Approaches to the Management of Vertisols in the Semi-Arid Tropics: The ICRISAT Experience

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Abstract

Vertisols are potentially productive soils within the dry tropics. When deep, these soils have a high water storage capacity, which allows 6–7 months of cropping in India if the rainfall exceeds 750 mm. However, because of their high clay content and related physical properties, they present a challenge in their management for increased crop production. The small farmers of limited means in the Indian semi-arid tropics generally prefer to raise only one crop in a year (during the postrainy season) on these soils even in areas with high and assured rainfall.

ICRISAT has now assembled a technology for improved management of Vertisols. It involves growing two crops, one in the rainy season and another in the postrainy season. Application of the technology has resulted in considerable improvement in erosion control and moisture conservation, higher rainfall-use efficiency, and annual yields of about 3000 kg ha^{-1} of cereal and 1000 kg ha^{-1} of legume grains for the last 9 years at ICRISAT experimental watersheds.

The technology has been evaluated in on-farm tests in a few agroclimates of the Indian semi-arid tropics with moderate but dependable rainfall. Gross profits from the improved technology were 2 to 5 times higher than those from the traditional technology, which involved only postrainy-season cropping. The improved technology required additional expenses ranging from Rs 590 to 1480 ha^{-1} (US $ 1 = Rs 12 approximately), but it gave a marginal rate of return averaging 230%. The tests also showed that the technology can be adapted to local conditions by suitable modification of one or more of the components involved. The transfer of this technology to other Vertisols in agroclimates similar to that of ICRISAT Center is relatively straightforward, but transfer to those in other agroclimates requires further testing. Establishment of a coordinated program for multilocational testing would help rapid exchange of information on experiences with the performance of the technology in various environments.

Résumé

Une approche pour la gestion des Vertisols dans les tropiques semi-arides—l'expérience de l'ICRISAT : *Les Vertisols sont potentiellement un des ordres de sol les plus productifs dans les zones tropicales arides. Lorsqu'ils sont profonds, ces sols ont une grande capacité de rétention d'eau qui permet 6-7 mois de culture en Inde si la pluviométrie dépasse 750 mm. Cependant, à cause de leur forte teneur en argile et des propriétés physiques reliées, ils posent un sérieux problème. Les paysans disposant de faibles moyens dans les tropiques semi-arides de l'Inde préfèrent normalement de ne*

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produire qu'une seule culture sur ces sols après la saison des pluies même dans les régions pluviométrie élevée et sûre.

L'ICRISAT a élaboré une technologie pour une gestion améliorée des vertisols. Cela implique la culture de deux récoltes, une pendant la saison des pluies et l'autre après. La mise à l'épreuve de la technologie a abouti à un bon contrôle de l'érosion, à une meilleure préservation de l'humidité, et a une efficacité accrue de l'utilisation des précipitations comparée aux systèmes de culture traditionnels. Dans les bassins versants expérimentaux de l'ICRISAT, cette technologie a produit des rendements de 3000 kg ha^{-1} de céréales et 1000 kg ha^{-1} de légumineuses par an pendant les 9 dernières années.

Cette technologie a été évaluée en milieu réel dans certaines régions tropicales semi-arides de l'Inde, où les précipitations sont modérées mais sûres Les bénéfices brûts de la technologie améliorée furent deux à cinq fois plus élevés que ceux de la technologie traditionnelle qui consiste à ne cultiver qu'après la saison des pluies. La technologie améliorée nécessitait des frais supplémentaires qui s'échelonnaient entre Rs 590 et 1480 ha^{-1} (US $ 1 = Rs 12 environ), mais donnait un taux marginal moyen de rendement de 230%. Ces tests ont également montré que la technologie peut être adaptée aux conditions locales en adaptant n'importe laquelle des composantes impliquées. Le transfert de cette technologie à d'autres Vertisols dans des conditions agroclimatiques semblables à celles du Centre ICRISAT est relativement facile, mais la transposition à des agroclimats différents nécessite des essais approfondis. L'établissement d'un programme coordonné pour des essais multilocaux permettrait un échange rapide de l'information sur les résultats de la technologie dans divers milieux agroclimatiques.

Introduction

The major areas of Vertisols and associated soils are located in Australia (70.5 million ha), India (70 million ha), Sudan (40 million ha), Chad (16.5 million ha), and Ethiopia (10 million ha). These five countries contain over 80% of the total area (250 million ha) of Vertisols in the world (Dudal 1965) In India, substantial Vertisol areas occur in Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, and Tamil Nadu (Murthy 1981) Most of these receive 500 to 1300 mm of annual rainfall, concentrated in a short period of 3 to 3.5 rainy months interspersed with droughts. Crop yields in this area are low and vary from year to year.

The aim of our Vertisol management research over the past 10 years has been to evaluate the traditional practices in terms of productivity and soil and water losses, and then to develop and test approaches for improving productivity through greater rainwater utilization and minimizing land degradation. This paper discusses some major constraints that limit productivity of Vertisols in the Indian semi-arid tropics and presents approaches and our experiences in Vertisol management. We believe that several of these methods and their underlying principles will find relevance for improved management of Vertisols located in other parts of the tropical world.

Attributes of Vertisols

Vertisols in India are heavy soils Their texture may be clay, clay loam, or silty clay loam, with the clay content generally ranging from 40% to 60% or more. They have high bulk density when dry (clod density 1.5-1.8 g cm^{-3}); high cation exchange capacity (47-65 cmol kg $soil^{-1}$); and pH values usually above 7.5. Tropical Vertisols are low in organic matter and available plant nutrients, particularly nitrogen, phosphorus, and zinc. The dominant clay mineral is smectite.

Because of their high clay content and related physical properties, these soils have a high moisture storage capacity. Average field capacity of the 185-cm Vertisol profile at ICRISAT Center is about 810 mm, and the lower limit of plant available water is 590 mm (Russell 1980). Thus, this typical deep Vertisol profile is able to hold about 220 mm of available water. (The lower limit is the observed minimum water content in the profile, as measured in the field under a well-managed, deep-rooted, long-season crop; the field capacity (upper limit) represents the of water retained by an uncropped Vertisol ..le after drainage stops.) Based on the estimates week-to-week changes in available moisture in relation to rainfall and potential evaporative demands, Krantz et al (1978) determined that the growing season on a deep Vertisol ranged from 21 to 33 weeks (147–231 days) in different years.

Vertisols are very hard when dry and very plastic, sticky, and not trafficable when wet. Their optimum soil moisture range for tillage is very narrow. Because of this, draft-power needs for land preparation are extremely high during the dry season. Farmers await the onset of the rainy season: but the early rains in many parts of India have a tendency to persist, and thus farmers cannot prepare their land or plant their crops in time because of poor trafficability.

Vertisols have a low terminal infiltration rate (about 0.2 mm hr^{-1}). During the rainy season, water may pond if drainage is inadequate and then crops suffer from waterlogging. Soil erosion is another serious problem in Vertisols, particularly in situations where soil cover is sparse and where concentrated flow of water occurs through unprotected channels.

Traditional Management of Vertisols in India

The management practices being used on deep Vertisols in India have been described and discussed by several authors (Michaels 1982, Ryan et al. 1982, Kanwar et al. 1982). In traditional management, deep Vertisols are usually fallowed during the rainy season and cropped only in the postrainy season on stored soil moisture. Frequent cultivation by a blade harrow (Fig. 1) is done during the fallow period, primarily to control weeds. Improved cultivars and chemical fertilizers are generally not used. Annual yields from farmer's fields on Vertisols in selected villages of peninsular India have been reported (Kanwar et al. 1982) to be quite low. Yields of some typical crops are:

Sorghum	500–900 kg ha^{-1}
Wheat	300–700 kg ha^{-1}
Chickpea	200–500 kg ha^{-1}
Safflower	300–500 kg ha^{-1}
Chillies, dry	200–700 kg ha^{-1}

The consequences of rainy-season fallowing in areas with dependable and high rainfall are serious

Figure 1. In traditional farming, repeated cultivation with a blade harrow (*bakhar*) keeps the fallow land free of weeds in the rainy season.

Table 1. Runoff and soil loss from Vertisol watershed under improved and traditional management, ICRISA'

Year	Seasonal rainfall (mm)	Management system: Improved[1] Runoff (mm)	Improved[1] Soil loss t ha^{-1}	Traditional[2] Runoff (mm)	Traditional[2] Soil loss t ha^{-1}
1976-77	688	73	0.80	238	9.20
1977-78	586	1	0.04	53	1.68
1978-79	1125	273	3.40	410	9.70
1979-80	690	73	0.70	202	9.47
1980-81	730	116	0.90	166	4.58
1981-82	1126	332	5.00	435	11.01
1982-83	615	10	0.20	20	0.70
1983-84	956	154	0.80	289	4.70
Mean	814	130	1.48	227	6.38

1. Improved system: Double-cropping with improved (broadbed-and-furrow) land management system.
2. Traditional system: Traditional flat system, with a single crop in the postrainy season following rainy-season fallow.

in terms of both low yields and high soil and water losses (Table 1). Water-balance studies of traditional Vertisol management systems at ICRISAT Center indicated that of the total rainfall, 24% was lost as runoff and 46% was lost as evaporation and deep percolation, thus leaving only 30% of rainfall for use in crop production (Table 2).

In the following section, we discuss the components for improved resource utilization and productivity of Vertisols.

Components of the Improved Technology

Land and Water Management

Improved land and water management practices for alleviating the physical constraints of Vertisols should promote intake of water, improve aeration and workability, reduce erosion and runoff, and facilitate safe disposal of excess water. To imple-

Table 2. Comparison of estimated water balance in Vertisol watersheds under improved and traditional management systems at ICRISAT Center over eight years (1976-83).

Water-balance component	Management system: Improved[1] Amount (mm)	Improved[1] % of rainfall	Traditional[2] Amount (mm)	Traditional[2] % of rainfall
Water used by the crops (evapotranspiration)	607	67[3]	271	30[3]
Water lost as surface runoff	130	13	227	24
Water lost as bare soil evaporation and deep percolation	180	20	416	46

1. Improved system: Double-cropping with improved (broadbed-and-furrow) land management system.
2. Traditional system: Traditional flat management system, with a single crop in the postrainy season following rainy-season fallow.
3. Rainfall-use efficiency.

improvements in drainage and runoff utili-, the topographical features of the land and natural drainage pattern need to be taken into account. In our studies at ICRISAT Center, micro-watersheds (3-15 ha) were taken as units for land and water management, and for agronomic practices. Because surface water in a watershed drains to a single outlet, we believe that the watershed is better suited than other land units for planning and installing efficient water conservation and reuse systems. Land smoothing and construction of surface drains are the first steps for improving surface drainage. In order to achieve greater efficiency, smoothing should be done in the direction of cultivation. Often, it is possible to improve the natural drains by clearly delineating, shaping, and straightening them. Animal-drawn implements and human labor were found to be adequate for executing land smoothing (Fig. 2) and surface drain construction at a reasonable cost in India (Kampen 1982).

Land Configuration

At ICRISAT Center, a broadbed-and-furrow (BBF) system—involving graded wide beds separated by furrows, which drain into grassed waterways—has been found to improve surface drainage and workability of the Vertisols. The flat bed and the furrow portions are 100 and 50 cm wide, respectively. A schematic sketch of the layout for a BBF system in a self-contained watershed is shown in Figure 3. The runoff water may be either drained out of the watershed or collected and stored in tanks within the watershed for later use as supplemental irrigation. The decision about runoff-storage tanks and their design should be based on runoff characteristics, seepage and evaporation losses, and response of crops to supplemental irrigation (Harikrishna 1982).

On the Vertisols at ICRISAT Center, the draft power requirements for cultivation operations were lower by about 30% in the BBF system than in the flat. Lower penetration resistance on beds (Fig. 4) facilitated land preparation during the dry season, as well as placement of fertilizer and seeds in dry soil at the desired depth (8-10 cm). Furthermore, air-filled porosity in the upper 15 cm layer was found to be significantly higher for BBF than for the flat system during wet spells (Fig. 5). Use of BBF increased profits by 30% compared with flat cultivation of a

Figure 2. Land smoothing by a bullock-drawn scraper.

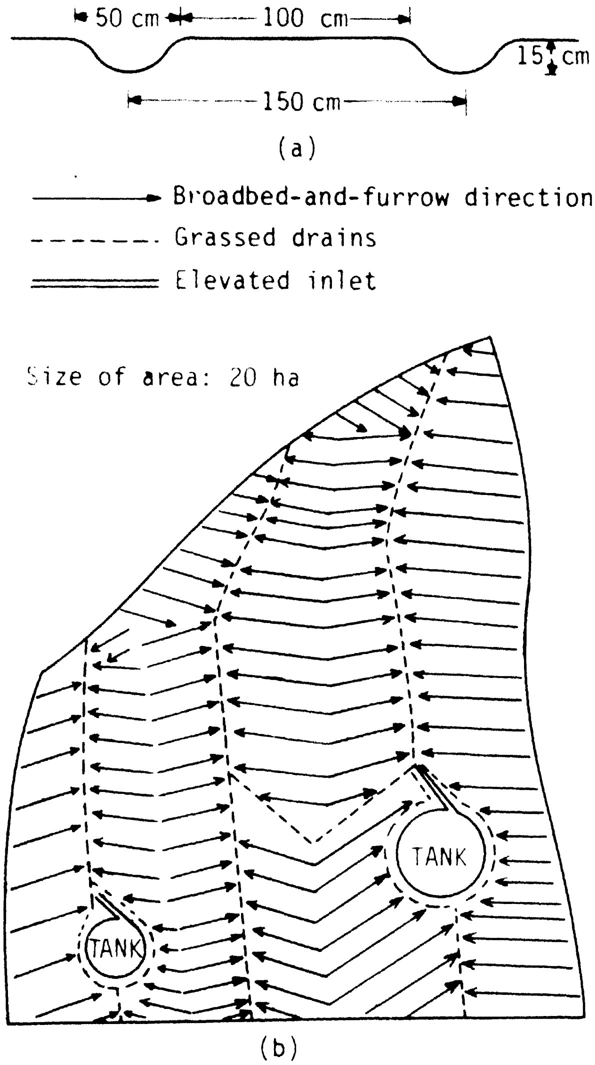


Figure 3. (a) A section of the broadbed-and-furrow configuration; (b) schematic sketch of watershed-based land and water management system, with broadbed-and-furrow layout and runoff storage tanks (After Krantz et al. 1981).

maize/pigeonpea intercrop, and by 20% for a maize-chickpea sequential system (Ryan and Sarin 1981).

Dry-Season Tillage

At ICRISAT Center, primary tillage operations to loosen the soil and prepare a rough soil surface are carried out just after harvest of postrainy-season crops in February or March. This leads to a cloddy soil surface. During the period from March to May, clods gradually disintegrate due to pr rains and fluctuations in diurnal temperatı blade harrowing is done soon after such rains, clods easily shatter and a satisfactory seedbed is attained.

Dry Sowing Ahead of Rainy Season

At ICRISAT Center, crops are planted in the dry soil just ahead of the monsoon rains to ensure early establishment and avoid the difficulty of planting in the wet, sticky soil. But success of dry sowing is dependent on both fairly dependable rainfall in the beginning of the rainy season, and deeper placement of seeds. Good stands can be established by dry seeding of crops such as mung, sunflower, maize, sorghum, and pigeonpea. Results were not satisfactory, however, for pearl millet, soybean, and groundnut.

Improved Cropping Systems

Improved cropping systems are a key component of the improved technology because they contribute substantially to increased crop yields and higher returns. Systems that provide crop growth from the beginning of the rainy season well into the postrainy season, while soil moisture is available, are most suitable for situations where annual rainfall is moderately favorable (> 750 mm, and dependable).

At ICRISAT, the intercropping of a short- and a long-season crop—such as pigeonpea—or sequential cropping of two short-season crops has been found most suitable. A number of crops can be fitted into these two basic systems: pigeonpea, for example, can be intercropped with maize, sorghum, soybean, cowpea, sesame, and sunflower. In the sequential system, maize, sorghum, or soybean can be followed by wheat, chickpea, safflower, or postrainy-season sorghum.

The production potential of a number of cropp systems options, as examined in small-scale expe ments at ICRISAT Center, has been discussed by Willey et al. (1989). The discussion in this paper is limited to our experiences on operational-scale watersheds.

Fertility Management

Vertisols are generally deficient in nutrients. Fertili-

is needed because the improved cropping sys-
ıs, covering the rainy and postrainy seasons, have greater nutrient demands than the traditional single-season cropping system, particularly when crops in both seasons are non-legumes (e.g., maize-safflower); the potential benefits of improved cropping systems and management are not realized fully without adequate fertilizer input.

The three important components of the improved technology—improved genotype, improved management of both land and crop, and use of fertilizer—were examined individually and in combination on a maize/pigeonpea intercrop. Improvement in genotype or land and crop management resulted in only small improvements in yield. Applying fertilizer alone doubled the cereal yield, even

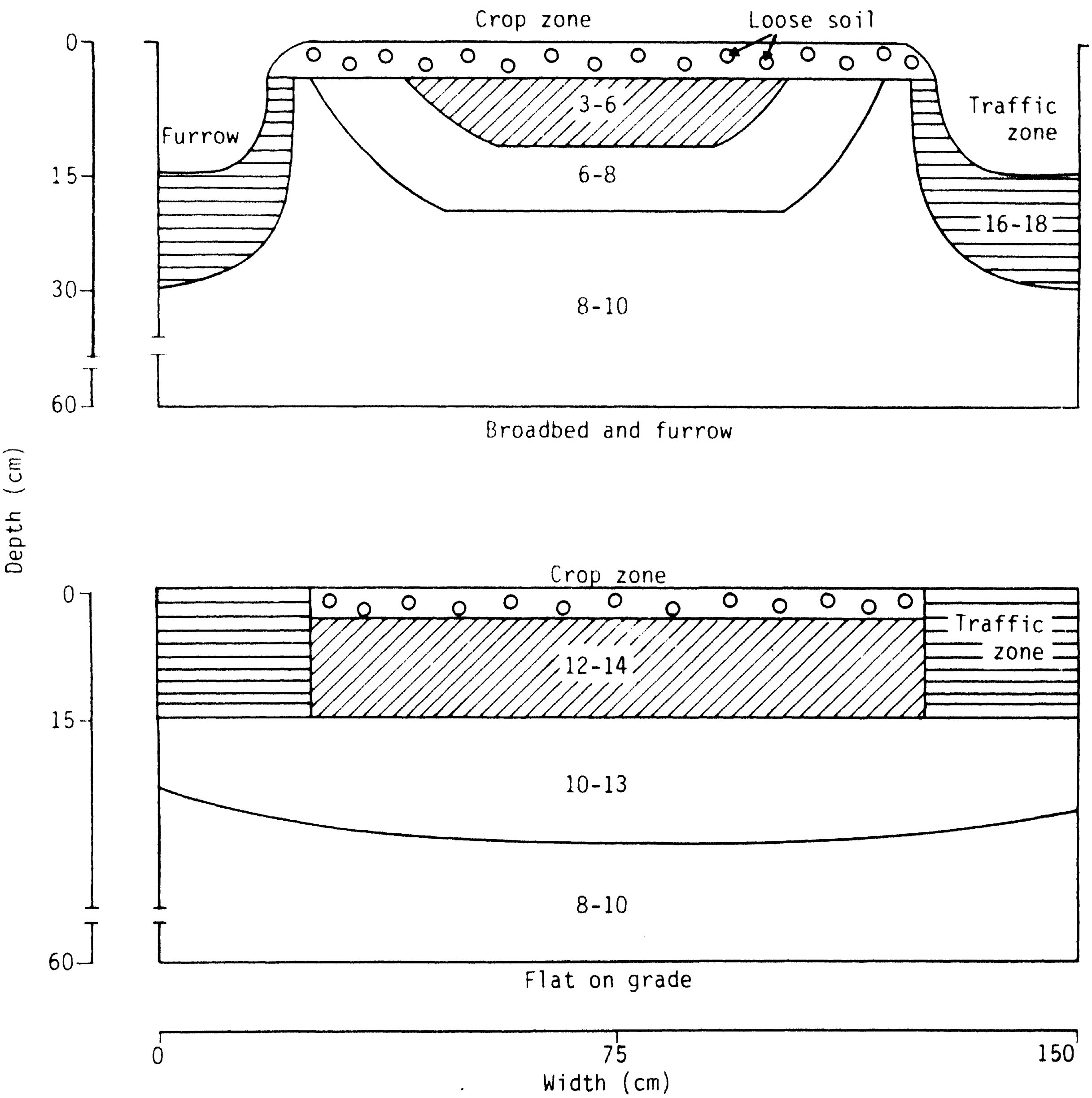


Figure 4. Penetration resistance zones (expressed in kg cm^{-2}) under broadbed-and-furrow and flat systems on Vertisols at ICRISAT Center. Gravimetric moisture contents were 24 ± 1.9% for 0–15 cm soil depth, 31 ± 2.4% for 15–30 cm, and 33 ± 2.9% for 30–60 cm. (Source: Srivastava et al. 1983).

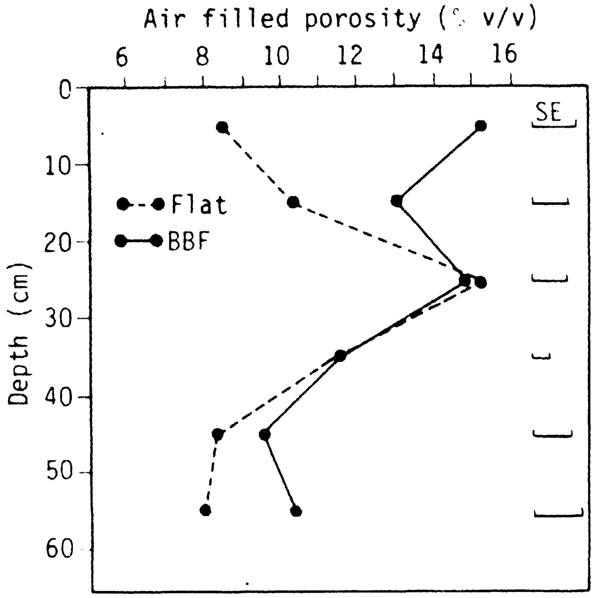


Figure 5. Air-filled porosity of Vertisols at high moisture content, under broadbed-and-furrow and flat land-management systems at ICRISAT Center, late August–early September, 1980 (Source: Srivastava et al. 1983).

though other components were not improved. But the effect of fertilizer was much more striking in combination with improved genotype or improved management, where the yields increased by twofold to threefold. When all the three factors were combined, the yields increased by more than fourfold (ICRISAT 1980). These results highlight the importance of fertilizer application and the synergistic effects than can occur among various inputs when they are used in combination.

Responses to N fertilization were much higher than with any other nutrient, and in a given year, response in the rainy season was greater than in the postrainy-season. Seasonal differences in rainfall and its distribution influenced the nitrogen responses (Burford et al. 1989). Other studies have confirmed that the cereals in intercrops respond to fertilizer N as in sole crops. Responses to P are also widespread especially in the case of cereals, and 15 to 20 kg P ha^{-1} can be recommended as a component of the improved production technology on Vertisols (El-Swaify et al. 1985). K fertilization is not required for rainfed Vertisols in India. Zn deficiency, seldom noticed under traditional systems, soon develops under continued intensive cropping with high-yielding genotypes; it needs to be corrected tained crop yields.

Equipment

For the successful implementation of the watershed-based Vertisol management system, an animal-drawn wheeled tool carrier has been adopted at ICRISAT to carry out such operations as seedbed preparation, sowing, fertilization, and weeding. This equipment helps improve the efficiency of bullocks, the most abundant locally available power source (Bansal and Srivastava 1981). Our recent experience in Central India has shown that the BBF system could also be successfully laid out by using tractor-drawn implements. The central aim of introducing some level of mechanization is to adequately prepare the land in time.

Pest Management

Weed Control

Weeds have not been a serious problem in the traditional low-production systems of Vertisol management because farmers are able to control them by repeated cultivation of the land during the fallow period. But in the double-cropping systems, especially with rainy-season crops planted by the dry-seeding technique, increased weed infestation is observed, which, if not managed properly, may lead to serious losses in crop yields. Since dry seeding precludes mechanical control of weeds that emerge with early showers, weeds also establish well along with crops. The restriction of cultivation to the bed area in the BBF system further increases weed infestation.

Three different weed management systems (hand weeding, herbicide, and smother-crop systems, in which extra-early-maturing, low-canopy legume were introduced into main crops to suppress weeds and a weedy check were compared with a weed-free system on an operational scale at ICRISAT Center (Table 3). Returns were 62% less in the weedy check than in the weed-free system. The herbicide and smother-crop systems with cowpea achieved 93% and 88% of the potential returns, respectively. Binswanger and Shetty (1977) have discussed the use of herbicides vis-à-vis hand labor for weeding: in situations where manual or mechanical weed control is difficult because of wet soil conditions, the use of herbicides appears desirable.

3. **Effect of weed management systems on yields and gross profits in a maize-chickpea sequential system in Vertisols** **ver 2 years (1979/80 and 1980/81) at ICRISAT Center.**

Weed management system	Grain yields (kg ha⁻¹)		Gross returns (Rs ha⁻¹)	Cost of weed control (Rs ha⁻¹)	Returns minus cost of weed control (Rs ha⁻¹)
	Maize	Chickpea			
Hand weeding (2 in rainy season + 1 in postrainy season)	2830	550	4870	430	4440
Herbicide system (Atrazine to maize and 1 weeding each in rainy and postrainy seasons)	3390	610	5630	550	5080
Smother-crop systems: (Smother crop + 1 weeding each in rainy and post-rainy seasons)					
(a) Smother crop of mungbean	2390	560 (220)[1]	5050	410	4640
(b) Smother crop of cowpea	2750	560 (200)[1]	5250	410	4840
Weed free (3 weedings in rainy season + 2 in postrainy season)	3660	690	6180	700	5480
Weedy check	1340	190	2000	-	2000
SE	±198	±42	-	-	

1. Yields of smother crops.

Insect Control

Our cropping entomology unit experimented with Controlled Droplet Applicator (CDA) units, mounted on the animal-drawn wheeled tool carrier. Each unit covers 1.5 m, and three such units were mounted on a machine having high ground clearance to avoid damage to pigeonpea. This required only one laborer and covered 1 ha in about an hour; thus the labor cost was only Rs 1.25 ha^{-1} (Pawar 1985). Another advantage with the CDA is that the quantity of water required for preparing the spray mix is very small (8-10 L water, compared to 500-600 L with the normal high-volume sprayers). For the most important insect pest on pigeonpea, *Heliothis*, spraying is recommended when infestation exceeds an average of 100 eggs and/or 3-5 small larvae (3-5 mm long) per plant.

Evaluation of Alternative Technologies at ICRISAT Center

Two main types of cropping systems were successful on experimental watersheds at ICRISAT Center: (i) the sequential system, with two crops grown, one during the rainy season (e.g., maize) and the other during the postrainy-season (e.g., chickpea); and (ii) the intercropping system, in which two crops are sown simultaneously at the beginning of the rainy season; one of them matures at the end of the rainy season (e.g., maize), and the other during the postrainy season (e.g., pigeonpea). Comparisons have been made between these two improved cropping systems and the traditional system of rainy-season fallow. The crops in the improved systems were grown on BBF using improved cultivars, and a moderate level of fertilizers (60 kg N and 13 kg P ha^{-1}). All field operations were carried out with the animal-drawn wheeled tool carrier. The yields of these systems over an 8-year period are given in Table 4.

Yields from the improved systems were substantial; averaged over 8 years, they were 3230 kg ha^{-1} of maize and 1170 kg ha^{-1} of chickpea in the sequential system, and 2710 kg ha^{-1} of maize and 1120 kg ha^{-1} of pigeonpea in the intercrop. Both these systems substantially outyielded the traditional system where only a single postrainy-season crop of chick-

Table 4. Grain yields of improved (double cropping) and traditional (postrainy-season) cropping systems in scale watersheds at ICRISAT Center over eight years, 1976/77 to 1983/84.

Year	Rainfall during cropping period (mm)	Improved systems				Traditional system	
		Maize/chickpea sequential		Maize/pigeonpea intercrop		Single crop, postrainy season	
		Maize	Chickpea	Maize	Pigeonpea	Chickpea	Sorghum
		(kg ha^{-1})					
1976/77	708	3120	650	3290	780	540	440
1977/78	616	3340	1130	2810	1320	870	380
1978/79	1089	2150	1340	2140	1170	530	560
1979/80	715	3030	590	1950	890	450	500
1980/81	751	4190	790	2920	970	600	560
1981/82	1073	3450	1320	2840	1070	1050	640
1982/83	667	3420	1380	2970	1030	1240	630
1983/84	1045	3020	2120	2780	1740	480	840
Mean	833[1]	3230	1170	2710	1120	720	570
CV (%)	25	18	43	16	27	41	25

1. Mean rainfall over 70 years (1901-1970) is 760 mm, with a CV of 24%.

pea or sorghum was grown without the benefit of broadbed-and-furrows, improved seeds, or fertilizer—and yielded less than 750 kg ha^{-1}, on average. The variability in crop yields, as measured by the coefficient of variation, was much lower in the improved systems than in the traditional system. Between the two improved systems, the better performance of the intercrop is noteworthy. Cereals' yield in the intercrop was only slightly lower than in the sequential system; pulse yields were similar, but they were less variable in intercropping than in the sequential system.

Maize is the preferred cereal in the improved systems because its cultivation poses fewer problems than cultivation of sorghum: it does not tiller; it does not suffer from shoot fly attack; it does not get head-mold infestation, which can be a problem on sorghum sown early so as to permit planting of a second crop. Unlike sorghum, maize does not ratoon and hinder planting of postrainy-season crops; further, maize tops can be removed or 'doubled over' after physiological maturity to minimize competition to pigeonpea in intercropping.

Monetary returns from these improved watershed-based technological options, compared with the traditional system, were evaluated by Ryan and Sarin (1981). Gross profits from the improved maize/pigeonpea intercrop averaged Rs 3650 $ha^{-1}a^{-1}$ over a 5-year period (1976 to 1981), compared to Rs 490 $ha^{-1}a^{-1}$ from the traditional system. Though the improved system required an additional investment of Rs 1140 ha^{-1}, it earned an additional profit of Rs 3160 ha^{-1}, giving a most attractive rate of return (277)%. The sequential system, however, incurred higher costs from additional expenses for planting the second crop, giving a 155% rate of return. The intercropping system is attractive for other reasons as well: (1) it avoids planting the second crop in October when demand for labor is at a peak, and (2) it obviates the risk of the crop not getting established when the rains cease early and the surface soil becomes dry.

On-Farm Verification

Testing at Different Locations

To test the performance of the improved technology, on-farm tests were initiated in 1981 in Taddanpally village, 42 km northwest of ICRISAT Center (Ryan et al. 1982). The soils there are deep Vertisols (> 1 m deep), and a substantial area is fallowed in the rainy season. The initial test was conducted on a small watershed of 15.4 ha, involving 14 farmers, in collaboration with the Andhra Pradesh State Department of Agriculture, Andhra Pradesh Agricultural Uni-

.sity, and the All India Coordinated Research Project for Dryland Agriculture. The experiment was meant to assess the biological and economic performance of the system. Subsidies or inputs to farmers were kept to a minimum. Farmers were encouraged to use the existing institutions for credit and input supplies. However, as a step toward winning the confidence of the farmers, an assurance was given that they would be compensated for any losses from the application of the improved technology.

ICRISAT provided two wheeled tool carriers, with accessories, and power sprayers. Advice for laying out drainage channels to service the entire watershed, for survey of the watershed, and on pest and insect control, was given. Scientific and technical guidance were provided and scientists visited frequently. All inputs—such as fertilizers, seeds, pesticides, fuel, labor, bullocks—were provided by the cooperating farmers, either by themselves or t ugh purchase on credit.

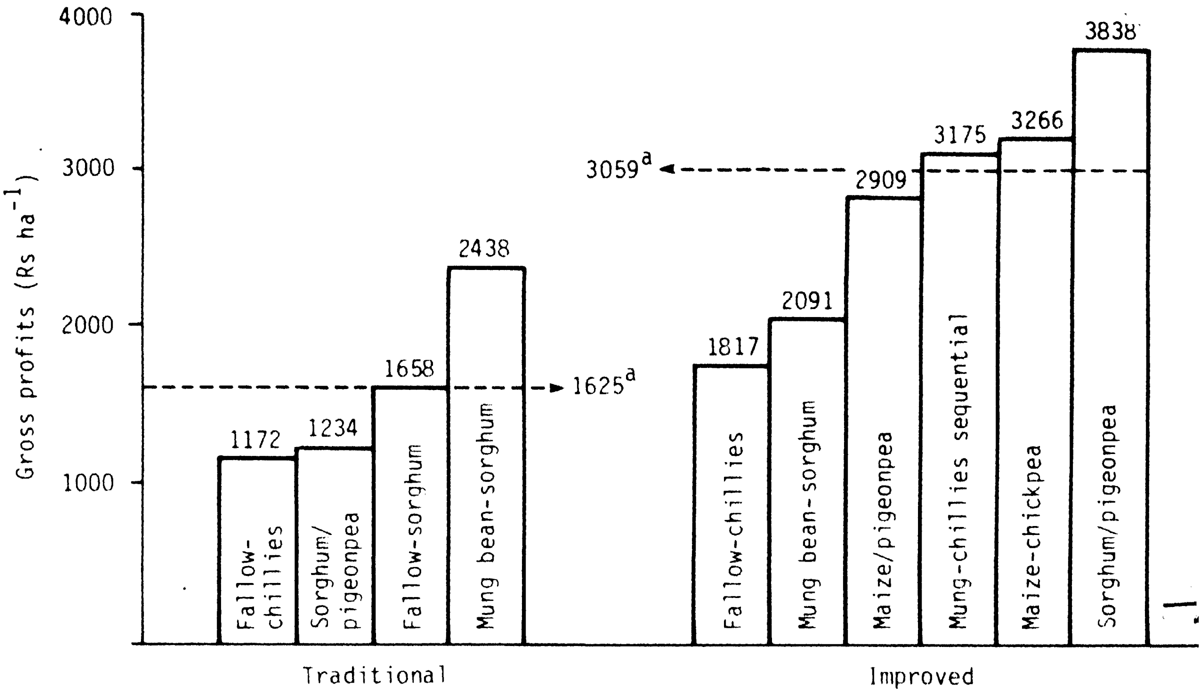
In February 1981, the area was surveyed and the watershed laid out without disturbing property lines. Then the farmers carried out land smoothing and made drainageways, using their own animals. Farmers quickly acquainted themselves with the wheeled tool carrier equipment. Although they had relatively small bullocks, and the soil was hard because harvest of crops had been delayed, the farmers were able to establish the broadbeds reasonably well. The total cost for developing the watershed was modest (Rs 254 ha^{-1}).

ICRISAT staff and other research agencies suggested what crops would be best, but farmers were allowed to make their own choices. As a result, nine cropping systems were tried. The rainy-season crops were planted in the dry soil ahead of the rains. The plant stand was good. In terms of crop production, as can be expected, some problems different from those encountered at ICRISAT Center did arise. These were: *Striga* weed on improved maize and the sorghum hybrids; inability of the farmers to cope with the harvest, threshing, and storage of the unconventional rainy-season crops (partly aggravated by the unusually wet conditions that year); and ineffective control measures against pod borer on the postrainy-season crops. Despite these problems, however, the improved technology performed remarkably well (Fig. 6). The average profit from the treated watershed was Rs 3059 ha^{-1}, 88% more than that obtained from the traditional system dominated by rainy-season fallow and postrainy-season sorghum. The improved system involved an additional operational expenditure of Rs 588 ha^{-1} but, interestingly, the rate of return on this added expenditure at 244% was close to that observed (254%) at ICRISAT Center. Sorghum/pigeonpea was the most profitable cropping system (Rs 3838 ha^{-1}), followed by the maize-chickpea sequential (Rs 3266 ha^{-1}).

Comparison of profits from sorghum/pigeonpea intercropping in the traditional and improved systems demonstrates that an improved cropping system in itself may be necessary, but it is not the only component that contributes to substantially higher profitability. Other practices—such as use of fertilizers, timely operations, pest management, and soil management—are necessary for deriving full benefits from the improved cropping systems.

In 1982/83 the on-farm test was repeated at Taddanpally and extended further to other Vertisol areas with problems different from those at ICRISAT Center (ICRISAT 1984). At two locations, Farhatabad (Karnataka) and Begumgunj (Madhya Pradesh), ICRISAT scientists directly supervised the tests, but at other locations they were conducted by the respective State Departments of Agriculture with advice from ICRISAT as required. Farhatabad has an average annual rainfall of 730 mm, and Begumgunj 1100 mm; early-season rains are much more assured at Begumgunj than at Farhatabad. Since some of the crops popular at these two ICRISAT-supervised sites were different from those tested at ICRISAT Center, cropping systems trials were conducted on the Government Seed Farms near these sites to evaluate locally recommended cropping systems and other options (Willey et al. 1989). The verification tests thus expanded to 22 locations in 1982/83, covering 1235 ha in four states. In these tests in the dependable-rainfall areas, the improved technology continued to perform well. The marginal rate of return on additional investment ranged from 26 to 381%, averaging about 240% (Table 5). Development costs for the watershed sites ranged from Rs 182 to Rs 1035 ha^{-1}; the highest cost was in Madhya Pradesh at Begumgunj where expenses for drain construction were high because of higher rainfall and the use of tractors instead of bullocks to develop the watershed.

The relative profitability of the improved technology (weighted over all the watershed cropping systems) was low at Begumgunj, compared with other locations, because of an unusual dry spell in late June and early July, followed by heavy rains leading to poor stand and inefficient weed control. Yet the



a. Weighted averages over all cropping systems.

Figure 6. Gross profits from major cropping systems in Taddanpally, 1981/82 (Source: ICRISAT 1983).

Table 5. Annual profitability (Rs ha^{-1}) of improved Vertisol management technology, compared to farmer's present practices in on-farm verification trials (1982/83) in four Indian villages.

Village District, State	Gross Profits (Rs ha^{-1})			Operational cost (Rs ha^{-1})			Marginal rate of return (%)
	Improved	Traditional	Difference	Improved	Traditional	Difference	
Taddanpally, Medak, Andhra Pradesh	3957	1722	2235	1035	448	587	381
Sultanpur, Medak, Andhra Pradesh	3576	1722	1854	1062	448	614	302
Farhatabad, Gulbarga, Karnataka	3323	2186	1137	1194	1142	52	
Begumgunj, Raisen, Madhya Pradesh	1172	786	386	2348	866	1482	26

Source: ICRISAT (1984).

1. Difference in operational costs was too small for meaningful comparison.

trial gave encouraging results, with the majority of farmers recognizing the potential of the system. Moreover, some cropping systems involving soybean, such as soybean/pigeonpea, emerged as the most promising (gross profit Rs 3535 ha^{-1}), followed by soybean-lentil (Rs 3215 ha^{-1}). The marginal rate of return calculated on the basis of these cropping systems was 175%. At Farhatabad, where the average rainfall is lower than at ICRISAT Center and less dependable, sole pigeonpea produced gross returns of Rs 4186 ha^{-1}, followed by mungbean-sorghum with Rs 4059 ha^{-1}. These were much better than the existing traditional system, a 2-year rotation of fallow-sorghum and pigeonpea, which gave only Rs 2186 ha^{-1}. At Taddanpally, where rainfall is similar to that at ICRISAT Center, the sorghum/pigeonpea intercrop produced the highest gross profits (Rs 4859 ha^{-1}).

In 1983/84 the on-farm verification trials were continued at Farhatabad and Begumgunj under the direct supervision of ICRISAT. At Farhatabad, rains started one month later than normally expected, resulting in the loss of viability in the dry-seeded crops and poor plant stand. However, waterlogging caused by subsequent continuous rains showed the importance of BBF in draining excess water. The cropping system that gave the highest gross profits was sesame/pigeonpea (Rs 7916 ha^{-1}), followed by sole pigeonpea (Rs 5228 ha^{-1}). The groundnut/pigeonpea intercrop (Rs 3524 ha^{-1}) gave higher returns than black gram/pigeonpea (Rs 2092 ha^{-1}). At Begumgunj, the improved technology performed well despite the occurrence of frost and fusarium wilt in pigeonpea.

Feedback from On-farm Verification

The multilocational on-farm testing has provided valuable information on the potential benefits of the technology for improved management of Vertisols and the regions of its adaptation, as well as its limitations; the testing has also raised questions that need further study. Given below are some of our experiences.

Not all components of the technology made a similar impact on farmers. While most farmers have realized the benefits of improved cropping systems, crop management, and fertilization, the BBF system appears to be needed only where waterlogging is a problem. Construction or improvement of surface drains was found to be important in most situations; neglect of this aspect caused ponding of water and crop damage (Fig. 7). Our experience shows that farmers are willing to construct the field drains required for good drainage within their fields, but they do not participate readily where drains are located outside their fields or involve drainage flows of many farmers. Policy guidelines and institutional arrangements for constructing community drains are required (Ryan and Sarin 1981).

Farmers have generally recognized the value of the wheeled tool carrier for making the broadbed-and-furrows, saving bullock power, and improving seed and fertilizer placement, and they were keen to use it. But in view of its high cost (Rs 8000 to 10000 each), very few are actually prepared to buy it.

Improved cereal genotypes will not be readily accepted by farmers unless they possess adequate tolerance to pests and diseases, and have good grain quality characteristics. Some of the new sorghum varieties (e.g., CSH 6, CSH 5) mature earlier than local sorghums and suffer from grain molds. These also showed greater susceptibility to *Striga*. Introduction of a new crop in an area should be viewed from the standpoint of fodder quality, availability of postharvest handling facilities, marketing, and pest susceptibility. Despite attractive profits from maize-based sequential systems, farmers in Taddanpally did not include it in the 2nd year of testing because, according to them, 1) cattle do not relish fodder of maize as much as that of sorghum, 2) maize suffered from *Striga* and nutritional disorders, and 3) shelling of maize is relatively costly (Sarin and Walker 1982).

Both on-station and on-farm work clearly showed the potential for using fertilizer in rainfed agriculture. Similarly, farmers fully realized the need for timely plant protection on pulse crops. Our experience shows that unless fertilizer and pesticides of the desired type are available within a short distance, dryland farmers will not use them. Moreover, since these inputs are costly, small farmers may not use them unless supported by institutional credit schemes.

Need for Agroclimatic Stratification

Probability analysis of rainfall and characterization of soil moisture variability of an environment help in deciding the applicability of new management approaches and for predicting further adjustments needed. Agroclimatic analysis in extending Vertisols

Figure 7. Water ponding in the lowest part of a farmer's field. Surface drains are necessary for efficient disposal of excess water.

technology is particularly important for the adoption of dry seeding of crops, and for determining the prospects for double cropping. Dry seeding is successful only in such places (e.g., Hyderabad) where rains commence abruptly and where early-season rainfall is dependable (> 70% probability); dry seeding is risky in places (e.g., Sholapur) where early-season rainfall is erratic (Virmani 1980). Double cropping is recommended for situations where the growing period is 23 weeks or longer. Quantification of the available soil moisture at the end of the rainy season is important for the success of the postrainy-season crop. Sequential cropping is recommended in areas where some rainfall is assured at the time of its sowing. Further work on classification of agroclimatic environments in Vertisol regions of the world is needed for predicting the success of alternative practices.

Concluding Comments

Vertisols are found in diverse agroecological environments. However, many of their qualities vary little. These are their high clay content, difficult water management, and gentle slopes. In India, differences in their management are primarily due to their location in a toposequence and prevailing agroclimatological regimes, which determine the choice of cropping systems.

The improved Vertisols technology developed at ICRISAT provides a framework for increasing crop yields on a sustained basis, while improving the land resource. Its components offer several options in each case. For instance, fertilizer levels can be varied according to targeted yields, available soil moisture, and soil nutrient levels; the design and layout of the surface drainage system can be varied according to

..t and distribution of rainfall and topographi- . features of the land; and an array of cropping systems is available.

ICRISAT's experience in verification and transfer of the improved technology has shown that it has the potential to be highly productive in areas agroclimatically similar to ICRISAT Center. It must be recognized, however, that the improved technology requires to be fine-tuned for different environments. The principles and approaches followed at ICRISAT can be utilized for devising appropriate technologies for Vertisols in different agroclimates. Multilocational testing of various components and packages would lead to rapid identification of suitable technologies. Training of field staff and middle-level administrators has been found important for extending the technology, which can best be carried out by the coordinated effort of multidisciplinary teams involved in the development of technology.

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Discussion

Burnett: You referred to the storm runoff impounded in small runoff reservoirs and said it might be used for supplemental irrigation, but you did not show this application. Is the runoff water used to irrigate during stress periods?

Virmani: Experience showed that there was only a small increase in yield with supplemental irrigation in most years, and in some years no runoff water was available. Thus the profitability of reservoir development is doubtful.

Dudal: (1) The new ICRISAT technology has been worked out for deep Vertisols. What is the depth of these 'deep' soils, and what is being measured? (2) How is the response of the technology on shallower Vertisols? (3) What is the proportion of deep Vertisols in the study area that ICRISAT has covered?

Virmani: (1) Our experience has sho technology is applicable to those areas available water-holding capacity of the soil is 150 mm, which requires a soil depth of at least 8 or so.

Swindale: Vertisols have minimum depths of 50 cm, so we are really talking about a deeper phase than minimum.

Taimeh: (1) What was the method used to redistribute the harvested water, and what was the anticipated cost if sprinkler irrigation were used? (2) How did the farmers react to this new adopted technology, and was it hard to convince the farmers to adopt this technology?

Virmani: (1) In terms of the water harvesting, there are two issues: (i) if the water is used on the donor area, i.e., the area from which the water was harvested, the cost is quite high, as one has to use a to bring it back and apply it. (ii) If the water is used below the tank, it is easier and cheaper because gravity is used. In the Indian context, the costs worked out by Dr J. Ryan were about 25 Rs/cm/hectare of water application. We applied it by *gated* pipes in the furrows. We applied only 2–4 cm, but laying out the whole system makes the cost high. With high-value crops, such as tomatoes, it paid off, but not with arable crops, such as pigeonpea. (2) The new technology has to be demonstrated at the door-steps of the farmers, so that they can be convinced over a couple of years.

Blokhuis: You mentioned an available water-holding capacity of 220 mm in the upper 185-cm of the soil profile. If this figure is based on measurements in the laboratory, are you sure that all this water reached the 185-cm depth? In other words: is this a capacity only, or is this amount really available to the plant roots?

Virmani: The figure of 220 mm is the plant-extractable water in the 185-cm profile, determined from field measurements of maximum and minimum water contents of the soil. The maximum water content is obtained from an uncropped profile following cessation of drainage, after infiltration of water in excess of that required to fully recharge it. The minimum water content of the profile is obtained by measuring the water content of the soil profile after maturity of well-managed, deep-rooted, long-season crops grown in the postrainy season. This plant-extractable available water is less than that obtained from 15-bar and 1 3 bar moisture contents (determined in the laboratory), which result in an available water content for the 185-cm profile of 300 to 350 mm.

Swindale: The internal rate of return (IRR) at Begumganj was low because some of the farmer-suggested cropping systems were not suited to the technology. The ICRISAT-suggested cropping systems gave high IRRs.