PROBLEMS AND POTENTIALS OF VERTISOLS AND ALFISOLS — THE TWO IMPORTANT SOILS OF SAT — ICRISAT EXPERIENCE

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The Semi-Arid Tropics (SAT) is the region of the world where average monthly rainfall exceeds potential evapo-transpiration for about 2-7 months in a year and mean monthly temperature is above 18°C. This geographical region contains a variety of soils, climates, crops and people. Here the poorest of the poor live, and disasters caused by droughts and failure of crops are very common, because most of the farming is rainfed and the rainfall is unreliable. The soil and management of edaphic and climate resources for increasing and stabilizing food production thus assume great importance in improving the standards of living of the people.

Soils of semi-arid tropics

There are many different kinds of soils in the SAT. Swindale (1981) using the FAO/UNESCO Soil map concluded that Arenosols, Luvisols, Vertisols and Ferralsols** are the 4 major soil groups of arable lands of the SAT covering approximately 24, 20, 14 and 10%, respectively, of the arable land area. Similar conclusions were drawn by Kampen and Burford (1979) who used the soil maps of Aubert and Tavernier (1972).

From the point of view of development of technology for improving agricultural production and removal of constraints to production from SAT soils highest priority is given by ICRISAT to Luvisols, Vertisols and Arenosols which cover about 3/5th of the arable land area of SAT. The first two are represented at our main research Center at Patancheru, Hyderabad (India) and the third at our Sahelian Center at Niamey (Niger, Africa). The Luvisols and Vertisols of the FAO/UNESCO classification system correspond to ALFISOL and VERTISOL of the soil taxonomy classification system and these are the names which we use for ICRISAT Center Soils. Fortunately ICRISAT Center was sited at a place where both these soils occur side by side. Also present at the Center are soils closely associated with Vertisols in that they are developed from similar parent material (e.g., basalt and dolomite) but are too shallow for full development of vertic properties. They are comparable to the Vertic Inceptisols and Entisols. The common names for the Vertisols and the associated Vertic type soils are deep black soils ($>$ 90 cm deep), medium deep black soils (50-90 cm deep) and shallow black soils ($<$ 50 cm deep). In this paper I am restricting my comments to Alfisols, Vertisols and Vertic type shallower soils as our last 8-year experience is limited to the study of these soils only. We have already started tackling the problems of management of the other important soils of SAT in our Farming Systems program in Africa.

Description of Vertisols and Alfisols and other associated soils and their agricultural environment

1 Vertisols

The Vertisols are heavy clay soils with clay content exceeding 50% and profile depth of more than 90 cm. They are commonly called deep black soils. Dudal (1965) reported the global area of black soils as being 257 million ha between 45° N to 45° S latitudes. Swindale (1981) estimates the total area of Vertisols in the world at about 180 million ha. According to Murthy (1981)

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** The corresponding approximate classes in Soil Taxonomy are Alfisol and Oxisol.

Vertisols and associated soils in India alone occupy 73 million ha out of which 38% (28 million ha) are Vertisols, 37% Vertic-Inceptisols and 21% Entisols.

The Vertic Inceptisols are medium black soils with 50 – 90 cm deep profile which occur on plateau remnants, while Vertic Entisols are shallow black soils with a profile less than 50 cm deep. These occur on the steeper upper slopes of the piedmont areas below the ridges. The soils of Vertic sub-group have ABC profiles and the thickness of the horizon is uniform throughout the pedon.

Besides India, the other countries with extensive areas of Vertisols are Australia, Sudan and Ethiopia. Vertisols also occur in smaller areas throughout sub-Saharan Africa, particularly in Chad, in Tanzania, south of Lake Victoria and elsewhere in east and central Africa. Lesser areas of these soils also occur in Mexico, in Central America, in Venezuela, in Bolivia and Paraguay (Swindale, 1981).

A Vertisol profile is characterized by a cyclic or intermittent Al horizon of varying thickness with micro knolls and micro depressions of gilgai relief within the pedon. This grades to C horizon through transitional A C horizon (Murthy, 1981). In Vertisols the clay content throughout the profile does not show much variation, increasing slightly with depth. Vertisols are generally calcareous, montmorillonitic isohyperthermic soils.

Because of the montmorillonitic nature of the clay minerals Vertisols undergo considerable shrinkage on drying and swelling during wetting, which results in large and deep cracks which close only after prolonged wetting. They become hard when dry and sticky when wet. They have a high cation exchange capacity (45–60 meq %), and alkaline reaction with pH ranging between 7.5 to 8.6, and a base saturation of over 80%. Calcium dominates the exchange complex, but with salinization these soils exhibit typical characteristics of sodicity even when the Na percentage in the exchange complex is much less than 15%.

The Vertisols of the tropics are usually low in organic matter, N, P, S, and Zn and respond to the application of fertilizers. Their available moisture storage capacity may run between 200 to 300 mm in a soil profile of about 180 cm depth. Russell (1978) observed that a 187 cm soil profile could store a total of 820 mm of water on complete saturation. The amount of water at the end of the crop season was recorded as 590 mm, thus indicating a maximum plant available soil moisture content of 230 mm.

The Vertisols and associated soils of Peninsular India are located in the heartland of the dry farming region of India. They are developed *in situ* from "Deccan Trap" base-rich geologic materials mainly basalt and dolomite. According to Murthy (1981) most of these soils occur on flat to undulating surfaces at an altitude of 300–900 meter above mean sea level.

There are two major groups of Vertisols, Chromusterts and Pellusterts which are most extensive. The Chromusterts occur in better drained conditions, and the Pellusterts occur under ill-drained conditions. Both these groups of soils are contiguous. In India most of the Vertisols are Pellusterts, while in Sudan they are Chromusterts.

2 Alfisols

Alfisols are comparable to Luvisols in the FAO/UNESCO classification system. Alfisols having a base rich argillic B horizon are probably the largest single soil group of the SAT. These soils are light textured in the surface horizons and may have higher clay content in deeper soil horizons. They occur on flat to rolling topography. This soil order is extensively found in SAT Africa, South Asia and South America. According to Swindale (1981) the red soils of India are preponderantly Luvisols, ferric Luvisols, chromic Luvisols and calcic Luvisols. Out of these chromic Luvisols which according to Soil Taxonomy are classified as Haplustalfs and Rhodustalfs are the predominant red soils of India. They occur mostly in the states of Andhra Pradesh, Karnataka and Tamil Nadu on gneisses and indurated and metamorphosed rocks on undulating to rolling topography. They are highly erodible particularly under conditions of inadequate crop cover. The rainfall on these soils varies from 600 mm to the upper limit of SAT (about 1250 mm). These soils originally supported natural vegetation of tall grasses, savanna and deciduous forests; but these lands have been over-grazed and over-populated.

The Alfisols at the ICRISAT center are fine kaolinitic isohyperthermic members of the family of Udic Rhodustalfs or Paleustalfs. The soils are characterized by red, reddish brown to yellowish brown colors. They are moderately saturated with bases, with a base saturation of about 80% or less and with a pH ranging from 5.6 to 6.7. Their total moisture storage and available moisture capacity are low (Fig. 1).

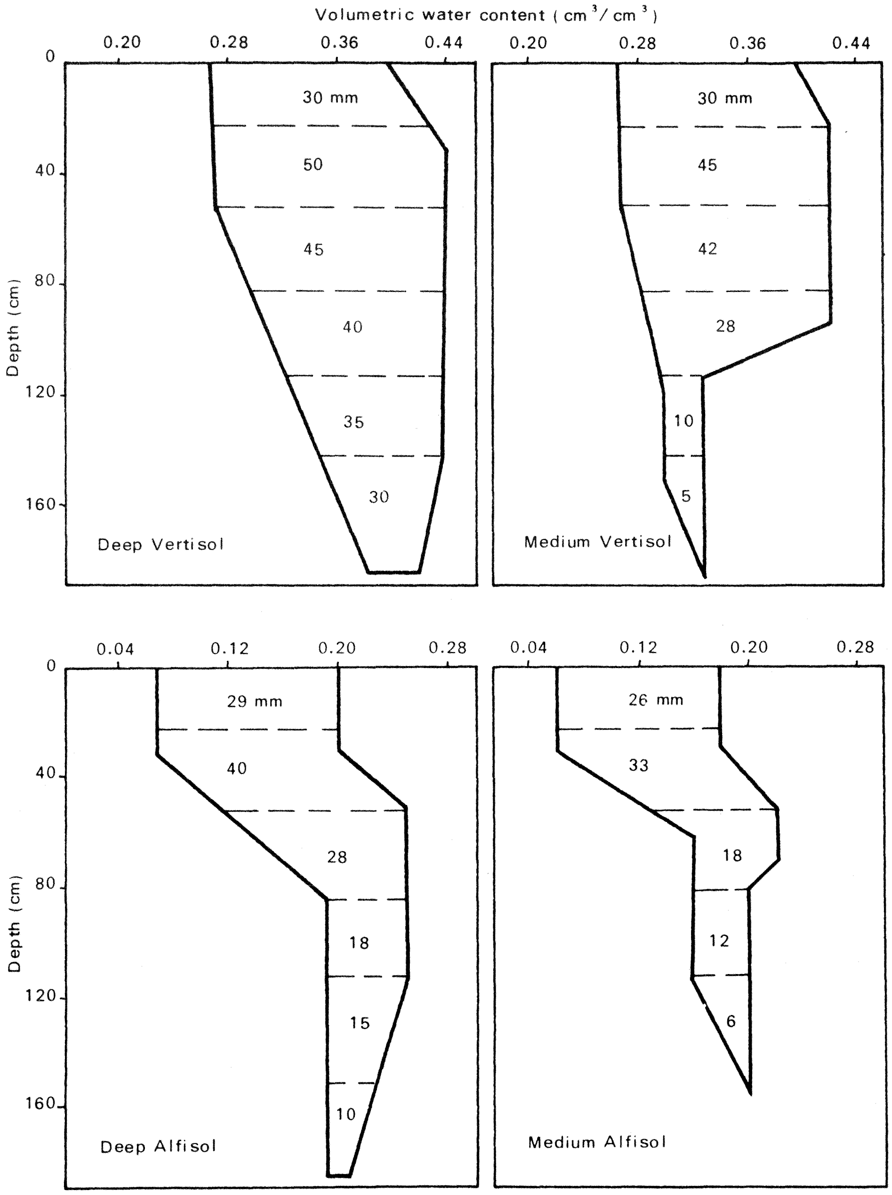


Fig. 1 Soil moisture characteristics of four soils which are found in the semi-arid tropics.

Crop production constraints of Alfisols and Vertisols

Under rainfed conditions sorghum and millets, pigeonpea, green gram, black gram, groundnut and castor are the main crops on Alfisols which are mostly intercropped. Under irrigation sole cropping and high intensity of cropping with crops like sugar cane, tobacco, groundnut and high yielding varieties of cereals are common. Tank irrigation is more common in Alfisols than in Vertisols and the associated Vertic type soils. Due to moisture and nutrient stress the cropping intensity and yields from these soils under rainfed conditions are low. They are mostly cropped during the rainy season, but with supplemental irrigation they can be double cropped.

On the Vertisols of the comparatively high and dependable rainfall areas of India are grown cereals such as maize, sorghum, millets, upland rice and wheat, pulses and oilseeds such as groundnut, safflower, soybeans, pigeonpea, green gram, black gram, and chickpea. Cash crops like cotton, chillies, tobacco and sugar cane are also extensively grown on these soils. Rice and sugar cane are mostly grown with supplemental irrigation but most of cotton is largely grown under dryland conditions. The yields of all these crops are low. The general crop yields based on ICRISAT Village Level Survey Studies for several Vertisol areas of Peninsular India are:

Sorghum	500–900 kg/ha
Wheat	300–700 kg/ha
Chickpea	200–500 kg/ha
Safflower	300–500 kg/ha
Chillies (dry)	300–700 kg/ha

The crop production in the Vertisol areas of India suffers from the twin problems of low average yields and high variability of production from year to year.

Both Vertisols and Alfisols have many constraints to stable and increased agricultural production in SAT. Some of these constraints arise due to the very nature of the soils, and others are due to the climate.

1 Workability

The high clay content and predominance of montmorillonitic clays impart certain characteristics to Vertisols which make them difficult to work. When too dry they crack; ploughing if possible, results in very large clods. When wet they are sticky; tillage is difficult, if not impossible due to poor trafficability. It is because of these features that most of the Vertisols in India remain fallow during the rainy season, as the farmer fails to make a proper seed bed in time, with the animal power available to him. It is estimated that about 12 million ha of Vertisols in dependable rainfall area (750 – 1250 mm rainfall area) of Peninsular India remain uncropped during the rainy season, when they could have been potentially cropped (Table 1, Ryan and Sarin (1981)). In some regions as much as 80% of the area is left fallow during the rainy season and cropped only after the rainy season. There are 34 districts in Madhya Pradesh, 12 in Maharashtra, 6 in Andhra Pradesh which fall in this category (Kanwar, 1981).

Research at the ICRISAT Center has shown that if Vertisols are ploughed immediately after the dry season crop, or when they are at the right moisture stage, an excellent seed bed can be prepared with minimal expenditure of energy. Since these soils are self-mulching, they form good structure, once the clods disintegrate.

The Alfisols are easy to work when wet, but harden on drying and may require greater use of energy for tillage.

2 Crusting

In India this is a severe constraint in Alfisols but not in Vertisols. Crusting is one of the primary causes of low yields on Alfisols because of serious reduction in germination and establishment especially of small-seeded crops such as pearl millet and sorghum. Crusting reduces infiltration of water so that an appreciable proportion of rainfall is lost as runoff, thus causing a greater susceptibility to droughts. Crusting is more common during periods of intermittent light rainfall or

Table 1 Estimates of extent of rainy season fallow in India

State	Years	Average annual area of rainy season fallow (000 ha)	% of net sown area fallowed in rainy season
Madhya Pradesh	1971 – 78	5,378	29
Maharashtra	1971 – 75	4,642	27
Andhra Pradesh	1972 – 78	2,259	20
Total of three states		12,273	26
India total	1970 – 71	26,200	19

Source : Ryan and Sarin (1981). Improving the management of India's deep black soils. pp. 39.

Table 2 Initial and equilibrium infiltration of a Vertisol and an Alfisol at ICRISAT

Time from start (hour)	Infiltration rate (mm/hr) Vertisol	Alfisol
0 – 0.5	76	73
0.5 – 1.0	34	18
1.0 – 2.0	4	15
After 144	0.21 ± 0.0	7.7 ± 3.7

after sudden drying of soil which was exposed to the impact of big raindrops.

Researchers are using several approaches such as mechanical and chemical methods, and organic mulches to alleviate the effect of crusting. At ICRISAT our physiologists are also screening for the differences in genotypes in securing good crop establishment in Alfisols. There is some evidence that genotypes of sorghum with glossy leaves, longer hypocotyle and greater resistance to high temperature are more able to break through crusts. Such research is still in its early stages.

3 Drainage

This is not a problem in Alfisols which are well drained soils. However poor drainage, both surface and internal is one of the main causes of low production from Vertisols. With the initial showers of rain, particularly when the soil is dry, the rate of infiltration in Vertisols is high because of cracks and granular structure. But as soon as the profile becomes filled up swelling of the soil reduces infiltration rates and affects internal drainage. A comparison of infiltration rates in both Vertisols and Alfisols is given in Table 2. The flat relief and reduced infiltration in Vertisols create surface drainage problems particularly when they are fully saturated. The improvement of surface drainage is essential for increasing crop yields from these soils. Our researches show that the graded broad bed and furrow (BBF) system of land configuration improves the surface drainage and induces more water infiltration in the soil. It also facilitates drainage of excess water through the grassed water ways.

In Vertisols of the low and undependable rainfall area of Peninsular India (rainfall < 750 mm) which are conventionally called drought prone areas and are primarily cropped during the dry season, deep ploughing or chiselling once in three years and vertical mulching have been found useful by many Indian workers. Randhawa and Mohan Rao (1981) reported that keeping sorghum stubble as vertical mulch in trenches 40 cm deep, 15 cm wide and protruding 10 cm above the ground level enhanced the available soil moisture by 4 – 5 cm. Such a practice has been found to improve grain yield by 400 – 500% in drought years and 40 – 50% in normal years (Table 3).

Table 3 Influence of vertical mulching on sorghum yield (kg/ha) in deep Vertisol of undependable rainfall areas of India

(kg/ha)

Treatment	Location					
	Ballary 1973–76		Sholapur 1974–76		Bijapur* 1973–74	
	Grain	Straw	Grain	Straw	Grain	Straw
Control	836	2,157	840	4,774	1,661	NA
Vertical mulch at 2m interval	1,172	2,961	1,237	6,276	–	NA
Vertical mulch at 4m interval	1,281	3,037	1,266	6,445	2,050	NA
Vertical mulch at 8m interval	1,186	2,927	1,123	6,231	1,823	NA

* Tested at 7–10m spacing

Source: Randhawa and Rama Mohan Rao (1981)

Because of the low infiltration rate and low moisture holding capacity the runoff loss of water is higher in Alfisols than in Vertisols (Table 4). In our experience over 8 years, the average runoff loss of water from cropped Alfisols has been about 30% and from Vertisols 10% of the total rainfall, but the main runoff came from storms of high intensity. From fallow uncropped Vertisols the runoff loss averaged 25.3%, and percolation loss 9.2% (Table 5).

Runoff water loss and soil loss in deep black soils (Vertisols) are less under the improved BBF system than conventional flat cultivation (Table 6). However the BBF system is not so effective on the shallower Vertic soils (Table 6) or on Alfisols (Table 7) as it encourages more runoff. It may however be advantageous for the harvesting and reapplication of water for use in life saving irrigation; it also facilitates cultivation and weeding, especially when trafficability is poor due to high soil moisture content.

4 Erosion

As mentioned in the previous section, the Vertisols without proper land treatment and crop cover during the rainy season are prone to soil and water loss but with proper treatments such as BBF and crop cover the losses are markedly reduced. On the other hand the Alfisols are more erodible than the Vertisols under BBF.

Table 4 **Rainfall and runoff on a cropped Alfisol and Vertisol watershed at 0.6% slope (data of 1976 from watershed management experiments, ICRISAT)**

Period	Rainfall record during the period (mm)	Runoff (mm)		
		Alfisol cropped	Vertisol cropped	Vertisol fallow
19th August (first big storm)	105	77.5	27.0	95.4
21st August (second big storm)	89	25.2	16.9	49.4
26th June to 4th September (9 small storms)	305	37.9	28.8	94.4
Total from 23rd June to 4th September, 1976 (normal rainfall)	499	140.6	73.0	238.2
Total of 15 storms from June to September during 1977 low rainfall year	349	45.1	1.5	52.9

Source: Kampen *et al.* (1978)

Table 5 Estimated water-balance components observed in studies of the traditional rainy season fallow system on Vertisols at ICRISAT Center

(mm)

Water balance component	Year 1973–74	74–75	75–76	76–77	77–78		1973–78 (%) 78–79
Runoff[a]	60	210	250	210	50	410	25.3
Deep percolation	100	15	140	20	0	160	9.2
Evaporation (rainy season fallow)	300	175	225	145	140	190	24.9
Evapo-transpiration (post-rainy season cropping)	280	375	350	290	325	290	40.6
Rainfall	740	775	965	665	515	1050	100.0
Soil loss (ton/ha)	NA	NA	NA	9.2	1.7	9.7	6.9[b]

a When crops are grown during the rainy season, runoff is reduced on average to less than 15% of the annual rainfall

b This average of 6.9 ton/ha 3 years compares with 1.4 ton/ha when crops are grown during the rainy season in an improved land management system.

Table 6 Runoff and soil loss under different treatments in field scale management trial on watersheds (mean of 4 years 1976–79)

	Deep black soils (Vertisols) (BW-5)		Shallow black soils (Entisols) (BW-8)	
	Flat	BBF	Flat	BBF
Total runoff (mm/ha)	337	261	83	109
Total soil loss (ton/ha)	5.2	3.3	1.00	1.5

(Total excludes the storm of 14-15 August in 1978)

Table 7 **Yields, runoff, soil loss under different treatments in Alfisol field scale management trials**

	Mean of 4 years	
	Flat	Broad bed and furrow
Sorghum kg/ha	3,116	2,820
Pigeonpea kg/ha	449	493
Runoff (% of rainfall)	21.7	34.2
Soil loss (ton/ha)	1.0	2.1

Source: Binswanger, Virmani and Kampen (1980)

5 Soil fertility

The Vertisols are generally low in organic matter, nitrogen, phosphorus, sulfur and zinc. It is interesting to note that even on ICRISAT farm of 1,400 ha, most of the Vertisol fields are low in N, P, and Zn, and in some of them after addition of about 1,000 kg of P_2O_5 in 8 years, the level of "available" phosphorus in the soil had not increased above the medium level, as indicated by the available P value obtained by Olsen's method (Table 8). Deficiency of zinc after land treatments becomes even more manifest because of the originally low zinc status and soil heterogeneity. Our experience shows that without the application of moderate doses of phosphate, nitrogen and occasional application of zinc sulfate satisfactory yields of crops are not possible. The failure to recognize the nutrient deficiency and changes in availability of soil and fertilizer nitrogen with season and management has serious implications for the realization of the production potential from these soils.

In Alfisols also the deficiency of the above-mentioned nutrients is common, and responses to fertilizers are high. Even potassium which may not be a limiting factor for crop production in the beginning becomes deficient with continuous cropping. The nutrient deficiency and responsiveness to fertilizer application on the farmers' fields is much greater than on the research stations. Thus the key to increasing crop production under rainfed conditions from Vertisols and Alfisols of SAT is the balanced use of fertilizers. Some pertinent results from ICRISAT for Vertisols are given in Fig. 2. The results indicate that in 1979, a lower than average rainfall season with two midseason droughts, the maximum increase in yield of sole sorghum resulted from the application of 40 kg N and amounted to 1,600 kg grain/ha but on the average and high rainfall years of 1977 and 1978 responses were 3,200 and 3,700 kg/ha at 80 and 120 kg N. The results were obtained in the presence of an adequate supply of phosphate and zinc. The results also show that the sole crop shows slightly higher response than the intercrop.

For Alfisols, fertilizers are required although the efficiency may be more variable due to the greater and more variable incidence of moisture stress. In years of good rainfall distribution, and with good agronomic management, the Alfisols show better fertilizer efficiency. Using ^{15}N, Moraghan (personal communication) obtained a recovery of 68% when urea was applied as 2 split applications; a lower, but still satisfactory recovery of 54% was obtained when all the fertilizer was applied at one time as a basal dressing.

Table 8 Status of available phosphorus at ICRISAT site after 8 years of cropping and fertilization

Soil	Low <5 ppm P	Medium 5–10 ppm P	High >10 ppm P
A. Percentage of fields in various categories of available phosphorus			
Alfisols	32	58	10
Vertisols	75	20	5

B. Present status of available phosphorus after 8 years of regular application of phosphate and cropping in selected fields of Alfisols and Vertisols

Field No.	Total P_2O_5 added in 8 years	Soil depth			Crop History
		0–15 cm	15–30 cm	30–60 cm	
Alfisols					
RP-5 Precision field	988 kg	7.3	1.6	0.5	Intensively cropped under irrigation and heavy fertilization
RP-7 Precision field	876 kg	19.3	4.1	2.1	– do –
Vertisols					
BP-7 Precision field	576 kg	3.7	1.1	0.7	Intensively cropped under irrigation and heavy fertilization
BP-11 Precision field	648 kg	6.5	2.0	1.0	– do -

Source: Unpublished report by Burford and associates, 1981

The efficiency of fertilizer improves with the management system as is evident from the following results reported by Venkateswarlu (1981) from the All India Coordinated Research Project on Dryland Agriculture.

Nitrogen added (kg/ha)	Response of sorghum to fertilizer N added (kg grain/kg N)	
	Traditional management	Improved management
25	7.1	26.5
50	17.0	25.2

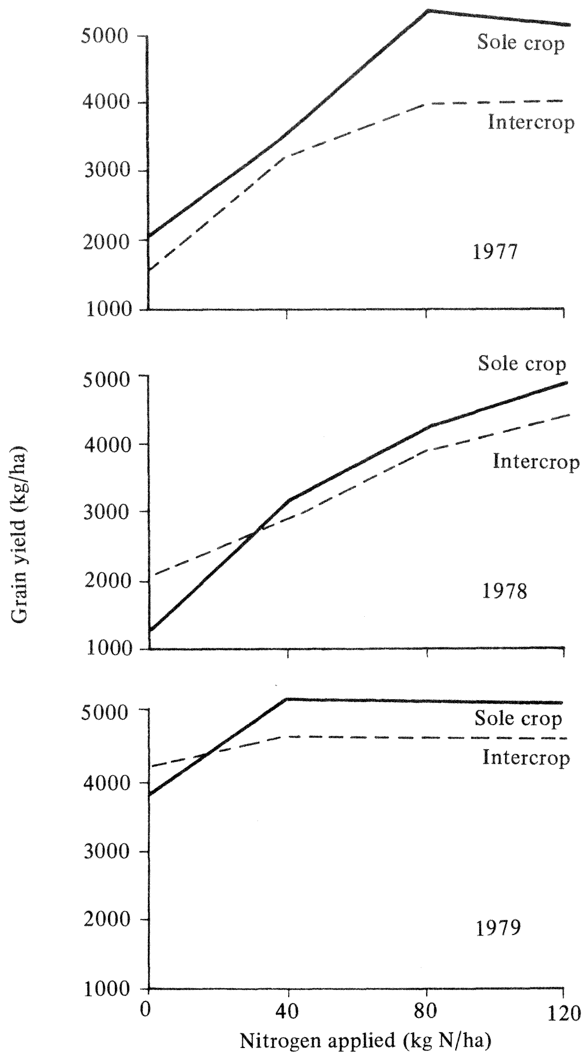


Fig. 2 Response of sole and intercropped rainy season sorghum to nitrogen on Vertisols at ICRISAT Center, 1977-79.

Potential and constraints to fertilizer use in these soils are critically reviewed by Kanwar (1980 a and b).

6 Soil moisture

Available soil water storage capacity, and the likelihood of moisture stress, are dominant factors affecting crop production in SAT. The Vertisols have a high moisture storage capacity as compared to the Alfisols as is evident from the available water profiles of 4 soils of ICRISAT site (Fig. 1).

Alfisols possess only about 1/3rd to 1/2 available moisture holding capacity of the Vertisols, thus the crops on Alfisols are more prone to suffer from mid-season and end-season droughts. The moisture retention capacity of soil varies not only with the nature of the soil but also with the soil depth. The moisture storage capacities of three typical soil profiles of the SAT of India as calculated by Virmani *et al.* (1978) are shown in Fig. 3.

From these results, it is evident that in the shallow Alfisols there is very little soil moisture storage for use over extended drought periods. In deep black soils (Vertisols) medium deep black soils and deep Alfisols there is a fair degree of moisture storage for substantially longer time. Thus under the same mean rainfall conditions the effects of short-term intraseasonal droughts will differ with the soils.

Vertisols are no doubt deep soils, and have high moisture storage capacity, but the same amount of total rainfall with differences in its distribution and probability of occurrence leads to different patterns and degrees of success of the crop. Virmani *et al.* (1978) presented different probabilities of success for a 90-day crop at Sholapur and Hyderabad (Table 9). Both places have more or less the same rainfall but different distribution and probability of occurrence.

The combination of soil depth plus difference between Alfisols and Vertisols in their moisture holding capacity per unit depth leads to a considerable range in the length of the growing season at ICRISAT Center on the different soils – the Vertisols, the shallower black soils (Vertic soils), and Alfisols (Table 10). Under the different rainfall probabilities there is a difference of 8 – 10 weeks in the length of the growing season, making all the difference in cropping strategies.

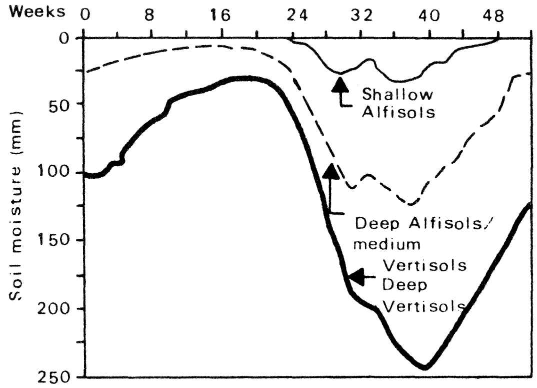


Fig. 3 Weekly soil moisture storage in three soils (Hyderabad, 1901–1970).

Table 9 Predicted reliability of cropping (90-day duration sorghum) on two Vertisols, receiving almost the same rainfall but with a different distribution

Soil	Annual rainfall	Probability of adequate moisture throughout the crop season	Probability of adequate moisture for rabi sorghum throughout	Probability of adequate moisture after kharif fallow
	mm	%	%	%
Sholapur deep Vertisols	742	33	60	80
Hyderabad deep Vertisols	764	62	50	83
Akola medium Vertisols	810	66	ND	ND

Table 10 **Length of the growing season in weeks for 3 soils with different moisture storage capacity**

Rainfall probability	Shallow black soil (Entisol) or shallow Alfisol	Alfisol	Vertisol
		Weeks for successful cropping	
		Average moisture storage capacity	
	<50 mm	150 mm	>300 mm
Mean	18	21	26
75%	15	19	23
25%	20	24	30

7 Probability of water harvesting and use

The assessment of economics of water harvesting was studied by Ryan and associates (1981) using a simulation model. The authors conclude that there is a good potential for water harvesting and supplementary irrigation on Alfisols at Hyderabad; particularly important was the need for supplemental water for crops at the flowering and physiological maturity stages. But for Vertisols, particularly under the BBF system, the potential need for irrigation is small, or negligible, because of the ability of these soils to store water.

During 1976, a normal rainfall year, 2 big storms produced most of the runoff water for storage tanks, and this runoff was greater from a cropped Alfisol than from cropped Vertisols. During 1977, a low rainfall year, the cropped Vertisol yielded virtually no runoff under the BBF system. Thus the probability of collecting water for irrigation from Vertisols at Hyderabad for sorghum in stress years is also low. The potential for water harvesting and reuse is confined to the soils with low water-holding capacity – Alfisols and shallow black soils (Entisols).

8 Climatic constraints and imperatives for better technology for crop production

The SAT areas remain dry from 5 to 10 months in a year and have a mean temperature of 18°C. The rainfall generally ranges from 500 to 1500 mm. Problems of moisture stress and drainage are frequent as the rain is highly variable from season to season and also erratic in distribution within the season. Because of moisture stress Alfisols can generally support only one crop each year, without irrigation. Because of drainage problems and difficulties in working the soils, many of the Vertisols remain uncropped during the rainy season.

Most conservative estimates show that there are 12 million ha of Vertisols in India (Table 1 which gives estimates for 3 states only) which remain uncropped during rainy seasons mainly due to difficulties in cultivating these when wet. The farmers have adopted a farming system that gives them stable but low yields. Subsistence farming using low input technology and intercropping to diversify the risks is the common philosophy of farming in SAT. The fluctuations in rainfall amount and distribution (seasonal and intraseasonal) are the greatest disturbing factors in SAT agriculture. Thus a technology is needed which can ensure best use of rain water and of soil resources along with most efficient use of meagre inputs available to the SAT farmer.

Improved technology for maximizing production from Vertisols and Alfisols

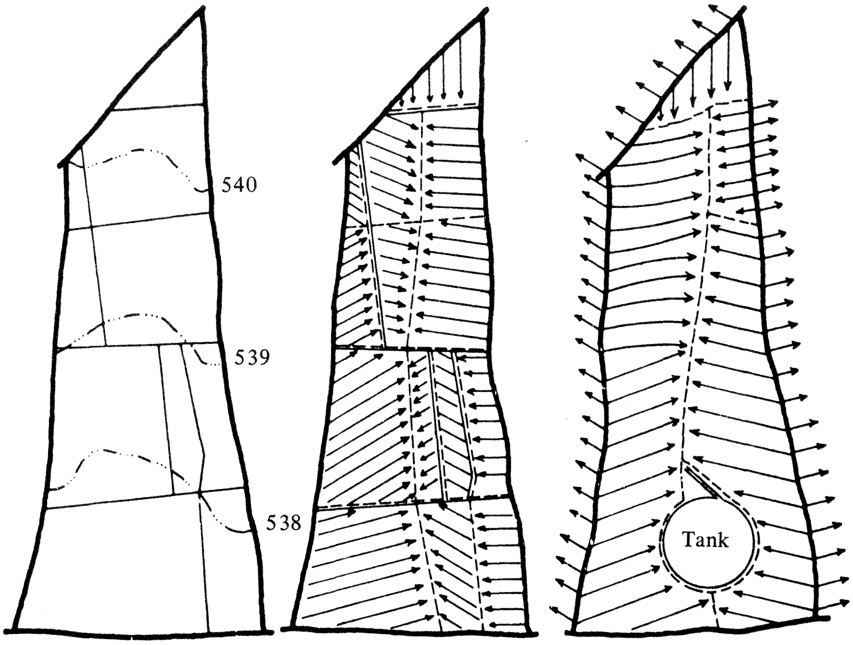
The ICRISAT scientists have attacked the above mentioned constraints, and developed a technology for maximizing production from the Vertisols and Alfisols under the harsh environments of the SAT. It has also been recognized that the technology should be within the reach of the small farmers of rainfed areas of the SAT which hopefully should be capable of getting similar type of "quantum jumps" which the farmers of the irrigated areas have realized.

The technology developed by ICRISAT has been described in many publications in the last few years. Among the more important ones which summarize the existing information is a paper by Krantz *et al.* (1978) which appeared in the Proceedings of the 11th International Congress of Soil Science. More recent publications in this area are by Binswanger *et al.* (1981), Virmani *et al.* (1981), Kanwar (1981) and Ryan *et al.* (1981).

The technology has been described as the watershed based, graded broad bed and furrow system (BBF). The important ingredients of the technology are:

(1) Watershed development to encourage and control surface drainage, which consists of:

i. Development of graded broad bed and furrows 150 cm apart on 0.4 to 0.6% slope. This is a better alternative to contour bunds which have failed to produce the described results (Fig. 4).



a. Contour bunds.

b. Broad bed and furrow system at 0.6% within field boundaries.

c. Broad bed and furrow system at 0.6% with grassed waterways and a tank.

→ Bed and furrow direction
—— Field bunds
- - - - Grassed waterways
═══ Elevated inlet
—··· — Contour bunds

Fig. 4 A Vertisol watershed with three alternative soil and water conservation and management practices.

ii. Development of waterway, preferably, grassed waterway for conducting excess water away and minimizing erosion risks.

(2) Soil tillage at the optimum soil moisture content using the efficient wheeled tool carrier (tropicultor).

(3) Dry seeding just before the onset of the rainy season to avoid difficulties of soil workability of Vertisols when wet.

(4) Using improved cropping systems, for example, a cereal/legume intercropping system with 2 rows of cereal and one of legume, or a sequential crop of maize followed by chickpea. Our experience is mostly with sorghum/pigeonpea or maize/pigeonpea intercrops or sorghum/chickpea or maize/chickpea sequential cropping systems.

(5) Making deep placement of basic fertilizer containing N and P (and Zn every few years) with the major input of nitrogen being made by a band application after emergence of seedlings.

(6) Proper weed management by mechanical interculturing.

(7) For all these operations the wheeled tool carrier or tropicultor with attachments for tillage, seeding, fertilizer applications has been found most useful.

(8) The broad bed and furrow system is adaptable to many row spacings and a variety of crops and could also be used for supplemental irrigation in the furrows.

Using this system of soil management on ICRISAT's operational scale watersheds over the 6 years, 1976–81, we have obtained the following average yields with different cropping systems. In all the years the mean yield of the improved system was about 4,000 kg, compared to 600 kg with the traditional technology (Table 11). The average production per ha with the improved technology based on watershed concept, graded broad bed and furrow, high yielding varieties, fertilizer and good management exceeded 600%.

The analysis of the cost/benefit relationships by our economists shows that on an average the improved technology also increased the profits by 600% compared with the traditional technology. The rate of return on the increased working expenditure was about 250%. It is stressed that this result is not the effect mainly of just one practice; rather it is the synergistic effect of all the ingredients of technology which produces such a spectacular result (Table 12).

The most important features of the technology are stabilization of production in spite of the rainfall fluctuations and creation of greater employment for the farmer, his family and animals.

Experience with shallow black soils (Entisols), medium deep black soils (Inceptisols)

In case of medium deep black soils (Inceptisols) and shallow black soils (Entisols) – the comparative yields obtained over 3 years from 1976–78 are given in Table 13. These results show that the effect of the BBF over the flat system of planting was only marginally superior.

Experience with Alfisols

The broad bed and furrow system has been tested in Alfisols. Although it introduces good soil conservation measures, the practice seems to confer no other special advantage. On the contrary it causes more loss of water through greater runoff and soil loss as is evident from Table 4. This is perhaps due to the compaction of the soil in the furrows. However, in Alfisols the synergistic effect of improved cultivar, fertilizer, and soil management is very marked (Table 14). Similar results have been obtained in other years also. These results show that under rainfed conditions the Alfisols also can produce many times more yields with proper soil management, use of fertilizers, high yielding varieties and crop management system. The runoff water could be recycled for enhancing production, stabilizing yield and extending the cropping season. Kampen (1976) has claimed many other advantages also for the system. The land treatment technique however needs much further research to develop improvements in moisture conservation and erosion control.

Table 11 Mean yields with improved and traditional technology

Cropping system and soil	Mean yields kg/ha (1976 to 1981)				Mean of 4 years
	1976 – 77	1977 – 78	1979 – 80	1980 – 81	
Deep Vertisol					
A. Maize-Pigeonpea intercropping system					
Maize	3,291	2,813	2,140	2,918	2,791
Pigeonpea	783	1,318	1,171	968	1,060
Total production	4,074	4,131	3,311	3,886	3,851
Average gross profits Rs/ha	–	–	–	–	3,650
B. Maize-Chickpea sequential system					
Maize	3,116	3,338	2,150	4,185	3,197
Chickpea	650	1,128	1,340	786	976
Total production	3,766	4,466	3,490	4,971	4,173
Average gross profits Rs/ha	–	–	–	–	3,063
C. Traditional system (rainy season fallow and post-rainy season crop of cereals or pulses)					
Sorghum	543	865	532	596	634
or					
Chickpea	436	377	555	563	483
Average gross profits Rs/ha	–	–	–	–	494
D. Sorghum-Pigeonpea intercropping system (medium deep Vertisol)					
Sorghum (2-year average)	–	–	–	–	3,055
Pigeonpea (2-year average)	–	–	–	–	365
Average gross profits Rs/ha	–	–	–	–	3,420

Available water in the deep Vertisols and medium deep Vertisols is 230 to 160 mm respectively.

Table 12 Synergistic effect of different treatments on crop production from interroropped maize-pigeonpea in Vertisols, 1976 – 1979

Treatment		Crop yield (kg/ha)	
		Maize	Pigeonpea
1.	HYV only	630	500
2.	HYV + Soil Management	960	640
3.	HYV + Fertilizer	2,220	540
4.	HYV + Fertilizer + Soil Management	3,470	604
	C.D. @5%	470	218

HYV : High Yielding Variety

Table 13 Comparative effect of different levels of treatments of treatments on production and returns

Treatment soil	Maize	Chickpea *	Total	Mean production value
		(kg/ha)		Rs/ha
Medium deep black soil (Inceptisol)				
Flat	2,287	777	3,064	3,705
BBF	2,670	954	3,624	4,362
Medium to shallow black soil (Entisol)				
Flat	1,873	433	2,306	2,881
BBF	2,040	593	2,633	3,128

* in medium shallow Vertisols instead of chickpea, the second crop was pigeonpea or safflower.

Table 14 Synergistic effect of different treatments on crop production from intercropping system of sorghum-pigeonpea in deep Alfisol (1978 – 1979)

Treatments	Crop yield (kg/ha)		Gross returns Rs/ha
	Sorghum	Pigeonpea	
Control (traditional technology)	970	910	2,950
Variety (improved)	1,150	640	2,400
Variety + Management	1,560	990	3,570
Veriety + Fertilizer	2,970	430	3,150
Variety + Fertilizer + Management	3,420	1,010	4,820
Veriety + Management + Fertilizer + Irrigation	3,290	1,040	4,900

Soruce : ICRISAT Annual Report 1978–79.

Water harvesting and use

The greater runoff from Alfisols enhances the potential for water harvesting and reuse. Most of the runoff water comes from storms of high intensity. Krantz *et al.* (1978) have reported the ICRISAT experience of such beneficial effects. It however hardly needs to be stressed that the economics of the system of water harvesting and use is to a considerable extent location specific, and it increases with the value of the crop and the efficiency of reduction of seepage losses from the tanks and the water conveyance system. There are still a number of problems which need attention from soil scientists and engineers before this can become a viable practice.

Potentialities and possibilities of increasing production from Vertisols and Alfisols

Under the rainfed conditions of farming in SAT, both Vertisols and Alfisols are much less utilized than their potential warrants. The Vertisols in the dependable rainfall areas are capable of producing two crops annually and giving more yield of about 3 ton/ha than they are doing now. In India alone, there is an area of 12 million ha of Vertisols that remains uncropped during the rainy season but on which double cropping is possible. From this area it appears possible to increase food grain production by about 36 million ton/year with the improved technology and inputs. The improved technology besides increasing food production can create more employment for farmers, their families and bullocks; it can also reduce the hazard of floods and minimize soil loss, thus introducing a long-term benefit in minimizing the deterioration of these most valuable soil resources. However the potential of harvesting water and its reuse from Vertisols is rather limited. In the Alfisols also a combination of practices such as land treatment, variety, fertilizer and use of harvested water for life saving irrigation can result in substantially improved production.

The possibility of the use of harvested water for stabilization of crop production from Alfisols needs investigation. Even the use of solar pumps for water lifting and plastic tubes for conveyance of water and its distribution needs a hard look at. If the rain water is properly managed *in situ,* through increasing storage in the soil and by harvesting the excess water, it can revolutionize agriculture in these areas.

Summary

The Semi-Arid Tropics (SAT) where the average rainfall exceeds potential evapo-transpiration for about 2 – 7 months in a year and mean monthly temperature exceeds 18°C is a region of great concern because of unstable food production and low yield of crops. Most of the cropping is under rainfed conditions and most of the farmers of this region are resource poor farmers. SAT forms a mandate area of concern for the ICRISAT's program of farming systems research which is aimed at developing improved technology for increasing production under such harsh environments.

ICRISAT's main center at Patancheru, Hyderabad (India) has 2 important soils – Alfisols and Vertisols and associated Vertic type soils. ICRISAT has recently set up a Sahelian Center at Niamey (Niger) which has sandy soils similar to Arenosols of FAO/UNESCO classification system and represent considerable areas of the West African SAT.

In the last 8 years ICRISAT scientists have studied the problems and constraints to producion in case of Alfisols and Vertisols and Vertisol associated soils which represent typical SAT soils in India. A technology has been developed for increasing production from these soils.

An evidence is presented that using small watershed concept, broad bed and furrow (BBF) system of land treatment, improved cultivars, fertilizers and good management the Vertisols in Indian SAT even under rainfed farming can produce about 600% more food. Estimates show that about 12 million ha of Vertisols (deep black soils) of Indian SAT which remain uncropped during the rainy season are capable of producing an additional 36 million ton of grain with improved technology. Similarly the Alfisols also with improved technology can produce many times more food. However, there are still some problems of Alfisols such as crusting and crop stand establishment, which require intensive investigation.

The techniques for management of sandy soils similar to Arenosols of Africa will be the subject of intensive research in the eighties.

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Discussion

Schlichting E. (Germany): The figures you gave for the water retention capacity of Vertisols have obviously been determined with swollen samples. From the ecological viewpoint, such figures are misleading since the pore size distribution varies with soil moisture, i.e. the permanent wilting point (PWP) and the field capacity (FC) are not constants. Vertisols may supply plants with water while the average soil moisture is below the PWP and may have seepage while this moisture is below FC, depending on the degree of cracking before rain or irrigation and on the rain density (mm/h). Do you have data on the pore size distribution (water retention) of Vertisols in different moisture status?

Answer: I do not have such data. In the case of Vertisols with deep profile, there is plenty of water available in deeper layers but not on the surface. We have introduced the system of dry sowing because of our awareness of changes in the pore size distribution.

Kyuma, K (Japan): Please tell me what "vertical" mulching is.

Answer: This practice consists of burying sorghum stubbles and straw in trenches 40 cm deep, 15 cm wide and protruding 10 cm above the ground level. Such practice enables to increase water intake and moisture storage in deep Vertisols of independable rainfall areas (about 500 mm). There is a reference on this method in my paper.

Kubota, T. (Japan): You mentioned that Vertisols were not prone to crust formation or erosion. On the other hand, slaking properties after drying (large clods to fine aggregates) are conspicuous, resulting in the packing of large pores on the soil surface, which in turn is detrimental to crop growth. Have you observed such phenomena?

Answer: I have not observed such phenomena as the Vertisols I referred to in my presentation occur on a 3% slope in a low rainfall area. The Vertisols you referred to in Thailand are located in flat areas and slaking may be due to internal drainage. In India, Vertisols do not present much of a problem for sorghum or millet crops whereas Alfisols under the same climatic conditions pose a serious problem of crusting which affects germination and crop stand establishment.

Briones, A.A. (The Philippines): At what moisture content for the type of Vertisols you have shown do you observe the cracks? How much shrinkage does occur?

Answer: The total amount of water retained in the profile may be 800 to 900 mm, out of it the available moisture must range between 200 and 300 mm. Shrinkage occurs at less than 10%, probably in relation to changes in the pore size distribution.