW1) at the ICRISAT Center, Patancheru, India.

Runoff under dry soil conditions: Occurrence of runoff under dry soil conditions is highly undesirable. The runoff behavior of Vertisols and Alfisols when the top soil layer was unsaturated (soil moisture below their field capacity) are quite contrasting (Fig. 5). During the early parts of the cropping season (June and July), very low runoff was recorded on the Vertisols when the top 30 cm soil profile was unsaturated. The high initial infiltration rate good surface retention storage due to rough soil surface and the presence of abundant large and micro-cracks under dry soil conditions, are mainly responsible for the low runoff under dry soils. This suggests that on Vertisols, the benefits of improved soil and water management practices due to additional infiltration of water are expected to be low.

On the Alfisols, a substantial runoff of 53 mm was recorded when the top 30 cm soil profile was not full to their field capacity (Fig. 5). This runoff under the dry soil conditions was primarily due to the low infiltration rate because of crusting and sealing of the surface layer, and presence of very low surface roughness storage (smoothing of soil surface roughness following rains, due to low structural stability of soil). This is highly undesirable because often the crops on these Alfisols suffer from the moisture stress particularly during the early parts of the rainy season. Therefore, for the Alfisols substantial benefits can be obtained by controlling such early season runoff through appropriate soil and water management practices.

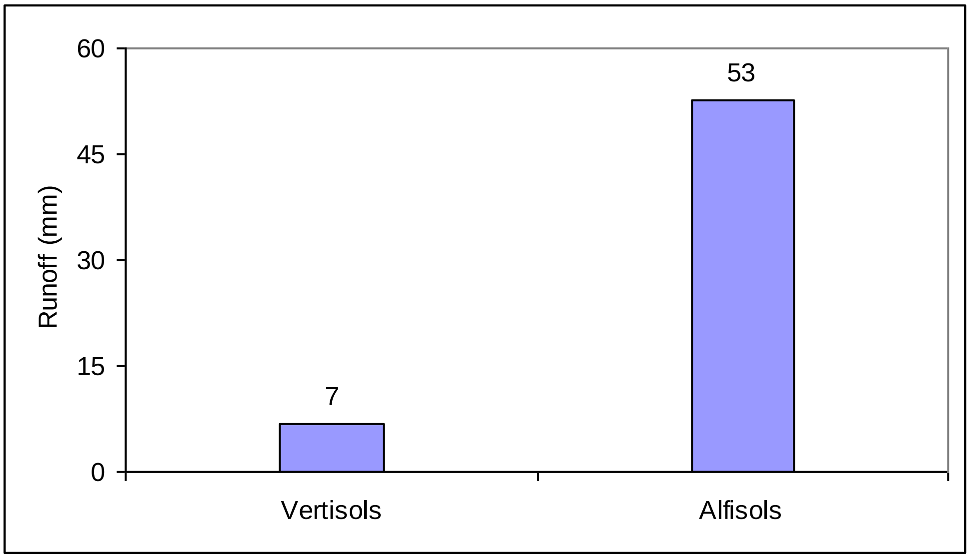

Fig. 5. Runoff when top 30 cm soil profile moisture less than its field capacity in the Vertsol and Alfisol watersheds at the ICRISAT Center, Patancheru, India.

Big runoff events: The contribution of a few big runoff events to annual runoff and soil loss recorded from Alfisol and Vertisol watersheds are quite high (Table 5). A close examination of the individual runoff events each year reveals that in most of the years, 1-2 big runoff events account for more than 72% of the annual runoff and 74% of the annual soil loss on the Vertisols. In the case of Alfisols, these events account for more than 63% of the annual runoff and 69% of the annual soil loss. Investigations of the rainfall events with higher weighted mean rainfall intensities for various years indicated that these big runoff and soil loss producing events were not necessarily those with highest rainfall intensities, but those with large amounts of total rainfall, particularly when received while the soils were still saturated from the previous rainfalls. However, the contributions of these big rainfall events to annual runoff and soil loss are relatively less in the Alfisols than in the Vertisols. This is primarily because on an average, more number of runoff events occur on the Alfisols than Vertisols every season (Table 6). This suggests that the proper management of big rainfall events is crucial for effectively controlling the runoff and soil loss on these two SAT soil types.

Table 5.

The contribution of 1 or 2 big runoff events to annual runoff and soil loss in Alfisols and Vertisols watersheds at the ICRISAT Center, Patancheru, India, 1976-2008

	Contribution of 1-2 big runoff events every year		
	Contribution to annual rainfall (%)	Contribution to annul runoff (%)	Contribution to annual soil loss (%)
Vertisol watersheds with BBF system	13.9	49-91* (72**)	51-89 (74)
Alfisol watersheds with BBF system	14.3	40-79 (63)	42-84 (69)

** range of values; ** Mean values*

Annual runoff during low, medium and high rainfall years: During the past 33 years (1976-2008) of study, the annual rainfall at the experimental sites varied from 580 to 1473 mm (Fig. 1). When the individual-year runoff and soil loss results from the Alfisol and Vertisol were closely examined, a trend emerged. The hydrological behaviour of these soils varied considerably during different years and this was greatly influenced by the total annual rainfall. The hydrological behaviour of Alfisols and Vertisols during low rainfall years (annual rainfall <750 mm), medium rainfall years (annual rainfall 750-900 mm) and high rainfall years (annual rainfall >900 mm) were contrastingly different (Figs. 6 and 7).

As expected with increase in the annual rainfall, the annual runoff increased substantially in both Alfisols and Vertisols. However, the increase in runoff is much higher in the Vertisols compared to Alfisols (Fig. 6). For example, the mean annual runoff in the Vertisols increased by 15 times (from 2 to 30% annual runoff recorded during low to high rainfall years) while in the Alfisols it increased only by 1.8 times (from 16 to 29% annual runoff recorded during low to high rainfall years).

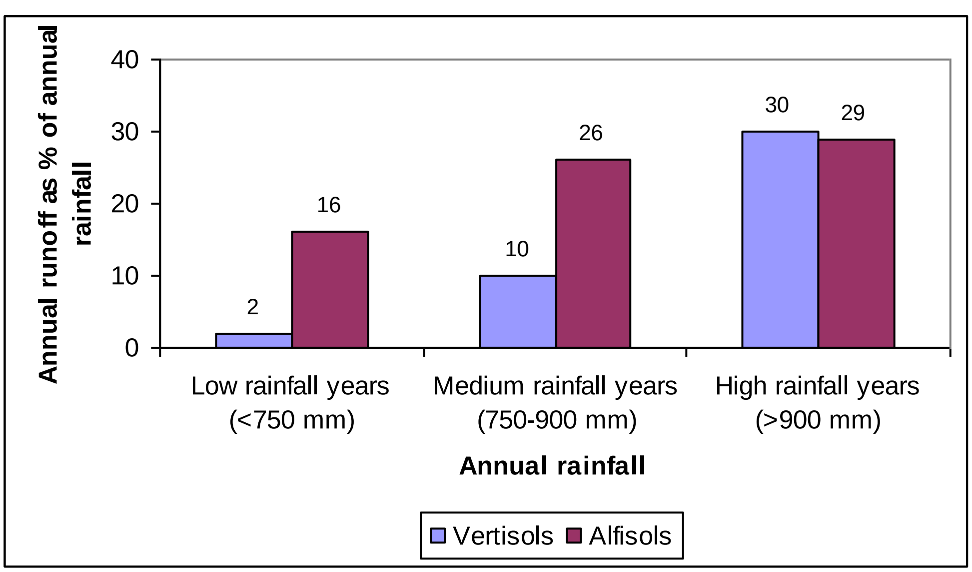

Fig. 6. Annual runoff characteristics of Verisol and Alfisol watersheds during low, medium and high rainfall years (1976-2008).

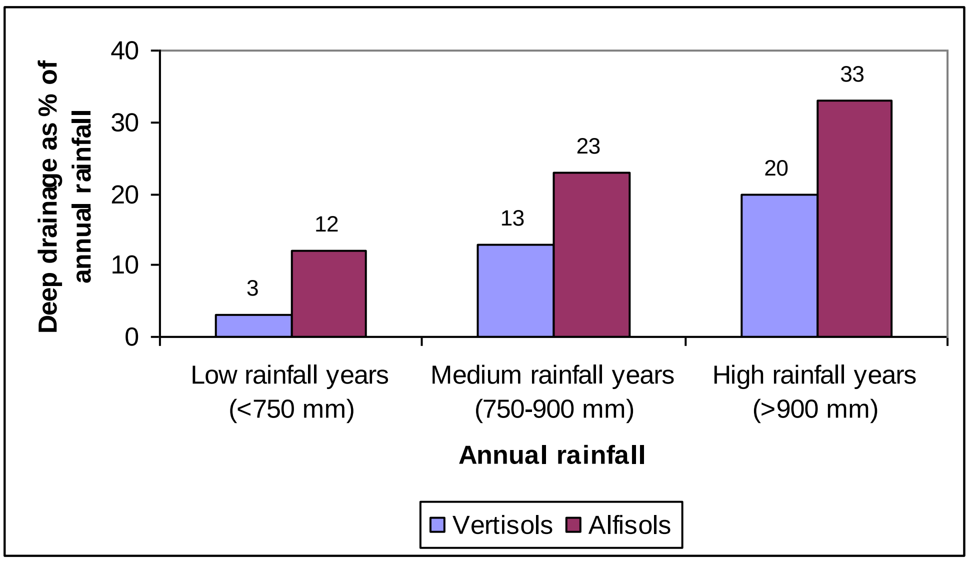

Fig. 7. Annual deep drainage losses in the Vertisol and Alfisol watersheds during low, medium and high rainfall years (1976-2008) at the ICRISAT center, Patancheru, India.

The annual rainfall greatly influences deep drainage losses from the both Alfisols and Vertisols (Fig. 6). As expected, the deep drainage loss increased with increase in the annual rainfall in both the soils. During all the years, the deep drainage losses were substantially higher in the Alfisols compared to the Vertisols. This indicates a greater groundwater recharge and its availability in the Alfisols compared to the Vertisols. The relatively higher deep drainage loss in Alfisols is primarily due to low water holding capacity of the soil profile and relatively higher saturated hydraulic conductivity (Tables 2 and 3) compared to the Vertisols, which have high soil profile water holding capacity, extremely low saturated hydraulic conductivity (Tables 1 and 2) and very poor profile internal drainage. Also in the Vertisols, the deep drainage loss is lower due to high moisture evaporation losses from the soil profile particularly during the hot summer months (February to May). It is estimated that annually about 160 mm of soil moisture is lost due to evaporation during the summer months. This accounts for about 18% of the mean annual rainfall, much higher than annual runoff or deep drainage losses in case of Vertisols. The formation of deep and wide cracks in Vertisols during the hot summer months exposes the deeper moist soil layers to evaporation loss, resulting in less net surplus water available for deep drainage during the subsequent years.

During the low rainfall years (<750 mm annual rainfall), the mean annual runoff from the Vertisols was low (Fig 5). On an average, the annual runoff from the Vertisol watersheds was only 2% of the annual rainfall. Infact there were some years, when the annual runoff on the Vertisols was almost nil. These results suggest that in low rainfall areas of SAT, the Vertisols may generate low annual runoff. During the low rainfall years, the deep drainage loss from the Vertisols was also very low (Fig. 6). The mean annual deep drainage loss was estimated to be 3% of the mean annual rainfall, clearly indicating a poor groundwater recharge on Vertisols in the low rainfall areas in the SAT regions. In contrast, on the Alfisols substantial annual runoff and deep drainage was recorded even during the low rainfall years. The mean annual runoff from the Alfisols was 16% of the annual rainfall, which is 8 times higher than that observed on the Vertisols. Similarly, on Alfisols, about 12% of the mean annual rainfall was lost as deep drainage loss, which is about 4 times higher than on the Vertisols. This suggests that on SAT Alfisols, even in low rainfall areas, there are good prospects of runoff water harvesting and groundwater availability.

During the medium rainfall years (750 - <900 mm annual rainfall), the mean annual runoff on the Vertisols was moderate (Fig. 6). On this soil, the average annual runoff was about 10% of the annual rainfall. This suggests that in the medium rainfall regions of Vertisols, there are low to medium prospects of runoff harvesting. In medium rainfall areas on Vertisols, about 13% of the annual rainfall is lost as deep drainage. This indicates moderate prospects of groundwater availability in such regions. In contrast, on Alfisols much higher annual runoff and deep drainage were recorded during the medium rainfall years. The mean annual runoff on the Alfisols is 26% that of annual rainfall, which is 2.6 times higher than that on the Vertisols. Similar trend is recorded for the deep drainage loss. This suggests that on the SAT Alfisols in the medium rainfall areas, there are very good prospects of runoff water harvesting and ground availability.

During the high rainfall years (>900 mm annual rainfall), a different trend in runoff behavior of Vertisols and Alfisols can be seen (Fig. 6). During these years, the Vertisols generated greater annual runoff compared to the Alfisols. It would appear that because of high rainfall, most of the time the soil stayed wet or saturated, leading to very low infiltration and high runoff. These results suggests that in the high rainfall areas, the Vertisols may generate extremely high annual runoff and hence very good prospects of harvesting runoff water. In high rainfall Vertisol areas, the deep drainage losses are higher but not of the magnitude as the surface runoff. This is because under extremely wet soil conditions, the internal profile drainage of the Vertisols is poor due to very low saturated hydraulic conductivity of different soil layers (Table 2). This leads to low deep drainage losses on Vertisols. Where as, on the Alfisols in high rainfall years, very high annual runoff and deep drainage were recorded. In such regions, 62% of the annual rainfall is lost only due to runoff and deep drainage. This indicates very high prospects of runoff water harvesting and groundwater availability on the Alfisols in the high rainfall areas of the SAT. High runoff on both soils results in serious soil erosion and waterlogging problems.

3.2 Soil loss and sediment concentration from Alfisol and Vertisol watersheds

The mean annual soil loss and sediment concentration recorded on the Alfisol and Vertisol watersheds during 1976-2008 are summarized in Tables 4 and 5. A large difference in both the mean annual soil loss and sediment concentration was recorded between these two soils. In Alfisols, the mean annual soil loss was about 3.0 times higher (4.62 vs 1.63 t ha^{-1}/annum) compared to Vertisols. The mean sediment concentration in runoff water was also higher by about 1.69 times (2.35 vs 1.39 gm $litre^{-1}$) in Alfisols compared to Vertisols (Table 6). This indicates that the Alfisols are more susceptible to soil erosion than the Vertisols. This is highly undesirable, since most of the Alfisols in SAT regions are poor in terms of physical, chemical and biological soil health parameters. Any further land degradation due to soil erosion is highly undesirable and may finally lead to unstable low agricultural productivity. On the other hand, the mean soil loss recorded from the Vertisol watersheds was relatively low. Since most of the SAT Vertisols are generally quite deep with relatively better soil health, a low level of soil erosion may not pose any immediate serious threat to agricultural productivity and environment.

Table 6
Some hydrological parameters recorded on the Alfisol and Vertisol watersheds at the ICRISAT center, Patancheru, India, 1976-2008

Hydrological parameters	Alfisol watersheds	Vertisol watersheds
Average annual runoff events (nos)	11	7
Annual runoff range as % of rainfall	6 – 32%	0 – 34%

Annual soil loss range (t ha^{-1})	1.21 – 6.20	0 - 3.29
Mean sediment concentration in runoff (g lit^{-1})	2.35	1.39

Effect of crop cover on sediment concentration: On both the Alfisols and Vertisols, crop cover have significant effects on sediment concentrations in runoff water (Fig. 8). The sediment concentration in runoff water was very high during the early parts of cropping season, when the crop cover was low. During months of August and September, when the crop cover was highest, the sediment concentration in runoff water was the lowest (almost half that recorded during the early part of the season). On both these soils, the sediment concentration gradually reduced as the crop cover increased during the crop growing season. Crops at the experimental watersheds are generally sown during 2nd or 3rd week of June and harvested in the 1st week of October. The crop cover gradually increases from June and reaches peak in the month of August or September (ICRISAT, 1984). This trend in the sediment concentration was similar on both Alfisol and Vertisol watersheds. Although, on the Alfisols, the sediment concentration in the runoff water was always relatively higher compared to that on the Vertisols. This reconfirms that in the SAT region, the Alfisols are more prone to soil erosion than the Vertisols and emphasis needs to be given on controlling soil erosion on Alsfisols.

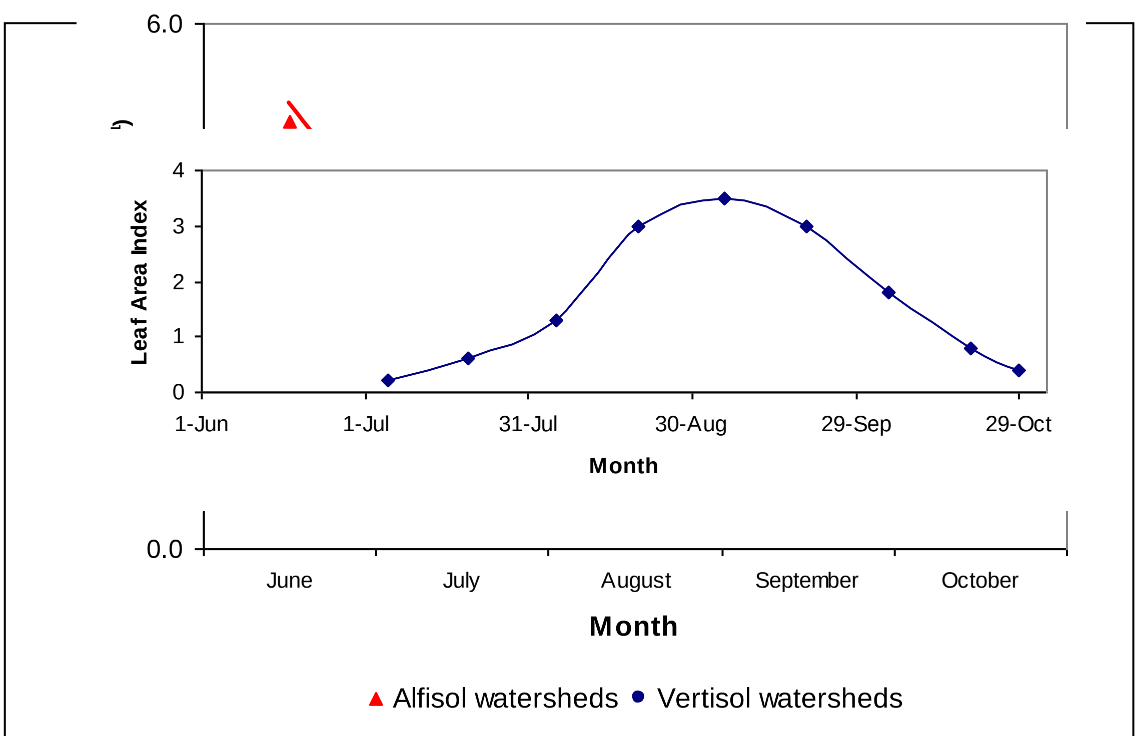

Fig. 8. Effects of crop canopy on sediment concentration in runoff water on Alfisols and Vertisols watersheds during rainy season crop at ICRISAT Center.

4. Implications of hydrological behaviour on soil and water management practices/strategies

Although Alfisols and Vertisols of the semi arid tropics often occur in close association, their hydrological behaviours are very different and contrasting consequently requires different soil and water management strategies and practices. The hydrological behaviour of these two soils are greatly influenced by the rainfall and soil conditions. Also, it is clear that soil crusting, sealing, smoothing of surface roughness, cracks formation, low structural stability and others have strong influence on the hydrological behavior. The implications of these hydrological findings for effective soil and water management strategies and practices in the low, medium and high rainfall areas of SAT are given below:

Vertisols and Alfisols in low rainfall regions (<750 mm annual rainfall)

- In the low rainfall region, the annual runoff on the SAT Vertisols is expected to be very low and hence a very low potential for the runoff water harvesting in surface storage structures. Therefore, in these regions the water harvesting structures or similar interventions may not be very effective and profitable.

- Since the runoff on Vertisols is expected to be very low, there may not be much benefit in improving infiltration through soil and water management system. For such regions, the soil and water management systems should focus more on reducing the evaporation loss (evaporation losses are extremely high in these regions) both during the cropping and non cropping seasons. The management system should focus more on the efficient utilization of stored soil profile moisture.
- Extremely low deep drainage loss is expected from Vertisols in low rainfall regions; and this suggests a very low probability of groundwater availability.
- Soil loss does not seem a serious problem in the SAT Vertisols of low rainfall regions. Very low annual soil losses are expected from Vertisols in such regions.
- In low rainfall regions, the annual runoff from the SAT Alfisols is expected to be moderate, resulting in a moderate potential of runoff harvesting. Since in the low rainfall regions, droughts are common, the benefits from the runoff water harvesting and supplemental irrigation is expected to be highly rewarding in increasing and sustaining crop yields.
- On Alfisols, the occurrence of early season runoff particularly when soils are dry needs to be controlled through appropriate soil and water management interventions. This is more important in low rainfall regions where moisture stress is quite common.
- Annual deep drainage from the SAT Alfisols in the low rainfall regions is expected to be moderate. This suggests that on Alfisols even in the low rainfall regions, there is moderate to good potential of groundwater availability and its utilization for increasing agricultural productivity.
- In low rainfall areas, the crop covers are effective in reducing soil loss on both Alfisols and Vertisols.

Vertisols and Alfisols in medium rainfall regions (750-900 mm annual rainfall):

- The SAT Vertisols in the medium rainfall regions are expected to generate low to moderate annual runoff, mostly in the later part of the rainy season. This indicates low to moderate prospect of harvesting runoff water. However, since most of the runoff is expected during the later part of the rainy season, the water availability and its usefulness for the rainy season crops is very limited. However, the stored runoff can be most effectively utilized as pre-sowing irrigation for post-rainy season crops. In the medium rainfall regions of Vertisols, excellent responses to pre-sowing irrigation have been recorded (Pathak et al., 2009).

- In the medium rainfall areas of Vertisols, the deep drainage is expected to be low to moderate and hence low to moderate potential of groundwater availability.
- On Vertisols with medium rainfall, not much benefit can be expected by increasing rainwater infiltration, since most of the runoff occurs when the soil profile is adequately full. In such situations, the soil and water management system should focus more on improving the drainage problems by a safe disposal of excess runoff. Also, the soil and water management should allow more efficient application of the limited irrigation water available.
- Even in the medium rainfall regions, high annual runoff is expected from the SAT Alfisols, indicating a very good prospects of runoff water harvesting. Even in the medium rainfall regions, the occurrence of droughts and moisture stress are common features in Alfisols and the use of stored runoff water as supplemental irrigation during rainy season is expected to be highly beneficial to the crops.
- Excessive early season runoff particularly when the soils are dry are expected on Alfisols. This needs to be controlled through appropriate soil and water management systems.
- Moderate to high annual deep drainage losses from the Alfisols suggest good prospects of groundwater availability.
- On the SAT Alfisols, high annual soil loss is expected even in the medium rainfall regions. Crop cover alone may not be enough for controlling soil erosion and loss and thus needs to be supported by appropriate soil and water management interventions.

Vertisols and Alfisols in high rainfall regions (>900 mm annual rainfall):

- Extremely high annual runoff is expected from the SAT Vertisols in high rainfall regions. This indicates very high potential of runoff water harvesting
- In high rainfall areas of Vertisols, the major focus of soil and water management system should be a safe disposal of the excess runoff without causing soil erosion. This is mainly to reduce the waterlogging problem, which affects agricultural productivity.
- On the Vertisols, the deep drainage loss even in the high rainfall regions are expected to be moderate, which indicates a moderate potential of groundwater availability.

- In the high rainfall regions, the annual runoff from the Alfisols is expected to be high, indicating an excellent potential for runoff water harvesting.
- On the Alfisols, soil moisture does not appear to be a major issue in such high rainfall regions. The soil and water management system should focus on a safe disposal of the excess runoff without causing soil erosion.
- The annual deep drainage loss from the SAT Alfisols is expectedly very high. This suggests an excellent potential of groundwater availability.
- In the high rainfall regions, on both Alfisols and Vertisols there is potential for high soil loss and a good crop cover is expected to provide only a limited control to soil erosion. In such regions, the soil and water management system must focus on reducing the soil loss. This is extremely important for the Alfisols since most of the SAT Alfisols are already in the degraded state.

Acknowledgement

Authors would like to acknowledge the contribution of Dr K L Sahrawat, Scientist, Global Team on Agroecosystems, ICRISAT for his comments and suggestions on the manuscript.

References

El-Swaify, S.A., Pathak, P., Rego, T.J., Singh, S., 1985. Soil management for optimized productivity under rainfed conditions in the semi-arid tropics. Adv. Soil Sci. 1, 1-64.

El-Swaify, S.A., Singh, S., Pathak, P., 1987. Physical and conservation constraints and management components for SAT Alfisols. In: Alfisols in the semi-arid tropics. Proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the productivity of SAT Alfisols and Related Soils, 1-3 December 1983, ICRISAT Center, Patancheru, India. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P. India. pp. 33-48.

ICRISAT, 1984. Soil Physics and conservation, Farming Systems Research Program Five-year report 1978-83. . Patancheru, Andhra Pradesh, 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp.

Pathak, P., Laryea, K.B., Sudi, R., 1989. A runoff model for small watersheds in the semi-arid tropics. Transactions of American Society of Agricultural Engineers. 32(5),1619-1624.

Pathak, P., Miranda, S.M., El-Swaify, S.A., 1985. Improved rainfed farming for the semi-arid tropics: implications for soil and water conservation. In: El-Swaify, S.A., Moldenhouer, W.C., Lo, A., (Eds.) Soil erosion and conservation, Iowa, USA, Soil Conservation Society of America. pp. 338-354

Pathak, P., Sahrawat, K.L., Wani, S.P., Sachan, R.C., Sudi, R., 2009. Opportunities for water harvesting and supplemental irrigation for improving rainfed agriculture in semi-arid areas. In: Suhas P Wani, Johan Rockstrom and Theib Oweis (Eds.), Rainfed Agriculture: Unlocking the potential. CAB International, Wallingford, UK. pp.197-221.

Pathak, P., Wani, S.P., Piara Singh, Sudi, R., 2004. Sediment flow behaviour from small agricultural watersheds. Agricultural Water Management. 67,105-117.

Pathak, P., Wani, S.P., Piara Singh, Sudi, R., Srinivasa Rao, Ch., 2002. Hydrological characterization of benchmark agricultural watersheds in India, Thailand, and Veitnam, Global Theme 3. Report No 2. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

Purandara, B.K., Kumar, C.P., 2003. Hydrologic characteristics of soils under different land covers in Ghataprabha basin. IE(I) Journal-CV. 84,1-5.

Rockström, J., Nuhu Hatibu, Theib Oweis., Wani, S.P. (2007) Managing water in rain-fed agriculture. In: Molden, D., (ed.) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, Earthscan, London, UK and International Water Management Institute (IWMI), Colombo, Srilanka, pp. 315-348.

Virmani, S.M., Pathak, P., Ranjodh Singh., 1991. Soil – related constraints in dryland crop production in Vertisols, Alfrisols and Entisols of India. Bulletin of the Indian Society of Soil Science. 15, 80-95.

Wani, S.P., Sreedevi, T.K., Rockström, J., Ramakrishna, Y.S., 2009. Rain-fed agriculture - Past trend and future prospects. In: Wani SP, Rockström J and Oweis T (eds) Rain-fed agriculture: Unlocking the Potential. Comprehensive Assessment of Water Management in Agriculture Series. CAB International, Wallingford, UK, pp. 1-35.