Management of Vertisols for Maximising Crop Production— ICRISAT Experience

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Abstract

Vertisols are an important group of soils in the semi-arid tropics (SAT) of India and elsewhere. They have high water-storage capacity and high production potential, which remains under-utilised because of the difficulty of managing these soils and the use of traditional technology. Drought and poor drainage are twin problems which discourage most farmers from cropping these soils in the rainy season and make them resort to post-rainy cropping.

A technology based on the watershed concept, broadbed-and-furrow system and land management, use of improved implements, high-yielding varieties, double-cropping and intercropping systems, balanced use of fertiliser and good crop management practices has been evolved and tested for 8 years at ICRISAT Center, near Hyderabad. The technology offers the possibility of increasing yield to 3 to 5 tonnes/ha and of giving profits up to 250% on the investment. The improved technology reduces soil and water loss and increases production. It is likely to improve the employment potential and well-being of the people of the SAT.

The technology needs trials in different agroclimatic environments in India and also critical evaluation and modification elsewhere.

The Vertisols, commonly known as black soils, and associated soils with vertic characteristics, cover 73 million ha of the geographical area in India; about 28 million ha of these are true Vertisols. About 80% of the Vertisols in India lie in the states of Maharashtra, Madhya Pradesh, Gujarat and Andhra Pradesh, 13% in Karnataka and Tamil Nadu, and the rest in other adjoining states (Murthy et al. this symposium). Unique features of this region are that it lies in a seasonally dry climatic belt. The rainy season is short (with only 2-4½ wet months) and rainfed farming is generally practised. It is no exaggeration to state that the future of agriculture in these six states lies in the efficient management of Vertisols.

Virmani et al. (1981) have divided the Vertisol region of India into two climatic regions: (1) areas with relatively dependable rainfall with a mean annual rainfall ranging from about 750 to 1250 mm or more; (2) areas with relatively undependable and low rainfall, mean annual rainfall generally less than 750 mm (Figure 1). The dependable rainfall areas are characterised by a marked reliability of rainfall occurrence at short intervals, while areas with undependable

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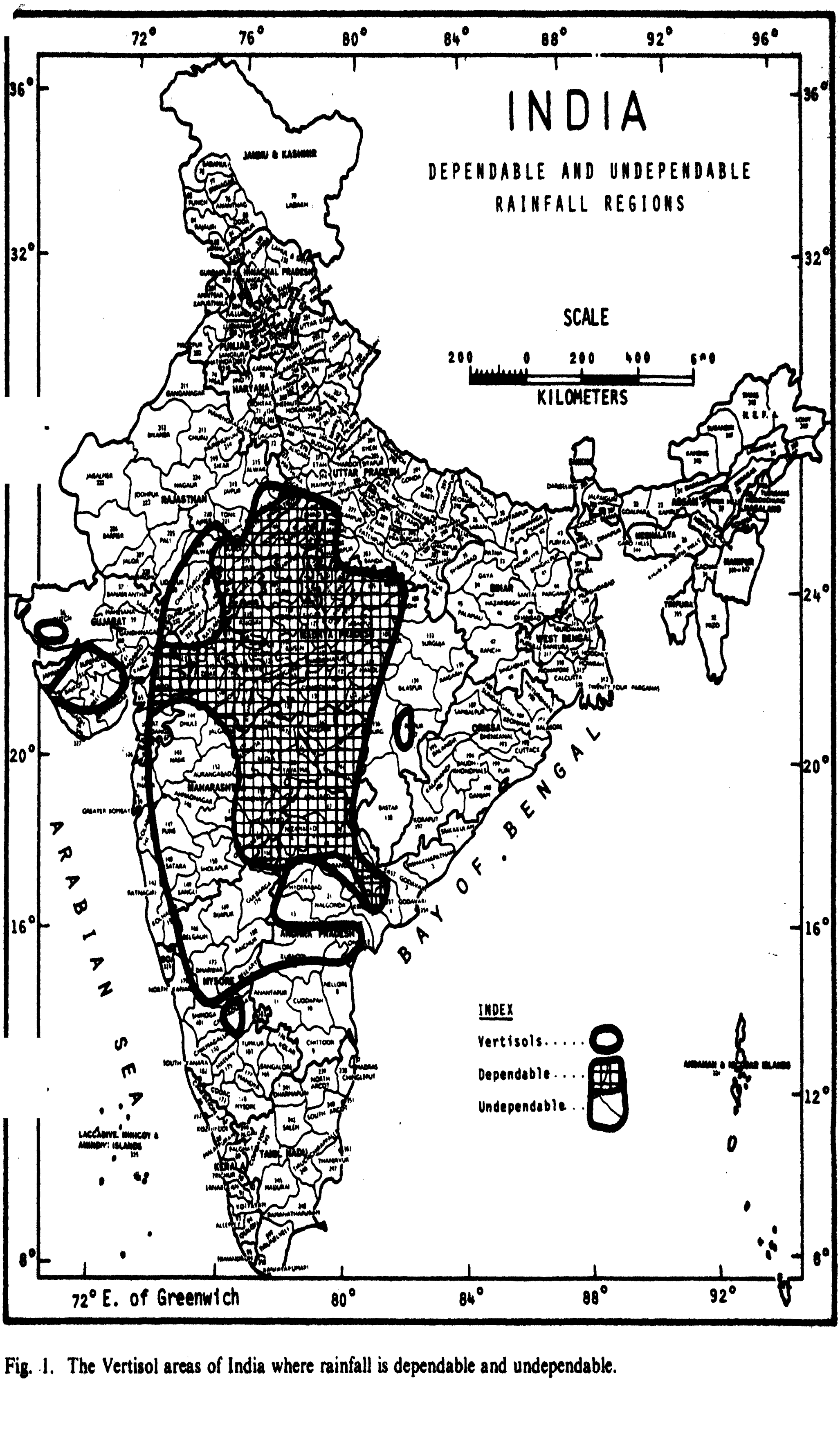

Fig. 1. The Vertisol areas of India where rainfall is dependable and undependable.

rainfall show frequent occurrence of long drought periods. Temperatures in the Vertisol region are conducive to year-round cropping, but the major constraint to the realisation of the region's agricultural potential is the relatively short growing season due to lack of available moisture.

Vertisols have a high moisture-storage capacity. The average field capacity of the 185-cm profile at ICRISAT Center is about 810 mm and the lower limit of plant available water is 590 mm (Russell 1980). The lower limit is the observed minimum content of water throughout the profile as measured in the field under a well-managed, deep-rooted, long-season crop and the upper limit represents the amount of water retained by an uncropped Vertisol profile following cessation of drainage. The distribution of extractable water in a typical deep Vertisol profile as given by Russell (1980) is shown in Table 1.

Table 1. Available water profile for a typical deep Vertisol.

Soil Depth (cm)	Available water content (mm)
0 - 22	30
22 - 52	50
52 - 97	45
97 - 115	40
115 - 145	35
145 - 185	30
0 - 185	230

Even though the available moisture capacity of the deep Vertisol is large and under favourable rainfall conditions the profile generally remains fully charged, it is surprising that these soils are highly under-utilised. They remain largely uncropped during the rainy season and are usually cropped only in the post-rainy season. We believe that with scientific management of soil and rainwater, Vertisols are capable of producing many times more food than they produce today. In the dependable rainfall area it should be possible to produce two crops a year instead of one.

Several speakers in this symposium have discussed the physical and chemical properties of Vertisols and their management. In this paper we plan to discuss the major management problems of Vertisols in India which have led to their under-utilisation and low productivity and to present evidence of their potential for increased production under rainfed farming with the new technology.

The Problems

Variable Length of Growing Season

Russell (1980) reported extensive studies on the water storage and use in Vertisols. He found that soil moisture use by a range of crops was related to the amount and timing of the rains as well as the size and rate of development of the crop canopy. He also observed that the development of the root system strongly influenced crop water use. Due to erratic and variable rainfall in the semi-arid tropics, the length and the characteristics of the growing season vary from year to year. Virmani (1976) carried out in-depth analysis of the water balance of a range of Vertisols with different water-holding capacities, using the approach developed by Nix (cited by Keig and McAlpine 1974). The results (Figure 2) showed that the water-holding capacity of the soil has a considerable influence on the availability of soil moisture during the growing season. For example, deep

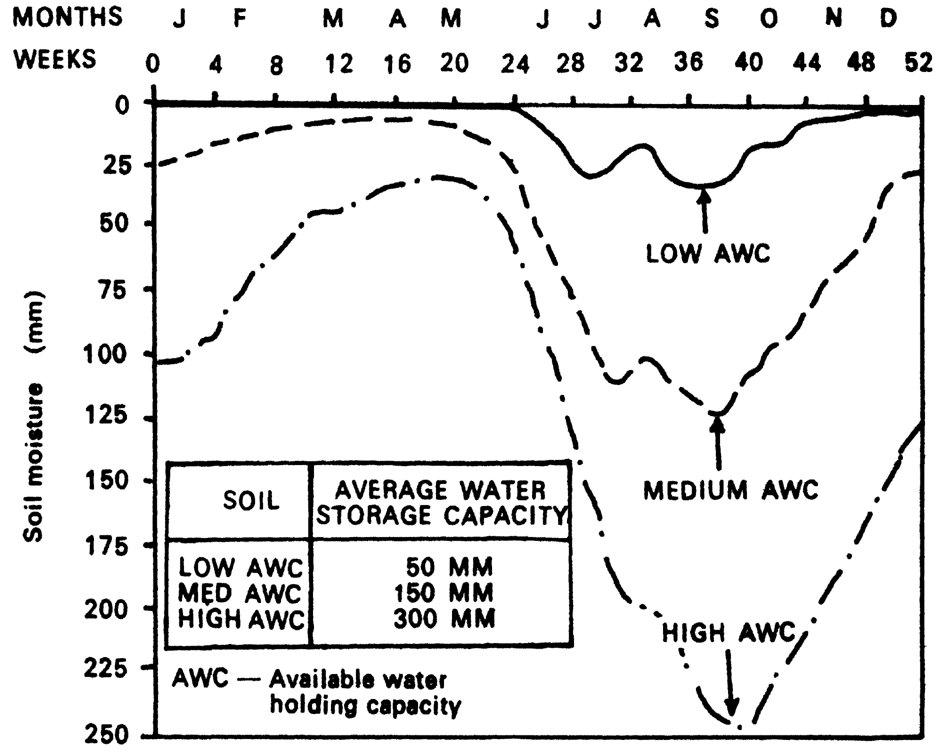

Fig. 2. Weekly soil moisture storage in three soils (Hyderabad 1901-70 rainfall records)

Vertisols with approximately 300 mm available water-holding capacity at Hyderabad (annual rainfall: 760 mm) are likely to have sufficient available water in most years. Using EA/PE* = 0.5 as a minimum threshold of water availability to plants, it was estimated that for the Hyderabad location the length of the growing season for a deep Vertisol would be of the order of 22, 25 and 28 weeks at 75%, 50%, and 25% probability levels respectively. Similarly for the medium-deep black soils, the relative estimates were 18, 20 and 23 weeks for 75%, 50% and 25% probability levels. The variability of the length of growing season in shallow

*EA is the actual evapotranspiration as simulated by the model and PE is the potential evapotranspiration for the location.

black soils is much more pronounced (Virmani 1976). The above estimates of the length of the growing season are based on the data from the start of the growing season in June until the moisture in the soil profile is sufficient to sustain crop growth. However, a comparison of the growing season length from the first week of October (i.e. commencement of the post-rainy cropping season) showed that at the Hyderabad location it was at least 12 weeks in 90% of the years.

Krantz and Russell (1971) and Kampen et al. (1974) have discussed reasons for rainy-season fallowing of Vertisols in high rainfall zones of India, where the necessity of such a practice cannot be explained by the lack or the unreliability of soil moisture during the rainy season. Kampen et al. (1974) and Kampen (1976) stressed undependability of early rains and variability of growing season length from year to year as important causes of rainy-season fallowing.

Difficulties in Cultivation and Seed-Bed Preparation

The Vertisols are high in clay content, particularly in expanding lattice montmorillonitic clays. These soils undergo pronounced shrinkage during drying, resulting in large cracks. The cracks close only during rewetting of the soil profile. The soils become very hard when dry and then are extremely difficult to plough. If dry soils are ploughed, the surface soil breaks into big clods. A tremendous amount of power is needed for such an operation. In the semi-arid zone of India where Vertisols predominate the landscape, the only tools available to the farmers are a wooden country plough and some simple harrows. His source of energy is himself and a pair of oxen. He therefore leaves the Vertisols uncultivated during the long dry season before the onset of the rainy season.

Vertisols when wet are highly plastic and sticky. For initial wettting of a dry cracking soil, a considerable amount of rainfall is needed. The rainwater tends to move into the cracks and wets the deeper layers of the soil profile, leaving the surface soil relatively dry. Optimum moisture conditions for cultivation are therefore difficult to obtain under the present management practices.

Once the rainy season sets in and the surface soil has been wetted, there may be few occasions for cultivation, which requires that the surface soil moisture be reduced enough for preparation of a friable seed bed with optimum tilth. Several dry days are required for the soil to reach this optimum condition and in dependable rainfall areas after the onset of rainy season, the probability of this occurring is low. This is probably another reason contributing to rainy-season fallowing of Vertisols in India.

Short-Term Waterlogging and Soil Erosion

The saturated hydraulic conductivity of the Vertisols is low, as indicated by the terminal infiltration rates shown in Table 2. Thus, once the soil profile is fully saturated, rainwater often stagnates. This occurs commonly in the semi-arid tropics, as the high intensity rainfall greatly exceeds the infiltration capacity of the soil and total season rainfall is often several times more than the capacity of the root zone to store water (Figure 3).

Table 2. Initial and equilibrium infiltration rates of a deep Vertisol at ICRISAT Center, near Hyderabad, India

Time from start (hr)	Infiltration rate (mm/hr)
0 - 0.5	76
0.5 - 1.0	34
1.0 - 2.0	4
After 144	0.21 ± 0.1

Vertisols in India are located either on relatively flat or sloping lands. Soil and water erosion is a serious problem in these soils under their present management, i.e., rainy-season cultivated fallow (Figure 4), and on some of the sloping land can, in course of time, assume serious proportions (Figure 5). Nutrient losses also occur.

Hydrologic studies conducted over a period of 6 years on a 150-cm deep Vertisol at ICRISAT Center have indicated that of the total rainfall, 25% is lost through runoff, another 25% through evaporation and 10% through deep percolation; thus only 40% is potentially available for the post-rainy season crop under traditional rainy-season cultivated bare fallow conditions (Table 3). The soil loss averages around 6 tonnes/ha per annum. Particle analysis of the soil loss samples showed that clay accounts for 68%, silt 20% and sand 11% (P.Pathak

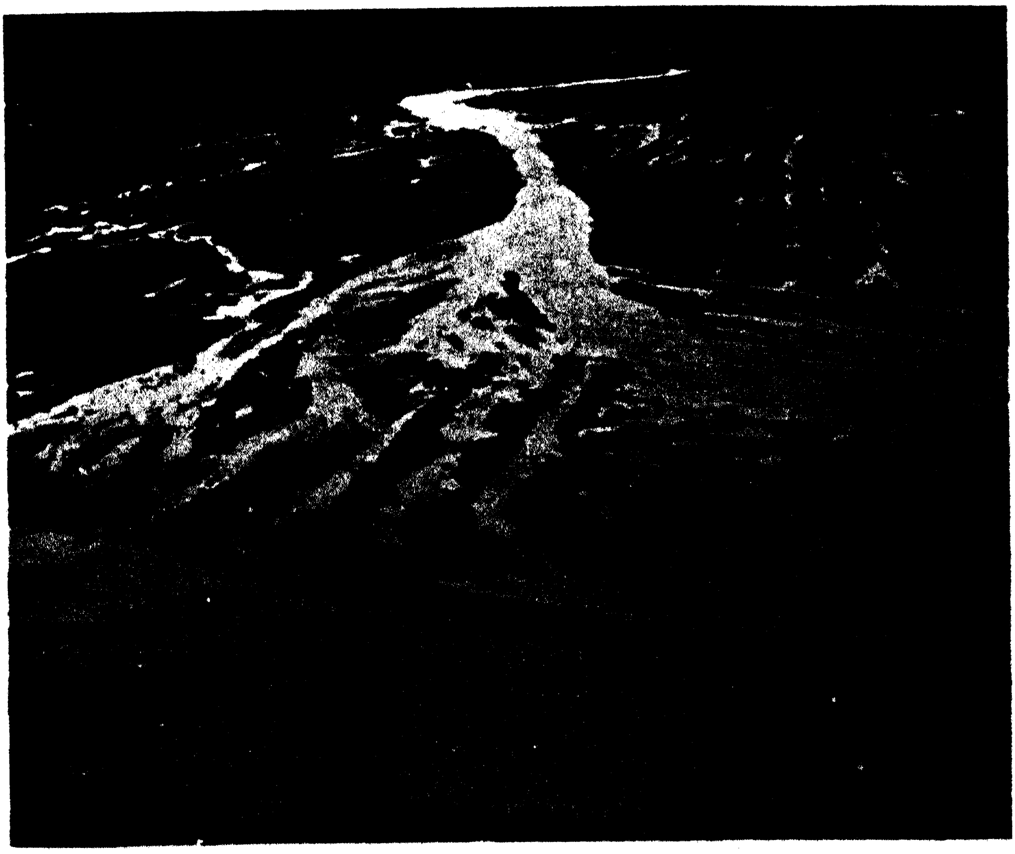

Fig. 3. In Vertisols considerable amounts of rainwater, stagnating on the soil surface, is lost through surface run-off due to low water intake rate of these soils.

Fig. 4. Sheet and rill erosion are the two common forms of soil erosion in cultivated Vertisols of tropical regions.

Fig. 5. Under severe soil erosion, the topsoil has been completely lost, exposing *murram* layer. Crop failures are quite common on such lands.

Table 3. Estimated water-balance components observed in the traditional rainy-season fallow system on deep Vertisols at ICRISAT Center, near Hyderabad, India.

Water balance component	Year						1973-78 (%)
	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	
			(mm)				
Run-off	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
Evapotranspiration (Postrainy-season cropping)	280	375	350	290	325	290	40.6
Rainfall	740	775	965	665	515	1050	100.0
Soil loss (tonnes/ha)	—	—	—	9.2	1.7	9.7	20.6[a]

a. These data pertain to 3 years: 1976-79.

personal communication). Preliminary results show that on an average about 24 kg N/ha is lost per year (K.L. Sahrawat, personal communication). Thus, the soil management technology currently in vogue in the Vertisol areas of India has serious consequences in terms of soil, water and nutrient erosion.

Traditional Subsistence-Oriented Farming

The SAT of india, where the Vertisols are largely found, have fairly high population: land ratios. The farmer of this region depends primarily on uncertain rainfall and nutrient-deficient and eroded soils that pose the most significant physical constraint to development of improved agriculture. The current picture of farming in the Vertisols of India is rather gloomy. The farmer uses little fertiliser. The power he uses is always animal or human. His own productivity and that of his animals is quite low. Major crops grown by him in the post-rainy season following the rainy-season fallow, are sorghum, wheat, chickpea, safflower and chillies. 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)	200-700 kg/ha

Thus the present system of management of Vertisols gives low yields, allows soil and water erosion and results in poor productivity of land, human and animal resources.

Need for Improved Land and Water Management System

Besides the special characteristics of the soils of the region, the history of their settlement has also played an important role in developing the traditional practices now common on millions of hectares of land. Earlier, when population densities were low, systems of shifting cultivation were introduced; only part of the total cultivable land was used for growing food crops and these areas were allowed to return to a bush fallow after 2 or 3 years of cultivation. Most of the time, the natural canopy provided effective protection to the soil from the effects of high-volume, high-intensity rains. As the population pressure increased, however, the demand for cropland increased and shifting cultivation was replaced by more permanent and settled agriculture, which aggravated soil erosion. This has led to environmental problems and poor productivity. It calls for introduction of improved technology for crop production and soil and water conservation. Although yields of 3000 to 5000 kg/ha of cereals obtained under improved technology at ICRISAT indicate the potential of these soils, actual production in most of these regions is only 300 to 900 kg/ha per year.

An Improved System of Vertisol Management for Increasing Food Production

Past approaches to resource development to increase agricultural production in the Vertisol regions achieved only limited success because they did not recognise basic environmental characteristics or utilise natural watershed and drainage systems (Kampen and Burford 1980). Farmers have not found it feasible to invest substantially in measures that will improve and maintain the productivity of their land because of very low production levels of the common cropping systems in these regions; a major reason for this situation is inability to obtain a good seed bed and to plant in time. During the past decade, more productive cropping systems have been developed for many of the diverse rainfed conditions, including those encountered in the Vertisol areas (Spratt and Choudhury 1978).

Since its inception in 1972, ICRISAT has been working on the development of suitable research methodologies to arrive at improved land management and farming systems for substantial gains in total food production, in consonance with resource conservation.

Better technologies are now being developed to ameliorate the effects of drought, improve drainage, reduce soil erosion, and increase cropping intensity, thus increasing food production per unit of land.

In rainfed agriculture the main source of available water is rain. Due to poor infiltration characteristics of Vertisols, run-off, erosion and waterlogging can be serious problems at various times during the rainy season. The solution lies in making use of the natural topography and drainage patterns. The small watershed is a natural framework for resource development through *in situ* conservation measures.

Broadbed-and-Furrow System

Our 8 years' experience at ICRISAT Center and our operational-scale studies in the farmers' fields show that a technology for land and water management on Vertisols using graded broadbeds and furrows within small watershed units (Figure 6) is successful in achieving the above objectives (Kampen 1980).

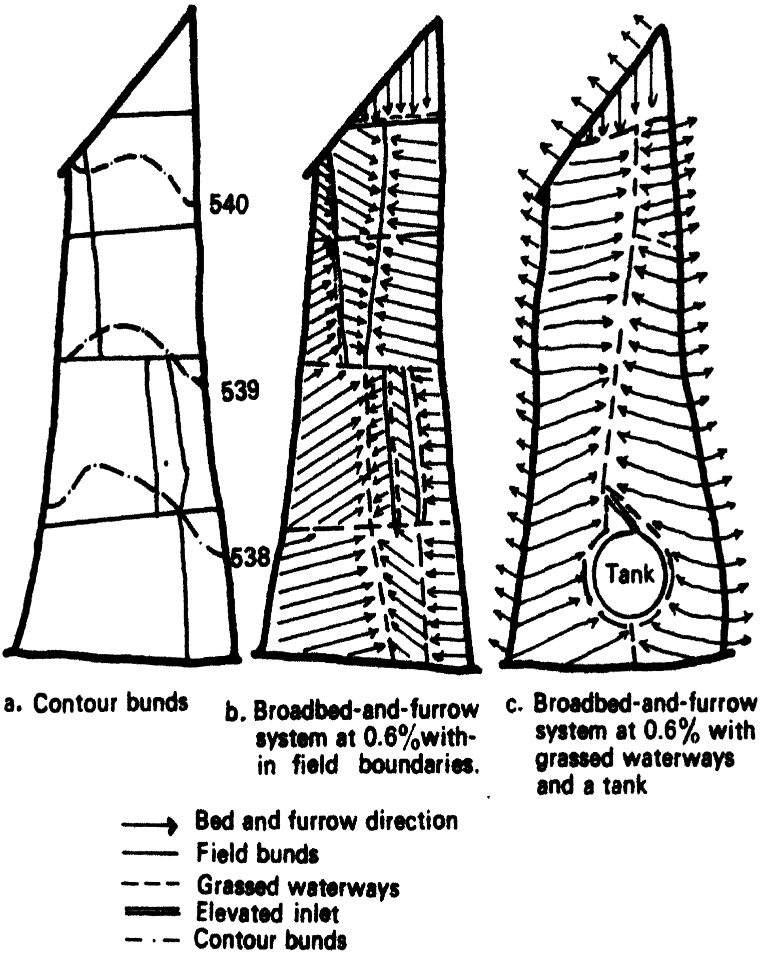

Fig. 6. A Vertisol watershed with three alternative soil and water conservation and management practices illustrated for the same watershed. The broadbed (150cm)-and-furrow system at 0.6% slope within the field boundaries (Layout b), established in 1975, still exists. Layout c shows the same permanent broadbed-and-furrow system with field boundaries removed, a grassed waterway and a tank. Contour bunds (Layout a) are seldom allowed by farmers as they do not want their small fields bisected. Therefore, the bunds are placed on the field boundaries and problems of water stagnation and bund breaching occur.

The 150-cm-wide beds are graded across the contour to a 0.6% slope and are separated by furrows that drain into grassed waterways. Once laid out, the broadbeds are stable for 2 to 4 years and allow a flexible planting pattern in rows spaced at 30, 45, 75 or 150 cm. They reduce runoff under both fallow and cropped conditions and greatly reduce soil erosion in comparison with ungraded fallow soils (Binswanger et al. 1980). The use of graded broadbeds and furrows gives higher gross returns and profits. They can be established successfully within existing field boundaries at some loss in profits.

The broadbed system is semi-permanent. Each bed (approximately 100 cm in width) is slightly raised, acting as an *in situ* 'bund' for good moisture conservation and erosion control. The furrow (about 50 cm in width) is shallow (15 cm deep), but provides good surface drainage to prevent waterlogging of the crops growing on the bed. Excess water is led off through a system of field drains and grassed waterways (Figure 7). Compared with contour bunding, the broadbed-and-furrow system gives more uniform distribution of moisture over the land surface. Ideally, the broadbed-and-furrow system is laid out in small natural watersheds or catchments, but it can be laid out within a farmer's existing field boundaries where adequate drainage is provided.

Fig. [illegible] Broadbed-and-furrow [illegible]
and safe water drainage [illegible]

The essential steps in laying out the broadbed-and-furrow system are: first, a survey to define the local topographic detail and to plan the layout of surface drains. The direction of beds and furrows is marked out in relation to these drains. Secondly, some land-smoothing is done to remove depressions and high spots. At ICRISAT this is achieved with animal drawn equipment, at a lower cost and with much less surface soil disturbance than terracing or other forms of land levelling. The necessary field drains and waterways for the safe disposal of excess water are then prepared and, finally, the beds are formed. A diagrammatic layout of an experimental watershed at ICRISAT is given in Figure 6.

A further feature of the broadbed-and-furrow system is that the runoff water can be 'harvested' in a tank and then recycled later for supplemental irrigation. On deep Vertisols with relatively dependable rainfall, the probability of moisture stress at critical stages of crop growth is relatively low for the rainy-season crops. However, supplemental irrigation may be worthwhile for the establishment of the post-rainy season crop in those years when the rains have ended early and the upper soil layers are too dry for good germination; this harvested water could also be profitably used for irrigating small areas of high-value crops. Where irrigation is used, the furrows of the broadbed-and-furrow system provide suitable irrigation channels along which the water can be conveniently run.

The Wheeled Tool Carrier

Another essential component of the ICRISAT approach has been the adaptation of an animal-drawn wheeled tool carrier to carry out all the operations of cultivation, sowing, fertilising and weeding required within the broadbed-and-furrow system (ICRISAT 1981a). The first wheeled tool carrier to be successfully used at ICRISAT was the Tropicultor, designed by Jean Nolle, a French engineer. The basic frame has a tool bar onto which a variety of implements can be attached with simple clamps. Two ridgers and a bed-former are used in the initial formation, or reshaping, of the beds. Other appropriate implements are used for seeding, fertilising and soil cultivation. The working depth can be adjusted to meet operational requirements. A lifting mechanism is provided to raise the implements into the transport position, or to lower them into the working position.

Experience has shown that all operations with the wheeled tool carrier can normally be done with a pair of medium-size bullocks (300 kg each). The equipment offers considerable time-saving advantages to the farmer. A traditional wooden plough in India with a maximum working width of 15 cm requires 66.7 km of travel by the farmer and his bullock to cover 1 ha. A 75-cm blade harrow requires 13.3 km of travel. In the broadbed-and-furrow system, where the machinery working width is 150 cm, the distance travelled per hectare is only 6.7 km—10% that required by the traditional plough. As a bonus, the wheeled tool carrier can also be used as a cart to provide transportation.

Dry-Season Primary Tillage

Dry-season primary tillage is a necessary operational step in the efficient management of Vertisols. These soils require different tillage operations when dry and when wet. However, primary tillage operations can be carried out more easily just after the harvest of the crops, because the surface soil contains some moisture and crop roots. A rough seed bed can be prepared. The data of rainfall analysis for a large number of locations in India (Virmani et al. 1978) show that the chances of carrying out pre-sowing tillage operations increase progressively from March to June. However, the number of opportunities available in any one year for seed-bed cultivation is highly undependable. In most years, only one or two cultivations may be possible. The analysis also shows that these one or two rains adequate for cultivation are quite spread out during the summer months. Pre-monsoon showers, which are nearly certain climatic events, soften the soil and the final land preparation.

Dry Sowing Ahead of Rainy Season

Final seed-bed preparation and planting of crops is difficult in Vertisols once the rains have set in and the soils are wet. Delays in sowing are undesirable, because of the loss in effective growing period and the possibility of increased pest attack (e.g. sorghum shoot fly). However, the raised broadbed system maintains a relatively open structure that allows for easy primary tillage during the dry season (Fig. 8). All primary tillage can be done on the beds without any rain, although it is naturally easier if there is an occasional shower.

Fig. 8. Preparation of seed bed ahead of the rainy season using wheeled toolcarrier allows for dry planting.

Primary tillage on the beds is confined to only 30% of the total area as compared to the flat cultivation under dry conditions (Bansal and Srivastava 1981). This early preparation of seed bed during the dry season allows crops to be sown dry just prior to the onset of the rains (Fig. 9). Seeds are sown deep (7 to 10 cm) so that germination is not induced by light pre-rainy-season showers. Fertiliser application is also done in the dry seed bed either as a separate operation prior to seeding or as a combined operation with seeding. At ICRISAT, rainy-season crops have been satisfactorily established in this way for the last 8 years, though in 1979, when the onset of rains was delayed, re-seeding was necessary because of rat damage to the initial sowing. Optimum sowing time is concluded to be just before the period showing a 70% probability of rain. The probability data for different Vertisol areas are available and could be used to advantage (Virmani et al. 1978).

This dry-sowing technique offers a considerable advantage in terms of ensuring an early start to the cropping period, but it does rely on a reasonable dependability of early rainfall in the cropping season (Fig. 10).

Fig. 9. Dry sowing of crops on Vertisols ahead of the rainy season [illegible]

Fig. 10. Dry sown crops in Vertisols get an early start as soon as adequate rains are received

Improved Cropping Systems

The broadbeds are adaptable to a wide range of sowing arrangements to accommodate different crops; at ICRISAT the number of rows per bed usually varies from one to four, giving effective row arrangements from 150 to 30 cm. With the individual seeder units on the tool carrier, it is just as easy to sow an intercrop as a sole crop. Some typical sowing patterns are illustrated in Figure 11.

In the experimental watersheds at ICRISAT the two major cropping systems that have been developed to utilise both the rainy and post-rainy seasons are:

1. A 'sequential' system of rainy-season maize (two rows per broadbed) followed by post-rainy-season chickpea (four rows per broadbed).
2. An intercrop system of maize/pigeonpea or sorghum/pigeonpea (one row of pigeonpea down the middle of the bed and one row of maize on either side).

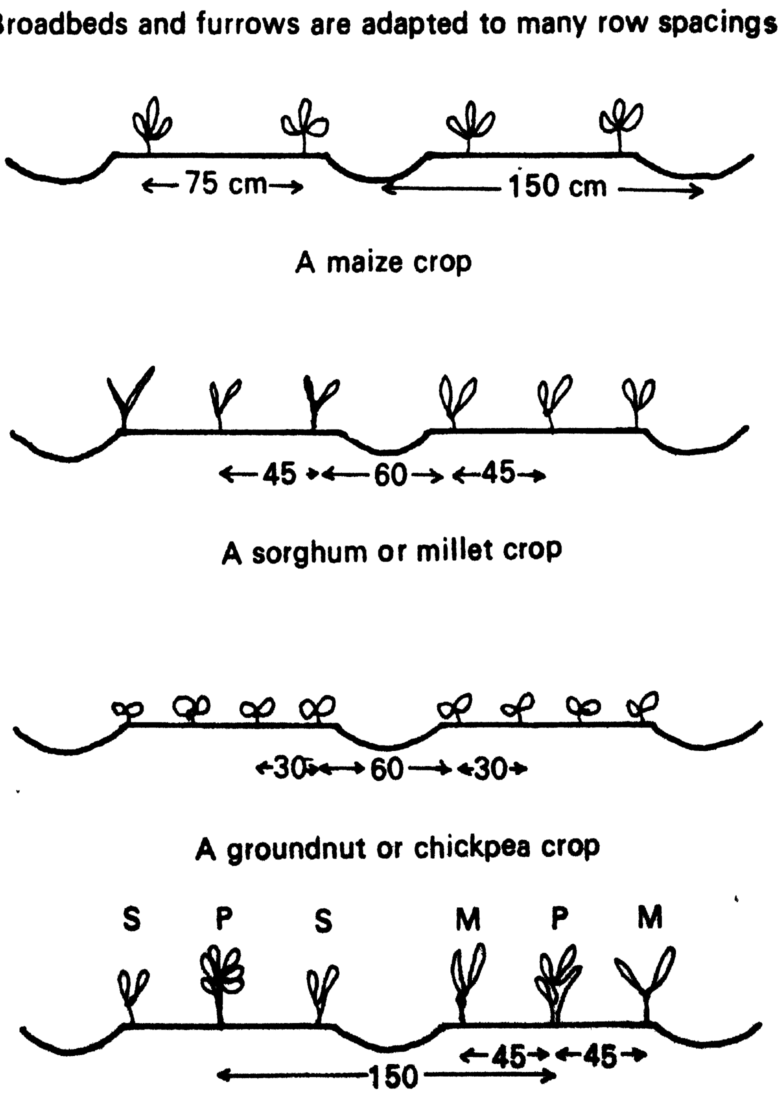

Fig. 11. Alternative cropping systems and row arrangements on broadbeds (150 cm). All dimensions in cm.

Maize has been the preferred cereal for sequential systems because its cultivation has fewer problems than the cultivation of sorghum. The yields of these two systems over 4 years at ICRISAT, from operational watersheds of several hectares are given in Table 4. Improved seeds and fertilisers were used as part of the technology and yields were substantial; averaged over the 4 years they were 3197 kg/ha of maize and 976 kg/ha of chickpea in the sequential system and 2791 kg/ha of maize and 1060 kg/ha of pigeonpea in the intercrop system. In the sorghum/pigeonpea system on a medium-deep Vertisol the yields were 3055 kg/ha of sorghum and 365 kg/ha of pigeonpea. Both these systems very substantially out-yielded the traditional rainy-season fallow system in which only a post-rainy-season crop of chickpea or sorghum was grown.

Table 4. Grain yields from a maize/pigeonpea intercrop system and a maize-chickpea sequential system compared with traditional rainy-season fallow from deep and medium-deep Vertisol operation-scale watersheds at ICRISAT Center, near Hyderabad, India.

	Grain yield (kg/ha)				
Cropping System	1976-77	1977-78	1978-79	1980-81	Mean
Deep Vertisols[a]					
Maize/pigeonpea intercrop system					
Maize	3291	2813	2140	2918	2791
Pigeonpea	783	1318	1171	968	1060
Maize-chickpea sequential system					
Maize	3116	3338	2150	4185	3197
Chickpea	650	1128	1340	786	976
Traditional fallow and single post-rainy-season crop					
Chickpea	543	865	532	596	634
Sorghum	436	377	555	563	483
Medium-deep Vertisols[a]					
Sorghum/pigeonpea intercrop system					
Sorghum			3100	3010	3055
Pigeonpea			270	460	365

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

In comparing these improved systems, the good performance of the intercrop is worth noting. In gross returns there may not be much difference between the systems, but in practical terms the intercrop may be particularly attractive, as both crops are established in one operation at the beginning of the rainy season. However, if the sequential crop is the preference and recycling of harvested water is under consideration, a number of alternatives may be possible. But the post-rainy-season crop has to be established at the end of the rains when the upper soil layers may have dried out; minimum irrigation may thus be necessary to moisten the upper soil surface layer to ensure proper germination and enable the young seedlings to establish contact with the lower moist layers. Another problem which the farmer faces is the peak demand for labour, as the harvesting operations of the rainy-season crop and sowing of the post-rainy-season crop have to be handled at the same time. This is one of the reasons why the intercrop system has given more stable net returns than the sequential system in these operational watersheds (Ryan et al. 1979) and is more popular.

Maize or sorghum intercropped with pigeopea has proved to be an effective system and the farmers can adopt any of the systems depending on their choice. If crop "failure" is based on a gross return of less than Rs 1000/-, then data from 98 experiments throughout India indicate that sole pigeonpea fails 1 year in 5, sole sorghum 1 year in 8, but a sorghum/pigeonpea intercrop fails only 1 year in 36 (Rao and Willey 1980).

Weed Management

The introduction of rainy-season crops in the Vertisols increases the incidence of weeds. The hot and humid environment encourages weed growth and crop yields, both in the sequential and intercropping systems, are seriously affected (Table 5) if proper weed control measures are not adopted.

Table 5. Effect of different weed management systems on crop yields in a deep Vertisol at ICRISAT Center (1980-81).

Weed management system	Sequential Cropping system		Intercropping system	
	Maize	Chickpea	Sorghum	Pigeonpea
	kg/ha			
No weeding	2869	245	1699	654
2 hand weedings	4142	361	2995	749
Weed free	5307	512	3841	1143

Source: ICRISAT (1981b)

Fertiliser Use: The Key to Vertisol Management

Finck and Venkateswarlu (this symposium) have discussed the fertility problems of Vertisols, which are generally low ih organic matter and deficient in N and P and are often low in available zinc. A detailed survey of the fertility status of Vertisols at ICRISAT has shown that all fields, despite annual application of fertilisers for the last 8 years, are still highly responsive to N, P and Zn. In Indian experience, significant and profitable responses to the application of fertilisers supplying N, P and Zn in cereals have been observed, but the degree of response varies with the amount of rainfall and nature of the crop and cropping system. In seasons with above-normal rainfall, sorghum showed significant and economic responses with up to 80 kg N/ha, but in drought years probably about 40 kg N/ha seemed to be an adequate dose. Responses to P have been quite marked in soils with low available P, particularly in conjunction with nitrogenous fertilisers. Pigeonpea showed responses to applied P on soils extremely deficient