An Approach to Improved Productivity on Deep Vertisols

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AN APPROACH TO IMPROVED PRODUCTIVITY ON DEEP VERTISOLS[1]

Introduction

Large areas of deep Vertisols in India (e.g., Madhya Pradesh, Maharashtra, and Andhra Pradesh) are fallowed during the rainy season and sown to crops during the postrainy dry season to grow on residual moisture. Many of those who become aware of this landscape and tradition have asked why these soils are not cropped during the rainy season itself. This question is particularly appropriate in those areas where early rains are reasonably dependable and the monsoon rainfall seems sufficient to grow one or sometimes two crops. Although annual potential yields on the basis of water availability may be estimated at 3-5 tonnes/ha, actual production in most of these regions is only 500-1000 kg/ha.

The reasons for the traditional practice of leaving millions of hectares of land fallow can be attributed to the settlement history and the special characteristics of these regions. Earlier, when the population densities were low, systems of shifting agriculture were introduced; only part of the total cultivable land was used for growing food crops, and after 2 or 3 years of cultivation these areas were left to return to a bush fallow. Most of the time the natural canopy provided effective protection to the soil against erosion due to high-intensity rains. When population and land pressure increased, shifting cultivation was replaced by permanent, settled agriculture.

The deep Vertisols are high in montmorillonitic clay; they become very hard when dry and extremely sticky when wet (Krantz et al. 1978). Thus, they can be easily cultivated and tilled only within a limited soil-moisture range. This is why farmers in medium- to high-rainfall regions (> 750 mm) presently fallow these soils during the monsoon. Though in some areas it is a practice to deep-plow part of the land in the dry season, the available draft animals are too few and too weak to furnish power to prepare a satisfactory seedbed on these soils before the rains come. During the monsoon, inadequate surface drainage and associated weed problems, combined with the limited workability of such soils, prevent the farmer from growing crops. In traditional farming the brief dry periods are used for cultivation with a blade harrow (bakhar) to control weeds (Fig. 1).

The implications of the rainy-season fallow system are serious both in terms of the overall productivity and with regard to the frequent occurrence of large quantities of runoff and soil erosion (Fig. 2). The lack of vegetative cover during most of the rainy season exposes the surface soil to the impact of high-intensity storms, causing the start of the erosion process (Hudson 1971). In the absence of a crop in the rainy

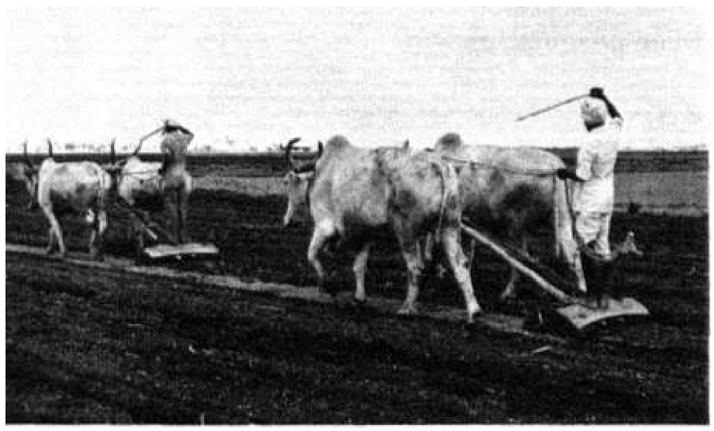

Figure 1. In traditional farming, repeated cultivation with a blade harrow (bakhar) keeps the fallow land free of weeds in the monsoon.

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[1]It must be understood that indeed the approaches towards a search for farming systems of improved productivity and stability are the focus of this paper and not the specific component practices discussed as examples.

[2]Undependability of early-season rainfall and risk of crop production in the rainy season are considered important reasons for the cultivated fallow on deep Vertisols in the relatively low-rainfall regions (Virmani 1980b); this agroclimatic situation is not discussed in this paper.

Figure 2. Runoff and soil erosion are serious problems on the deep Vertisols under a cultivated rainy-season fallow.

season the potential utilization of the total rainfall is limited to the maximum moisture-storage capacity of the soil profile and whatever little rainfall may occur in the dry season. Hydrologic studies of traditional farming systems at ICRISAT Center indicate that in many years only one-third to one-fourth of the seasonal rainfall is actually utilized for evapotranspiration by postrainy-season crops, such as sorghum, chickpea or wheat (Table 1).

Farmers have not found it rewarding to make substantial investments to improve and maintain the productivity of their land because of the very low productivity of the common rainfed crops in these areas. The major reasons for this situation are inability to obtain a seedbed and a good plant stand. Therefore, the cultivated land in many Vertisol areas of the rainfed semi-arid tropics still resembles the "plowed savanna": exceptions to this general rule are areas with wells and small tank systems for supplemental irrigation of crops such as rice and groundnut, and those where contour bunds have been constructed. However, these techniques were introduced primarily on medium to shallow Vertisols, Inceptisols, and Alfisols. For the deep Vertisols, contour bunds have been found unsuitable and no effective technologies for soil and water conservation and overall improved resource use seem to be available (Kampen 1980).

Table 1. Estimated water-balance components observed in studies of the traditional rainy-season fallow system on deep Vertisols at ICRISAT Center.[a]

Water-balance component (mm)	Year						1973-78
	1973/74	74/75	75/76	76/77	77/78	78/79	
Runoff[b]	60	210	250	210	50	410	25.3
Deep percolation	100	15	140	20	0	160	9.2
Evaporation (fallow rainy season)	300	175	225	145	140	190	24.9
Evapotranspiration (cropped postrainy season)	280	375	350	290	325	290	38.9
Rainfall	740	775	965	665	515	1050	100.0

a. Traditional varieties of sorghum were grown as the postrainy-season crop.

b. When crops are grown during the monsoon, runoff is on the average reduced to less than 15% of the annual rainfall.

It is evident that in most areas development of the land-resource base had to await the generation of more remunerative systems of farming. During the past decade more productive cropping systems have been developed for many of the diverse rainfed conditions, including those encountered in Vertisol areas (Spratt and Choudhury 1978; Randhawa and Venkateswarlu 1980).[3] It has, therefore, become imperative that more effective in situ soil and water conservation and surface drainage practices, seedbed preparation techniques, and planting methods be developed for the deep Vertisols to improve their productivity primarily through rainy-season cropping.

One of the primary goals of researchers at ICRISAT since 1972 has been to develop suitable methodologies for improved land management and soil tillage and to assist the regional research centers in generating more efficient technologies for these areas. It is envisaged that substantial gains in total food production can be attained if the present postrainy-season cropping can be replaced by farming systems that permit growing of two crops in most seasons.

Critical Land Management Components to Improve Productivity on Vertisols

Scientists at ICRISAT in cooperation with their colleagues at national research centers have investigated several alternative avenues to improve the productivity of the deep Vertisols with reasonable annual rainfall. It must first of all be stressed that no "package of practices" has yet evolved that can be universally applied. Though the basic principles of the technology may be similar, practices suitable to a particular region will always be quite location-specific because of the climatic, social, and economic differences that exist within the large areas of deep Vertisols.

Nevertheless, several important components of the research approach may be distinguished; these components, we believe, can be regionally tested, adapted, or changed and then reassembled into technically and economically viable farming systems. Another important lesson learned at ICRISAT is that concurrent innovations in several technology components are required (Kampen 1980) to bring about significant improvement in the productivity of the deep Vertisols. This makes the task of technology implementation more difficult and complex.

Land smoothing and field drains

The overall macrorelief of major ridges and valleys on the surface of most Vertisols is frequently overlain by small differences in microrelief; the latter often cause depressions of various sizes with impeded surface drainage. To locate such small depressions and to determine the best way of eliminating their influence, a detailed topographic survey is necessary (Fig. 3). Experience at ICRISAT indicates that on Vertisols with average land slopes of 0. 5 to 3% such surveys need to be sufficiently detailed (grids of 25 x 25 m or less) to facilitate preparation of accurate maps at a scale of 1:1000 to 1:2500, with contour lines at 25 to 30-cm intervals. Such maps indicate the layout of the small natural drainage basins or watersheds, so one can determine the most appropriate directions of cultivation "across the steepest gradient" of given land parcels of a particular overall slope (Fig. 4). To alleviate the influence of the microrelief on surface drainage, it is often necessary to "smooth" the land surface. This is of course

Figure 3. A detailed topographic survey is a prerequisite for planning land development, to decide upon roads and field drains and to execute land smoothing.

3. For further information, see the ICRISAT Annual Reports and other publications of organizations such as the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and ICRISAT.

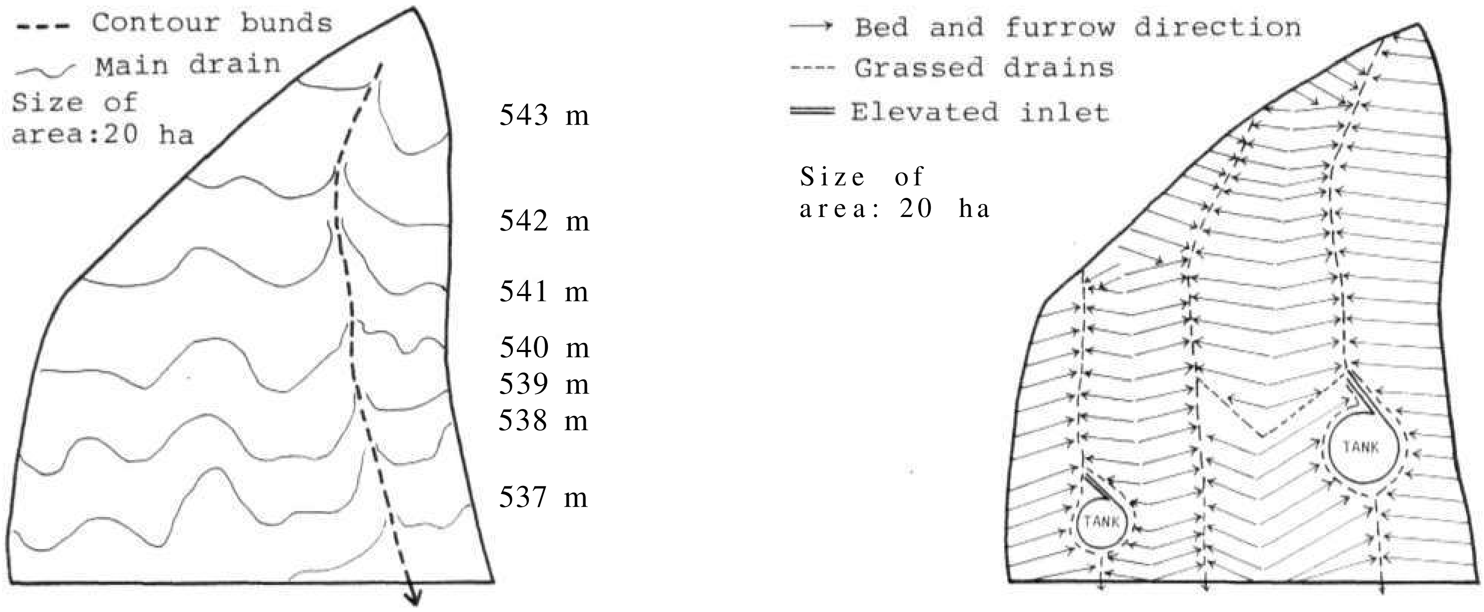

Figure 4. Topographic maps with contour intervals of 25-30 cm and a scale of 1:1000 to 1:2600 are most suitable for the design of land improvement plans.

most efficiently done if executed in the direction of envisaged cultivation. Land smoothing can often be implemented at. a much lower cost — and with much less surface soil disturbance — than terracing or other forms of land levelling.

Excess runoff frequently occurs in many of the deep Vertisol regions under medium to high average rainfall (Virmani et al. 1979). Therefore provisions must be made for prompt and safe removal of such excess runoff when crops are grown during the rainy season. The natural drainage system can be easily identified with the help of topographic maps (Fig. 4), and if field roads are required, they should be located on the major ridges. Often, it is possible to improve the natural drains by clearly delineating and straightening them and by adjusting their longitudinal slopes so that they will be stable after the development of a grass cover. There is often a trade-off between the intensity of the field-drain system and the work involved in providing adequate land smoothing.

The field drains can be constructed by several different means. When large-scale equipment, such as graders and tractor-drawn scrapers, is available, the drain construction can be executed very rapidly, once the preparatory survey and staking work has been done. However, experience at ICRISAT indicates that field drains can also be effectively constructed at reasonable cost utilizing animal-drawn implements and human labor (Fig. 5). Thus, where these resources are available, particularly in the dry seasons when there is little alternative employment, their utilization in land development may be preferred (Ryan et al. 1979). If substantial quantities of soil are to be removed in the drain construction process, it is important that such earth be used to minimize the earlier existing microrelief by deposit of the excavated material in nearby depressions; thus,

Figure 5. Field drains can be efficiently constructed using animal-drawn scrapers and human labor.

drain construction must be completed before land smoothing is begun.

Land smoothing can also be done in several ways. Until a few decades ago, irrigated rice fields in India were largely levelled by hand. Large areas in semi-arid China were terraced and levelled entirely by human labor. On the other hand, tractor-drawn planes can efficiently smooth the microrelief of large areas in a short time. At ICRISAT, effective land smoothing has been attained on several watersheds on deep Vertisols by first plowing and then utilizing small animal-drawn scrapers. Although it is ideal to initiate these activities immediately after the previous crop, dry-season showers are often necessary to make plowing with animals feasible. If these do not occur, tractor-drawn plows may be used to loosen the surface soil. Table 2 illustrates the activities involved and the relative

Table 2. Costs of on-farm watershed development at Shirapur.[a]

Activity/operation	Bullock hire	Labor	Materials[b]	Total cost	
	Costs (Rs)			Rs	Rs/ha
Waterways	732	1560		2292	165
Structures	32	268	342	642	46
Subtotal	764	1828	342	2934	211
Chiseling	276	182		458	33
Plowing[c]	510	322		632	60
Harrowing	246	106		352	25
Smoothing	240	699		939	68
Furrowing	256	192		448	32
Cultivation[d]	176	132		308	22
Bedshaping	176	132		308	22
Subtotal	1880	1765		3645	262
Tropicultor hire charges[e] (at Rs 28/day)				1252	84
Total costs	2644	3593	342	7831	557

a. Shirapur is located 25 km west of Sholapur; eight farmers cultivate a total of 13. 9 ha of land on the watershed. This research project was executed as part of the Mahatma Phule Krishi Vidyapeeth (MPKV) / Indian Council of Agricultural Research (ICAR)/ICRISAT cooperative research program on watershed development

b. The materials consisted of granite stones and cement for drop structures in drainageways.

c. Plowing costs were relatively high because no rains occurred and the soil was extremely hard; after pre-rainy-season rains, plowing costs might be much reduced.

d. The cultivation and bedshaping costs are recurrent operations; thus, the actual total land development costs amounted to about Rs 425/ha.

e. The cost of Tropicultor with a full range of attachments is presently estimated at about Rs 10, 000.

costs incurred in recently initiated on-farm watershed development. It is important to realize that land smoothing, although probably most efficiently done on a watershed basis, can also be effective when executed within boundaries of individual fields.

The broadbed-and-furrow system

In the semi-arid tropics, high intensity rains may occur at any time; if this happens during the dry season or the early rainy season when crop cover is limited, serious runoff and erosion may result. Also, even a smooth land surface without any local depressions may not provide adequate surface drainage conditions, particularly on deep Vertisols during the extended periods of rainfall that frequently occur. Thus, there is a need for an improved in situ soil and water conservation and drainage technology that can protect the soil from erosion throughout the season and provide for water control at the place where the rain falls.

At ICRISAT Center a "broadbed-and-furrow" system has been found to satisfactorily attain these goals on deep Vertisols, especially under conditions of high and assured rainfall by facilitating earlier and more effective crop cover. The system consists of a relatively flat bed or ridge approximately 90-cm wide, and a shallow furrow about 60-cm wide. It is important to attain a uniform shape without sudden and sharp edges because of the need in many crops and cropping systems to plant rows also on the shoulder of the broadbed (Fig. 6).

The broadbed-and-furrow system is most effectively implemented in several operations or passes. After the directions of cultivation have been set out, based on the topographic survey, furrow making is done (Fig. 7). At ICRISAT, a multipurpose tool carrier called the Tropicultor, to which two ridgers are attached, is used for this operation. It is important to have the ridgers operate at shallow depth in order to attain straight lines; sharp curves must be prevented. A bed-former is thereafter used to further shape the broadbeds (Fig. 8). If additional opportunities arise (after showers) before the actual beginning of the rainy season, another cultivation is done to eliminate weeds and improve the shape of the broadbed-and-furrow system. Thus, at the beginning

Figure 6. A smooth broadbed facilitates planting of many row spacings required for alternative crops and cropping systems.

Figure 7. Ridges and furrows are first marked on the ground using the Tropicultor with the ridgers set shallow.

Figure 8. The bedformer and ridgers give final shape to the broadbeds.

of the growing season this seedbed is receptive to rainfall and, importantly, moisture from early precipitation is stored in the surface layers without disappearing in deep cracks.

The grade under which the broadbed-and-furrow system is normally laid out on deep Vertisols at ICRISAT is 0.4 to 0. 8%. At that grade, furrows of 100 m or less in length have performed satisfactorily with regard to discharging excess water with minimal soil erosion and the provision of adequate surface drainage even during long rainy spells. The broadbed system also provides great flexibility to fit crops and cropping systems with widely differing row-spacing requirements (Fig. 6). Precision placement of fertilizer is facilitated even when seed and fertilizer are applied separately because the wheels of the Tropicultor follow the furrows. The system also is easily used for supplemental water application. Soil compaction due to animals and equipment wheels is limited to the furrows. This is important, particularly during interculture when soil is moist.

Figure 9. Primary tillage in the dry season immediately after harvest leaves a cloddy surface receptive to rains.

Figure 10. Final seedbed preparation can be done after prerainy-season showers have occurred.

Land preparation

Because the deep Vertisols are difficult to work when wet, it is critical to develop a farming system where most soil tillage and cultivation operations can be executed during the dry season. Although these soils are very hard when dry, experience at ICRISAT has been that they can often be worked immediately after the harvest of the previous dry-season crop. If initial land preparation is executed at that time, a cloddy soil surface results (Fig. 9); although the soil is not yet suitable as a seedbed, most of weeds and stubble are removed from the beds and furrows. In most regions of the semi-arid tropics, some rains may occur between the harvest of the dry-season crop and the beginning of the subsequent rainy season. If another cultivation is executed soon after such a rain, the clods easily shatter and, in many cases, a clean, friable seedbed can be attained (Fig. 10).

Runoff collection and supplemental irrigation

In several regions, the capacity of the root profile to store moisture and the maximum infiltration rate of the surface soil may be exceeded several times during the rainy season, even when crops are grown on deep Vertisols. If this occurs during high-intensity rains, runoff becomes inevitable. A potential may exist for the collection of such excess water and its later use for supplemental irrigation (Hari Krishna 1980). On deep Vertisols with reasonably dependable precipitation in the rainy season, the probability of moisture stress at critical crop growth stages in the monsoon is small. However, some evidence exists indicating that significant returns may be gained from the application of relatively small quantities of supplemental water on the postrainy-season

Figure 11. A small research watershed on Vertisols at ICRISAT; note the graded cultivation, the waterways, and the small runoff collection reservoirs.

crops of sorghum, wheat, chickpea, and of the high-value vegetable crops. The potential of small runoff collection reservoirs for supplemental irrigation is being further explored (Fig. 11) at ICRISAT.

Soil Tillage and Crop Management to Improve Productivity

All components of an improved farming system are links in one chain; if one component is imperfect, the whole system may fail. Some other important components of the system investigated at ICRISAT are:

Dry seeding

Application of chemical fertilizer and seeding are difficult once the Vertisol has become wet. Also, if the initial rains continue for a substantial period and the soil surface remains sticky, the beginning of the effective growing season is delayed because no cultural operations are feasible. With crops such as sorghum where early establishment is important to escape shoot fly, the entire rainy growing season may be lost if the seedlings cannot establish during the first few weeks.

A technique of applying seed and fertilizer to the dry soil before the first rains occur may be successful in those areas where these early-season

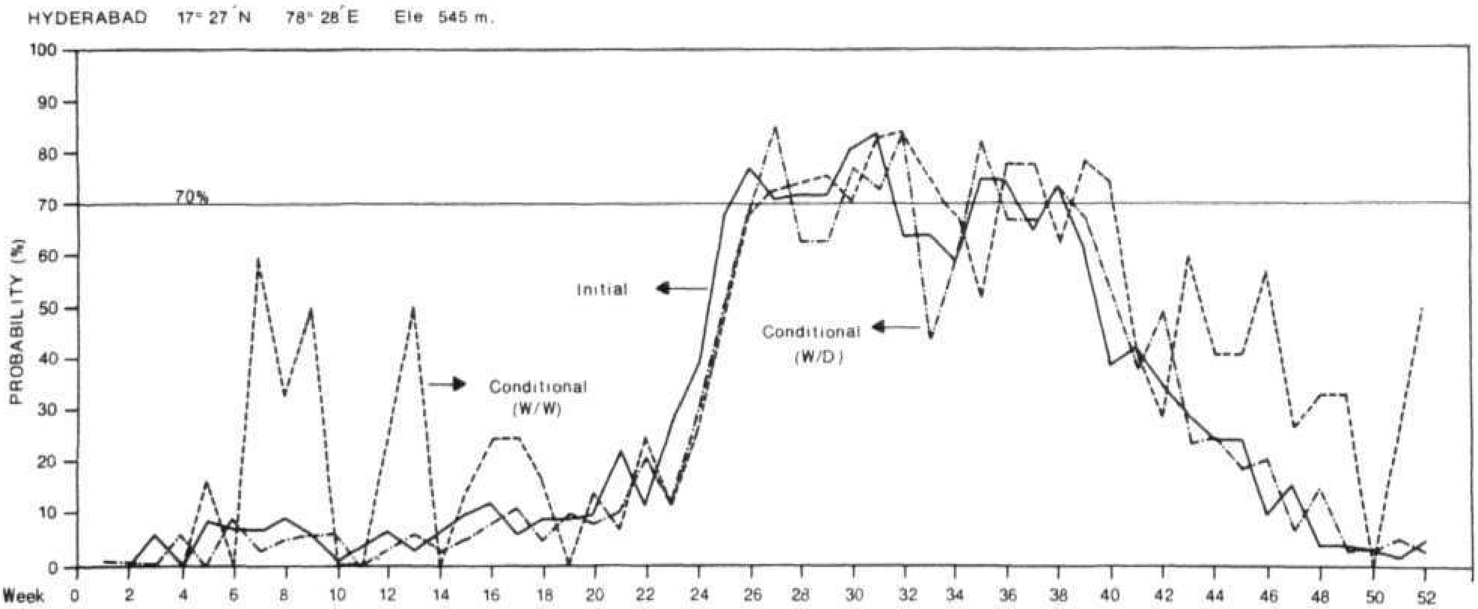

Figure 12. Initial and conditional rainfall probabilities[a] of R/PE[b] > 0.33 at ICRISAT Center.

a. The probability of receiving certain amounts of rainfall during a given week is indicated by the initial probabilities P(W); the probability of rains next week if rain was received this week, by the conditional probability P(W/W)," and the probability of the next week being wet if the current week has been dry, by the conditional probability P(W/D).

b. R = Rainfall; PE = Potential evapotranspiration.

rains are reasonably dependable (Virmani 1980a). Studies of the rainfall probabilities over short periods of 1 week or less at ICRISAT have illustrated the potential feasibility of dry seeding (Fig. 12). During the past 8 years, rainy-season crops have established satisfactorily when fertilizer and seed have been applied immediately before the rainfall probability begins to increase to the level of 70% (about the 24th week at ICRISAT Center). Small showers may wet the surface soil, but this moisture soon evaporates if no further rain follows. In order to guard against germination after small quantities of rainfall, the seed must be placed relatively deep; in the case of sorghum, pigeonpea and maize, for example, at 5 to 7 cm depth. Small-seeded crops such as millet and Setaria cannot be sown deep; for such crops dry seeding is not a viable technique. It is important to guard the seed against rodents, particularly if the rains are delayed.

The rainfall pattern in most deep Vertisol areas indicates that, as the rainy season begins, on a given day (at ICRISAT normally during the latter half of June) one single shower or several successive ones together can amount to 25 mm or more, sufficient to wet the seed.

As soon as these first "germinating" rains occur, the growing season has started. An early start of the rainy-season growing period makes it feasible in most years to grow a second crop on residual moisture in the postrainy season. The only operations left for the early rainy season are one or two interculture operations or hand-weedings to control weeds (Fig. 13). Recent experience at ICRISAT indicates that in some years even these operations may be difficult to execute because of continuous wet conditions (Shetty and Krantz 1980). Therefore, application of limited quantities of preemergence herbicides to attain satisfactory weed control needs to be further explored for such crops as maize and sorghum.

Rainy-season crops

To facilitate the successful growing of a second crop, it is advisable to harvest the rainy-season crops at or soon after they attain physiological maturity (Fig. 14). Early crop establishment facilitated by dry planting frequently causes harvesting time to coincide with the periods during which rainfall probabilities at ICRISAT are high (see Fig. 12). On the Vertisols, particularly, the number of days with suitable weather and soil conditions to harvest are often limited (Virmani 1980b). The risk of damage due to moist weather (molds, lodging, etc.) can therefore be large. Thus, until mold resistance has been incorporated, the present varieties of sorghum or millet may not be suitable as rainy-season crops on these soils under conditions similar to those at ICRISAT Center. At ICRISAT, maize has been used successfully in the monsoon; progress on developing more suitable (mold-resistant, humidity-tolerant) sorghums is presently being made. When intercropped with pigeonpea, the maize stalks are broken above the cobs to facilitate pigeonpea growth and field-drying of the maize cobs (Fig. 14).

Figure 13. The Tropicultor used for interculture on Vertisols at ICRISAT Center in the early rainy season.

Figure 14. Bending maize stalks in intercrops at physiological maturity in September.

Postrainy-season cropping

The most efficient way to grow a postrainy-season crop on the deep Vertisols is by means of intercropping because this eliminates the necessity of a second land preparation at the end of the rainy season. Tillage at that time may also be difficult because of the unpredictability of the late-season rains. Pigeonpea has been used mostly as an intercrop on Vertisols at ICRISAT Center. However, because of food requirements related either to the rainy-season crops or to the postrainy - season crops, or because of the suitability of specific crops in particular regions, it may be necessary to grow sole crops in large areas. In this situation, minimum tillage approaches may be useful.

At ICRISAT Center, the land for the postrainy-season crops is prepared by shallow tillage of the space between the remaining stubble of the preceding crop on the bed and reridging the furrows with the Tropicultor (Fig. 15). This limited tillage is feasible only with nonratooning rainy-season crops such as maize. If sorghum were grown, the ratooning stubble would have to be plowed under, resulting in considerable time (and moisture) loss, unless satisfactory ratoon crops could be grown. Research on this potential possibility of ratoon cropping is presently under way at ICRISAT.

Figure 15. In land preparation for postrainy-season crops the stubble of the rainy-season crop remains. Here chickpea and sunflower are sown as postrainy-season crops in maize stubble.

Both application of the basal fertilizer dose and planting generally must be executed while the soil is fairly moist. Since these operations must be done separately, the time requirement for them is greater than for land preparation in the dry season. One interculture operation and sometimes one hand weeding are usually sufficient for weed control in the postrainy-season crops such as chickpea or sorghum. To further minimize the "turnover'' time, it may be feasible to develop viable relay cropping technology where the second crop is sown in the standing first crop. Progress may also be made in the development of suitable weed control practices using herbicides to reduce "turnover" time and moisture loss.

Primary tillage for the subsequent cropping season

At ICRISAT, the broadbed-and-furrow system on the deep Vertisols has evolved into a "semi-permanent" system. Immediately after the harvest of the dry-season crop (at ICRISAT sometime in February or March), primary tillage is executed on the already existing broadbeds. This is often the most appropriate time for this operation, because immediately after the harvest of the dry-season crop the surface soil may still contain some moisture. If the soil is exposed to the drying influence of wind and sun for any extended period of time, primary tillage becomes difficult. Experience at ICRISAT indicates that the surface soil in Vertisol areas that have been in the broadbed-and-furrow system for several years is much more friable and can therefore be more easily tilled than that in flat-cultivated areas.

The most satisfactory primary tillage method at ICRISAT has been the use of a left hand and right hand moldboard plow attached to the Tropicultor (Fig. 16). These moldboard plows are set in such a way that they turn over most of the stubble and weeds of the preceding rainy-season and dry-season crops in the seed zones of the next crop; the center of the bed is left in a cloddy condition. Any weeds remaining in the furrow may also be removed through a ridging operation. Depending upon the draft power available, these two operations of moldboard plowing and furrow cleaning may be executed either concurrently or separately. Primary tillage immediately after harvesting of the previous crops helps to prevent weeds from setting

Figure 16. Primary tillage on broadbeds using two moldhoard plows and the Tropicultor.

seeds, thus reducing weed survival and multiplecation (Shetty et al. 1977). After primary tillage, the soil surface is receptive to any rain that may occur during the dry season. When this happens, the final land preparation should be initiated immediately. After this, the broadbed-and-furrow system is again ready for planting the next year's crop.

Implications

Better rainwater utilization, facilitated by improved systems of farming, can make a significant difference in the efficiency with which the total available resources are used. For the deep Vertisols, the potential productivity of some agroclimatic environments appears to be three to five times higher than that attained by the traditional systems of farming (Table 3). However, as emphasized earlier, no single farming system is yet universally applicable even within the reasonably homogeneous deep Vertisols with reliable rainfall. Although the basic principles that apply may be similar across different regions, the specific design criteria, the systems of cropping, and certain other factors will have to be developed separately for each area. Thus, much more than "testing" and adaptation will be required to develop technically and economically viable systems for different regions. A "steps in technology " approach at ICRISAT, in which several technology components are integrated into a system of farming and where the impact of these components individually as well as their synergistic effects can be measured, has proved useful to develop a "first approximation. "

After study of their resource environment and the characteristics of the existing farming systems, local researchers and extension personnel can identify the innovations in critical components that will facilitate the development of improved and more stable and productive systems of production in their region. Experience at ICRISAT indicates that one must consider:

1. Land development for: (a) In situ surface water management and control, (b) Reduction of erosion and nutrient loss, (c) Safe disposal of excess water.
2. Seedbed preparation during the dry season.
3. Timely planting, if feasible before the rains.
4. Avoidance of soil compaction in the plant zone.
5. Multirow cultivation and fertilizer and seed application.
6. Suitable crops, cropping systems, and crop and fertility management.
7. Effective weed control.
8. Minimum tillage after the rainy-season crop.
9. Runoff collection and supplemental water use in the dry season.
10. Organization for land development and system management.

Improvements with regard to these components must be tested, both in isolation and in synthesis, before attempts towards further on-farm adaptation and implementation are made (Kampen 1980). It is expected that this research approach

Table 3. Grain yields[a] (kg/ha) and gross monetary returns (Rs/ha) for several crops at Kanzara village in 1979/80.

Watershed No.	Cropping system	Soil mgt	Sorghum	Pigeonpea	Cotton	Groundnut	Black gram	Gross value
Improved technology[c]								
1	Sorghum/pigeonpea	Beds	2000	200				2630
1	Sorghum/pigeonpea	Flat	1470	210				2100
1	Cotton/sorghum/pigeonpea	Beds	760	60	630			3382
1	Cotton/sorghum/pigeonpea	Flat	560	60	490			2633
Existing technology								
1	Cotton/sorghum/pigeonpea	Flat	20	20	180			767
1	Cotton/blackgram	Flat			250		60	1112
Improved technology								
2	Sole groundnut	Beds				670		2177
2	Sorghum/pigeonpea	Beds	1470	200				2073

a. The yields are based on small samples; actual threshing floor yields were somewhat (5 to 10%) lower.

b. The monetary values are based on the following prices at harvest time; sorghum Rs 105/100 kg, cotton Rs 385/100 kg; pigeonpea Rs 265/100 kg; groundnut Rs 325/100 kg, and blackgram Rs 250/100 kg.

c. "Improved" technology implies the use of recommended agricultural techniques in terms of seed, fertilizers, weed and insect control; "Existing" technology represents examples of the productivity attained with practices that are presently most common in the region.

d. Estimates of yields in adjacent fields.

will result in significantly increased food and cash crop production from the deep Vertisols (Fig. 17) and thereby contribute to improving the quality of life of the people in these regions.

Figure 17. Harvesting high yields of rainy-season crops from Vertisols — A challenge for the next decade.

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