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Management of Rainwater and Technology Transfer

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Good management of rainwater begins where the rain falls on the land, i.e. where feasible, improved in situ water conservation and use should be explored first; it involves all farming systems' components, from ploughing of the land to the harvest of the crop. ICRISAT data illustrate that such an approach for example on deep Vertisols with medium rainfall might result in a three to five-fold productivity increase. Land development for better water utilisation is most effectively executed on the basis of watersheds and Frequently requires participation of several farmers. Operation and maintenance of improved resource management systems necessitates adaptation and development of organizational and administrative structures.

Development, transfer and implementation of new technology to manage and use the available precipitation for more productive and stable agriculture is a complex task. Three phases need to be strengthened concurrently: (i) component research to solve identified problems; (ii) operational-scale research to integrate new technologies into viable Farming systems; and (iii) on-farm operations research to tailor new systems to Farmers' requirements and constraints. A pilot project on medium rainfall deep Vertisols is suggested to test this approach. Because of the site-specific nature of agricultural production techniques, successful transfer and implementation of new technology also presupposes continuous updating and training of research and extension personnel in the generation of innovative solutions to specific problems.

Key Words: Rainwater, Deep Vertisols, Land Management, Operational research, Semi-arid tropics, New Technology

Introduction

Increases in population pressure and greater demands for food require fundamental changes in the production systems characteristic of rainfed areas in the Semi-Arid Tropics (SAT). Given the significant expenditures for conventional irrigation development, equity considerations justify investments in productive capacity in those regions that remain dependent upon the variations of seasonal and annual rainfall (Kanwar 1980). Methods for natural resource management that more effectively conserve and utilise the rain and the fertility of the soil, and new crop

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production systems that maintain productivity and assure dependable harvests are urgently required. Before exploring supplemental irrigation to back up rainfed agriculture (Had Krishna 1980), the potentials for improved in situ soil and water conservation and use should be investigated. An illustration of these potentials will be given for deep Vertisols.

The soil, climatic and socio-economic diversity of the Indian SAT demand greatly increased research and the development of effective methods to adapt technology to specific environments and to farmers' constraints. The watershed represents the natural framework for soil and water conservation, surface drainage, and the storage and utilisation of excess water. This has implications for operational-scale research at Research Centres and on farms to facilitate technology development and transfer. Cooperative research projects of ICRISAT, the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) of the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities, will illustrate this approach.

Improved Productivity Through Better Water-use on Deep Vertisols

The Present Setting

Many of those familiar with the landscape- of the large areas of deep Vertisols that are fallowed during the monsoon and where crops are grown only during the dry season on residual moisture, have asked why these soils are not cropped during the rainy season itself (Krantz & Russel 1971). Either one of two-agroclimatic situations is generally encountered: (i) low (<750 mm) and undependable rainfall[1]; or (ii) reasonably high annual rainfall (>750 mm). The question therefore particularly applies to those areas where the precipitation seems sufficient to grow one or sometimes two crops and where the early rains are reasonably dependable. Although potential yields on the basis of water availability may be estimated at 3-5tons/ha, actual production in most of these regions is only 500-1000kg/ha. These deep Vertisols appear therefore, to represent a situation where the rewards from better rainwater utilisation could be very large indeed.

The traditional practice of a cultivated monsoon fallow is presently common on millions of hectares of land (Binswanger et al. 1980). An important reason is; that the Vertisols are high in montmorillinitic clay. Such soils become very hard: when dry and extremely sticky when wet. Thus, the Vertisols can be easily cultivated and tilled only within a limited soil moisture range. This property-represents one of the most important reasons why farmers in medium to high rainfall regions presently fallow these soils. Once the monsoon has started,. inadequate surface drainage and associated weed problems combined with the limited workability of the soil preclude the farmer making use of the opportunity to grow crops. In order to keep the land free of weeds, all brief dry periods are: used to cultivate the soil with a blade harrow (figure 1).

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[1]Undependability of early season rainfall and risk of crop production in the rainy season is considered an important reason for the cultivated fallow on deep Vertisols in the relatively low rainfall regions; this agroclimatic situation is not further discussed here.

Figure 1 Farmers cultivating monsoon fallowed Vertisols with the bakhar, a blade harrow.

The implications of the rainy season fallow system are serious with in terms of the overall productivity of the resource environment and with regard to the frequent occurrence of large quantities of runoff and soil erosion (figure 2). The lack of vegetative cover during the rainy season exposes the surface soil to the impact of falling raindrops during high intensity storms, this causes the start of the

Figure 3 Large quantities of runoff and soil erosion are serious problems on the Vertisols under the cultivated rainy season fallow system.

erosion process (Hudson 1971). In the absence of a crop in the rainy season, the moisture storage capacity of the soil profile becomes the major constraint limiting the potential utilisation of the total available rainfall, Hydrologic studies of traditional systems of farming indicate that in these regions only one-third to one-fourth of the seasonal rainfall is actually utilised for evapotranspiration by post-rainy season crops such as sorghum, chickpea or wheat (table 1).

Table 1 *Estimated water balance components observed in studies of the traditional rainy season fallow system on deep Vertisols at ICRISAT**

Water balance component (mm)	*Year*						*1973-78*
	197i-74	*74-75*	*15-16*	*76-77*	*77-83*	*78-79*	**(%)**
Runoff †	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 post-rainy season Oct 1-Feb end)	280	375	350	290	325	290	40.6
Rainfall	740	775	965	665	515	1050	100.0

* Sorghum was grown as the post-rainy season crop.

† When crops are grown during the monsoon, runoff is on average reduced to less than IS percent of the annual rainfall (Hari Krishna 1979).

‡ The evapotranspiration values are relatively high because of the use of traditional long duration varieties.

Because of the very low yields of the common rainfed cropping systems in these areas, farmers have not found it feasible to invest substantially in measures that will improve and maintain the productivity of their land. It is evident that in most areas development of the land resource base had to await the generation of more productive systems of cropping and farming. The cultivated land in many Vertisol areas of the rainfed SAT therefore still resembles the "ploughed savanna"; exceptions to this are small tank systems for supplemental irrigation of crops such as rice and groundnut (von Oppen & Subba Rao 1978), and in some areas contour, bunds. However, these techniques were introduced primarily on Alfisols and on medium to shallow Vertisols and Inceptisols. For deep Vertisols, there were no effective technologies for soil and water conservation and improved resource use.

During the past decade more productive cropping systems have been developed for many rainfed conditions including those encountered in Vertisol areas (Krishnamoorthy et al. 1977, Spratt & Chowdhury 1978, and Randhawa & Venkateshwarlu 1980). It has therefore become imperative that more effective in situ soil and water conservation and drainage practices be developed for the deep Vertisols to improve their productivity primarily through facilitating rainy season. cropping.

The objectives of developing suitable research methodologies to arrive at approaches towards improved land management and soil tillage and of assisting Regional Research Centers in generating effective technologies for these areas has been one of the primary goals of researchers at ICRISAT since 1972 (Kampen & Associates 1974). It is envisaged that very substantial gains in total food production can be attained if the present postrainy season cropping systems can be replaced by farming systems where two crops are grown in most seasons (Krantz et al. 1978).

Land Development and Primary Tillage for Improved Productivity

Scientists at ICRISAT in cooperation with their colleagues in National Research Organisations 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" that can be universally applied has evolved.[2] Those familiar with the diversity that exists within the large areas of deep Vertisols will understand that the finally tailored practices suitable to a particular region, will always be quite location-specific. 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 systems of farming. Another important lesson learnt at ICRISAT is that significant and visible improvement of agricultural productivity on the deep Vertisols will require innovations in several technology components concurrently, this makes rapid widespread implementation on farms more difficult.

Land Smoothing and Field-Drains: The overall macro-relief of major ridges and valleys of the land surface of most Vertisols is frequently overlain by small differences in micro-relief; the latter often cause depressions of various sizes with impeded surface drainage. To alleviate the influence of the micro-relief on surface drainage, it is necessary to "smoothen" the land surface. This is of course most efficiently done if executed in the direction that one ultimately envisages cultivation. Land smoothing can be done at a much lower cost—and with much less surface soil disturbance—than terracing or other forms of land levelling.

The rainfall characteristics of many of the deep Vertisol regions under medium to high average rainfall are such that excess water will be a frequent occurrence (Virmani et al. 1979). Thus, provisions must be made for the early and safe removal of such excess runoff when crops are grown during the rainy season. Frequently there are opportunities to improve the natural drains by clearly delineating, shaping and straightening them and by adjusting their longitudinal slopes such that they will be stable after having been provided with a grass cover.

In the construction of field-drains one can make use of several different means. Where large scale equipment such as graders and tractor-drawn scrapers are available, the drain construction can be executed very rapidly once the

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[2] It should be understood from the outset that indeed the *approaches* towards a search for farming systems of improved productivity and stability and not the specific component practices are the focus of this paper.

preparatory survey has been done. However, experience at ICRISAT indicates that field drains can also be effectively constructed, and at reasonable cost, utilising animal-drawn implements[3] and human labour. Thus, where those resources are available and find little alternative employment (e.g. in the dry seasons) their productive utilisation in land development may be preferred. If substantial quantities of soil are to be removed in the drain construction process, it is important to realise that such earth can be used to minimise the earlier existing micro-relief by depositing the excavated material in nearby depressions.

Land smoothing can also be done in several ways. Until a few decades ago, irrigated rice fields in India were mostly levelled by human labour. If available, tractor-drawn land planes can efficiently smoothen the microrelief of large areas in a short time. At ICRISAT, effective land smoothing has been attained on several small watersheds on deep Vertisols, utilising small animal-drawn scrapers (figure 3). The feasibility of this approach depends upon the occurrence of some pre-rainy season showers after which ploughing to loosen the surface soil should immediately follow. Another possibility is to use tractor-drawn ploughs for the initial loosening of the soil and to depend on animal-drawn equipment and labour for drain construction and land smoothing. It is important to realise that land smoothing, although probably most efficiently done on a watershed basis, can also be effective when executed within the boundaries of individual fields.'

An illustration of the activities involved and the relative costs incurred in a cooperative research project on small scale watershed development on deep Vertisols in the village of Shirapur near Sholapur is given in table *2*. The watershed was

Figure 3 Small animal-drawn scrapers can be effectively used to smoothen the land surface

[3] At ICRISAT, the "tropiculteur", an animal-drawn toolbar has been used for most land development and cultural operations *(see for example figures 4, 7 10 and 11).*

Table 2 *Costs of on-farm watershed development at Shirapur**

Activity | Operation	*Bullocks*	*Labour*	*Materials*	*Total Cost*	
	Costs (Rs)			*Rs*	*Rs|ha*
Waterways	732	1560		2292	165
Structures	32	268	342	642	46
Sub-total	764	1828	342	2934	211
Chiseling	276	218		458	33
Ploughing†	310	322		832	60
Harrowing	246	106		352'	25
Smoothing	240	699		939	68
Furrowing	256	192		448	32
Cultivation‡	176.	132		308	22
Bed shaping	176	132		308	22
Sub-total	1880	1765		3645	262
Total costs	2644	3593	342	6579	473

*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 is executed as part of the Mahatma Phule Krishi Vidyapeeth (MPKV)—Indian Council of Agricultural Research (ICAR)—ICRISAT cooperative research programme on watershed development.

†Ploughing costs were relatively high because no rains occurred and the soil was extremely hard—after pre-rainy season rains costs of ploughing might be much reduced.

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

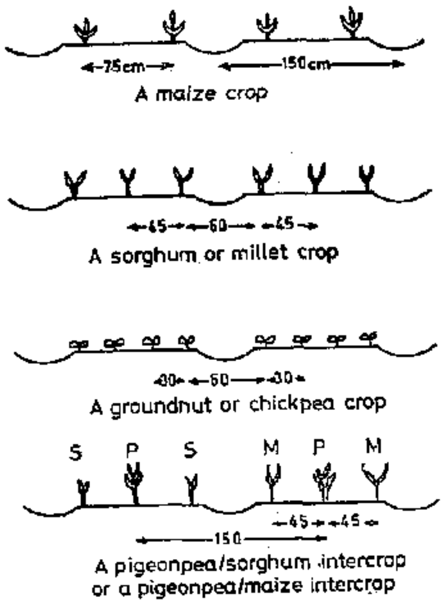
developed during the dry season of 1978-79 when normally draft animals were idle and labour underemployed. Farmers were continuously involved in the planning stage's and participated in the development activities. The total land development costs amounted to about Rs. 425/ha: less than 10% of these costs consisted of capital charges; the rest was paid for locally hired labour and bullocks. A similar study on land development was done as a cooperative project between Punjabrao Krishi Vidyapeeth (PKV), AICRPDA and ICRISAT on medium Vertisols at Kanzara village in Akola District. Land development costs on different farmers' fields ranged from about Rs 200 to Rs 500 per hectare depending upon the degree of smoothing required, the extent of field drains and the equipment used.

The Broadbed-and-Furrow System; In the semi-arid tropics, high intensity rains may occur at any time; if such storms happen during the early rainy season when crop cover is limited, serious runoff and erosion may result. Also, even a smooth land surface void of local depressions may still provide inadequate surface drainage conditions, particularly during extended periods of rainfall; such periods frequently occur. Thus, there is a need for an improved "in situ" soil and water conservation and drainage technology that protects the soil from erosion throughout the entire season and provides for water control at the place where the rain falls.

At ICRISAT, a "broadbed-and-furrow" system has, on deep Vertisols, been found to satisfactorily attain these objectives. The system used at ICRLSAT is 150 cm wide and consists of a relatively flat bed or ridge of approximately 90 cm wide and shallow furrows of approximately 60 cm. The tropiculteur with ridgers is used to mark the layout; a bedformer is then applied to shape the broadbeds (figure 4). If additional opportunities arise before the beginning of the rainy season to eliminate weeds and improve the shape of the broadbeds, another cultivation is done. Thus, at the beginning of the growing season the seedbed is receptive to rainfall and moisture from early precipitation is stored in the surface layers without disappearing in deep cracks.

The grade under which the broadbed-and-furrow system has normally been laid out on deep Vertisols at ICRISAT is 0.4 to 0.8%. At that grade, furrows of 100m or less in length have behaved satisfactorily with regard to discharging excess water with minimal soil erosion and providing adequate surface drainage even during long rainy spells (Kampen & Krishna 1978). The broadbed system also provides great flexibility to fit crops and cropping systems with widely differing row spacing requirements (figure 5). Precision placement of fertilizer is facilitated even when seed and fertilizer are applied separately; the system is also

Figure 4 The broadbed-and-furrow system implemented by an animal-drawn toolbar or ''tropiculteur"



Figures The broadbed-and-furrow system provides great flexibility in accomodating widely varying row spacing requirements.

easily used for supplemental water application. Soil compaction due to animal feet and equipment wheels is minimised to the furrows.

Dryland Preparation: Because the deep Vertisols are difficult to work when wet, it is important 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, ICRISAT scientists have found that they often have a limited workability immediately after the harvest of the previous dry season crop. If initial land preparation is executed at that time, a cloddy soil surface results: Although the soil is yet entirely unsuitable as a seedbed, weeds are largely removed.

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 monsoon season. If another cultivation is executed soon after such a rain, the clods easily shatter and a clean, friable seedbed can be attained. If more than one rain occurs during the pre-rainy season, the seedbed preparation tillage can be repeated to eliminate weeds.

Cropping Systems and Cultural Practices

Maintenance of a continuous vegetative cover is the most effective erosion protection technique. The productivity of the crop or cropping system selected directly determines the efficiency with which the total available rainwater resource is used. Thus, the entire package of crop management practices is important in attaining a more efficient use of rainwater. Some of the important components that may facilitate double cropping on Vertisols are:

Dry Seeding: The application of chemical fertilizer and actual seeding are difficult to do once the soil has become wet. Also, if the initial rains continue for a substantial period and the soil surface remains too moist, the beginning of the effective growing season is delayed because no operations are feasible. With crops such as sorghum where early establishment is important to escape shootfly, the entire rainy season growing period may be lost if the seedling cannot be established during the first few weeks.

A technique of applying seed and fertilizer to the dry soil before the first rains occur may be feasible in those areas where the early season rains are reasonably dependable. Studies of the rainfall probabilities over short periods at ICRISAT have illustrated the potential feasibility of dry seeding (figure 6). During the last 8 years, rainy season crops have been established satisfactorily after fertilizer application and seeding during the period immediately before the rainfall probability begins to exceed the level of 70%. (i.e. at ICRISAT, about the middle of June). In order to guard against germination after small quantities of rainfall, the seed must be placed relatively deep; in case of sorghum, pigeonpea and maize for example at 5 to 7 cm depth.[4]

As soon as the first "germinating" rains occur, the growing season has started. The only operations left for the early rainy season are one or two interculture

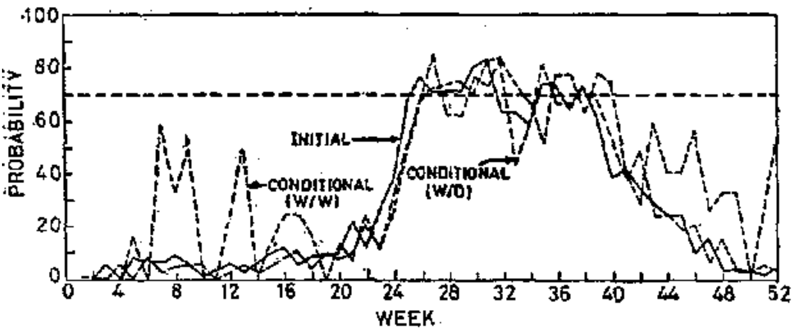


Figure 6 Initial and conditional rainfall probabilities[a]. of R/PE[b] >.33 at ICRISAT.

[a]The probability of receiving certain amounts of rainfall during |a given week indicated by the initial probabilities P(W): the probability of rains next wet 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 PI(W/D).

[b]R=Rainfall PE=Potential evapotranspiration.

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[4]Small seeded crops such as millet and setaria cannot be sown deep; "for suchcrops dry seeding is not practical.

operations or hand-weedings to control weeds. Recent experience at ICRISAT appears to indicate that in some years even these operations may be difficult to execute because of continuous wet conditions. The application of limited quantities. of pre-emergence herbicides to attain satisfactory weed control has shown promising results in sole crops such as maize (Shetty & Krantz 1979). In most years an early start of the rainy season growing period makes it potentially feasible to grow a second crop in the post-rainy season.

Minimum Tillage for Post-rainy Season Cropping: The most efficient way to grow a post-rainy season crop on the deep Vertisols is by means of inter-cropping because this eliminates the necessity of a second land preparation at the end of the rainy season and also provides continuity in crop cover (Rao & Willey 1980). Tillage at that time may again be difficult because of tie unpredictability of the late rains.

However, it may also be necessary to grow sole crops because of food or cash-crop requirements either related to the rainy season crops or to the post-rainy season crops. In this situation minimum tillage approaches may be useful. At: ICRISAT, the presently followed technique consists of shallow tillage of the space between the remaining stubbles of the preceeding crop on the bed and also the re-ridging and cleaning of the furrows with the tropiculteur. In both intercropping; and sequential cropping it is attempted to harvest the rainy season crop at. physiological maturity such that the post-rainy season growth period begins as early as possible. The potential returns from double cropping on deep Vertisols are illustrated in table 3.

Primary Tillage for the Subsequent Cropping Season: 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 sometime in February or March; primary tillage is executed on the already existing broadbeds (figure 7). This frequently is the most opportune time for this operation, because immediately after the harvest of the dry season crop the surface soil may still contain some-moisture. Also, experience at ICRISAT indicates that the soil on the broadbeds is. more friable than with flat cultivation and therefore facilitates dry land preparation. If the soil is exposed to the drying influence of wind and sun for any extended period of time, tillage becomes difficult. After primary tillage, the soil surface is receptive to any rain that may occur during the dry season. When this happens, final land preparation should be initiated immediately. After this, the broadbed and furrow system is again ready for planting the next rainy season's crop.

Table 3 *Gross returns from traditional rainy season fallowing technology and double cropping with improved soil, water and crop management on deep Vertisols at 1CR1SAT.*

*Watershed**	*Gross returns (Rs|ha)*							*Average*
	1973-74	*'74-75*	*'75-76*	*'76-77*	*'77-78*	*'78-79*	*'79-80*	*1973-78*
BW4C	1792	212S	1642	660	368	680	914	1169
BW1	7398	6120	6012	3S40	5280	6893	4122	5666

*On BW4C a rainy season-fallow traditional system of farming is simulated; on BW1 the improved; system is applied

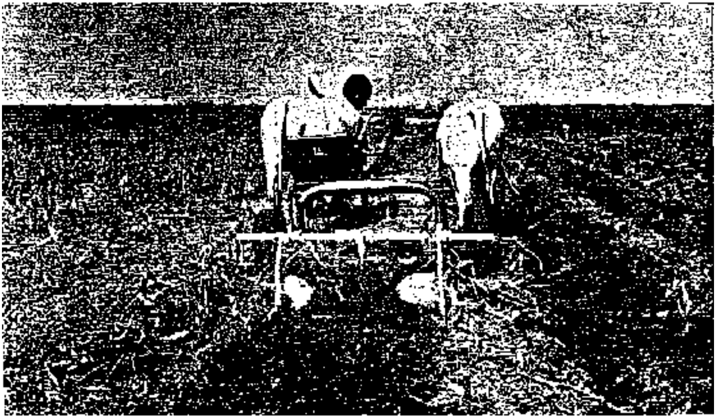

Figure 7 Primary tillage on broad beds, immediately after harvest of the dry season crop

Productivity Gains from Improved Farming Systems

A; preliminary impression of the potential effects of the implementation of an improved system of farming may be gained from the 1979/80 crop yields at Kanzara (table 4). Although the early part of the rainy season of 1979 was reasonably favourable in, terms of onset and distribution, rainfall in late August and early September was scanty. All crop yields were seriously depressed by moisture stress. Nevertheless, improved technology out-yielded traditional systems consistantly and substantially. Field observations also showed that new cropping systems together with improved land management resulted in less erosion and runoff.

Runoff Collection and Supplemental Irrigation

In several regions, the capacity of the root prome to store moisture may be exceeded several times during the rainy season even 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 the use thereof for supplemental irrigation later (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, considerable evidenced exists indicating that significant returns can be gained from relatively small quantities of supplemental water on post-rainy season crops e.g. sorghum, wheat, chichpea and high value products such as vegetables.

Implications

Better rainwater utilisation, facilitated by improved systems of farming can

Table 4 Grain *yields** *(q/ha) and gross monetary, returns*† *(Rs/ha) for several crops at Kanzara village in 1979/80*

W. shed No.	*Cropping system*	*Soil mgt*	*Sorghum*	*Pigeon-pea*	*Cotton*	*Ground nut*	*Black gram*	*Gross value*
Improved technology‡								
1	Sorghum-Pigeon pea	Beds	20.0	2.0				2630
1	" "	Flat-	14.7	2.1				2100
1	Cotton sorghum-pigeonpea	Beds	7.6	0.6	6.3			3332
1	" "	Flat	5.6	0.6	4.9			2633
Existing technology‡								
1.	Cotton-sorghum-pigeonpea	Flat	0.2	0.2	1.8			767
1	Cotton-blackgram	Flat			2.5		0.6	1112
Improved technology								
2	Sole groundnut	Beds				6.7		2177
2	Sorghum-pigeonpea	Beds	14.7	2.0				2073

* The yields ace based on small samples; actual threshing floor yields were somewhat (5 to 10 per-cent) lower.

†The monetary values are based on the following prices at harvest time: sorghum Rs. 105/q; cotton Rs. 385/q; pigeonpea Rs. 265/q; groundnut Rs. 325/q and blackgram Rs.250/q.

‡Estimates of yields in adjacent Melds.

make a very significant difference in the efficiency with which the total available resources are used. As illustrated for the deep Vertisols, the potential productivity of some agroclimatic environments appears to be three to five times higher than what is attained by the traditional systems of production (tables 3 & 4). However, it must be realised that no single farming system will be found universally applicable; this is true even within the reasonably homogeneous deep Vertisols with reliable rainfall. Thus, much more than "testing" will be required to develop technically and economically viable systems for different regions within the deep Vertisols. It is on the one hand critically important to realise that where an existing farming system is. replaced by an entire new set of technologies, a "package" is necessary. On the other hand, it is evident that the new systems of farming consist of components; these must be individually and in synthesis sound.

After study of their resource environment and the characteristics of the existing farming systems, local researchers can indentify the cutical components that will facilitate the development of new, more stable and productive systems of production that makes a better use of the rainwater resource. These components must be tested both in isolation and operationally; before attempts towards further on-farm adaptation and implementation are made. It is expected that such a researh approach will result in significantly increased food and cash crop production from the deep vertisols (figure 8).

In other agroclimatic zones, there is at present less evidence available to indicate the potentials of improved rainwater management to facilitate and to contribute to better overall resource use and greater productivity. Component areas that represent priority research needs are : soil fertility management, in situ soil conservation practices, alleviation of the effects of soil crusting, appropriate cropping systems providing continuous plant cover, minimising risk of fertilizer use under undependable rainfall, adequate surface drainage, efficient soil tillage systems, supplemental irrigation, and most importantly, training of scientific manpower. Thus, the research and development inputs required may be greater and a longer time frame may be necessary before improved farming systems can be synthesized.

It is nevertheless envisaged that in many other regions improved water management, land development and soil conservation technology combined with more efficient cropping systems also can contribute significantly towards greater productivity, less uncertainty and risk and, ultimately, a better quality' of life for the people of the SAT.

Operational-Scale Research to Develop and Transfer Technology

Several components of the systems of farming now common. in the SAT must be improved simultaneously to attain better rainwater use and substantially increased and more stable production. In some agroclimatic regions, for example the dependable rainfall, deep Vertisols, some of the critical components have been identified and investigated. Thus, there is now an urgent need for the generation of efficient methodology towards the integration of new techniques into technically and economically viable farming systems which fit major constraints faced by

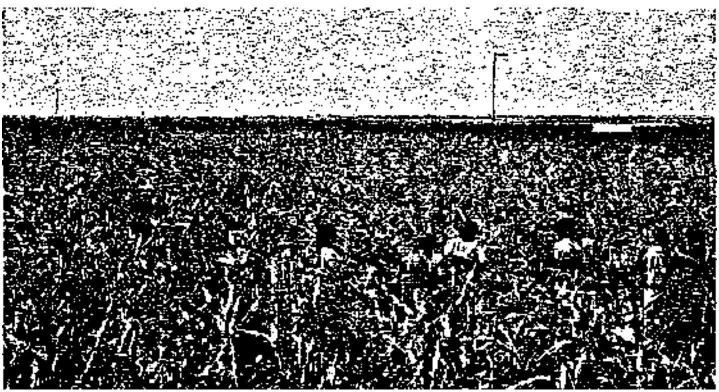

Figure 8. Harvest of rainy season crops from deep vertisols at ICRISAT. The maize stalks are bent to allow more light for the intercrop pigeonpea.

farmers. Such integration may be most effectively - studied in operational-scale systems research at Research Centres and on farms (Kampen 1979).

Operational-scale Studies at Research Centres

In studies on resource utilization for the SAT, the central objective is to make the best use of the rain that falls on a given area. In order to study water as an input, small, natural watersheds were chosen as a unit for research at ICRISAT and in cooperative research projects with AICRPDA (figure 9). Alternative land and water management techniques are simulated and evaluated on Alfisols and Vertisols. Improved cropping systems are superimposed on these treatments. All cultural operations are executed using two of the important resources of farmers in the SAT; animals for draft power, and labour. Thus, these watersheds are operational-scale pilot plants where the integrated effect of alternative systems of farming on, productivity, resource use, and conservation can be monitored and evaluated, and where feedback to specific research projects is generated. The operational-scale research at Research Centres provides for the initial screening of technology; the final tailoring of new systems to the farmer's' needs must be done on farms.

Operations Research on Farms

Region-specific knowledge on improved soil and water management and farming systems can be developed through the initiation of small-scale (10 to 50 ha), on-farm, watershed management projects/To ensure success of these projects and to build the foundation for regionwide implementation and long-term continuity,

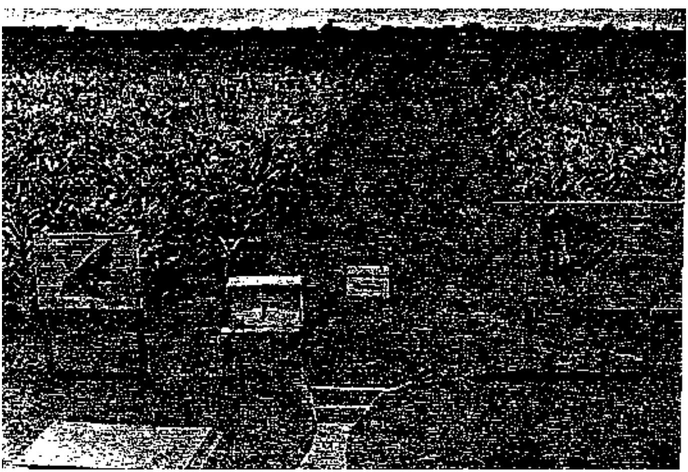

Figure 9 A small research watershed on Vertisols at ICRISAT.

these programs ought to' be part and parcel of the activities of existing research institutions and coordinated research projects with involvement of action departments at national and state levels. Leadership must be provided by state and university staff. Participation of scientists in the fields of soil and water engineering, crop improvement, agronomy, plant protection, economics, and sociology during the phases of project development, execution and evaluation will be necessary; farmers must also be involved in decisions on appropriate resource development and watershed management. ICRISAT tries to facilitate the initiation of such projects through participation in cooperative research at a few carefully selected, representative locations (figures 10 & 11).

Integrated, on-farm projects for operations research on natural resource development would ideally consist of four distinct phases; the collection of basic data, the design of an improvement program in which farmers participate, the; implementation and an evaluation. Successful execution of such applied research programs in representative, agroclimatic regions will probably require not less than five years. Such projects will have an important training function. On-farm research projects are considered essential to facilitate farmer's acceptance and to prepare ground for larger scale programs aimed at improved watershed management and better rainwater utilisation..

Regional research programs for improved-watershed management would have a number of primarily technical objectives related to the specific agroclimatic environments. However, such projects ought to be focused to realize the following

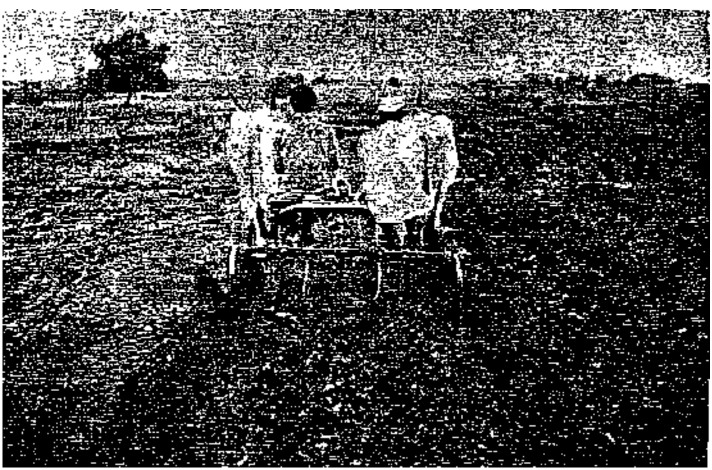

Figure 10. Final tillage on the broadbed-and-furrow system in the Mahatma Phule krishi Vidyapeeth (MPKV)-ICAR-ICRISAT cooperative research project on Verisol water development at Shirapur.

Figure 11 Interculture in groundnut grown on broadbeds in the Punjabrao Krishi Vidyapeeth (PKV)-ICAR-ICRISAT cooperative research project on watershed developed at Kanzara near Akola

three goals, which are considered to be of critical importance:

(1) To develop holistic soil, water and crop management technology which supports the maximization of economic and social returns, especially to the less advantaged cultivators; to test if efficient labour-intensive rather than capital-intensive technology can realize this objective; to involve farmers in the technology development process.

(2) To shorten the time lag between the development of new soil, water, and' crop management technology at research institutes and its application on farms; to test the profitability and applicability of research results under on-farm conditions; to provide feedback on priority research needs to scientists.

(3) To evolve through field research, guidelines, on the desirability and the required incentives for group action in the development of natural resources and the operation of new watershed management systems.

Given the research evidence now available for the deep Vertisols with medium annual rainfall, such operations research projects might: be proposed for the Vertisol regions of southern Madhya Pradesh and northern Maharashtra.

Cooperative Studies on Alternative Integrated Development Approaches

Before natural resource development projects integrated into agricultural production programs are applied to large rainfed areas, it is advisable to identify and test the most promising technical, organizational, and financial development approaches on larger watersheds (exceeding 1000 ha). A few representative regions —in terms of land uses, crops, soils and rainfall—could be selected to test the viability of alternative agricultural development approaches and to monitor results and costs as well as other requirements. The goals of such projects, cooperatively executed by research and extension organisations, would be:

(1) To survey and quantify the resource base; to identify priority problems and potential solutions; to' determine how the available infrastructure could be better used; and, to set short- and long-term development goals.

(2) To select, in consultation with farmers and development agencies, two or three viable solutions and implementation methods.

(3) To integrate overall land use planning and implementation (forage, horticulture, silviculture) with development of the resource base for food and cash crop production.

(4) To monitor progress and bottlenecks, to feed information back to research centers; to determine costs and results with action agencies.

(5) To train technical staff of development programs in innovative implementation of new resource management and utilization technology across large areas.

Involvement of farmers in selecting and adapting technical solutions to a particular resource environment should be sought rather than implementing just one selected "package" (figure 12). Assuming that enough is known to arrive at integrated, effective solutions, these studies on development alternatives would contribute greatly to maintaining a problem-oriented focus for research institutions. It is

Figure 12. Interaction of researchers and farmers provides for appropriate technology that fits the farmer's needs.

evident that ultimately the success or failure of agricultural development programs depends on the quality of the staff involved in implementing such projects. The suggested cooperative studies would provide a real world setting for in-service training of large numbers of technicians. Successful projects would also serve a demonstration function for extension staff and farmers from other areas.

Conclusions

Present farming systems in the SAT are characterized by low and undefendable yields and by an inefficient use of the rain and the soil. Thus, substantial improvement in the productivity of the resource base is required. Recent research results from operational-scale research at Research Centres and on farms indicate that this goal can be attained through watershed-based natural resource development and management and the introduction of improved cropping systems.

Watershed-based natural resource development and use ultimately involves the optimum utilisation of the water and the soil to the benefit of the people inhabiting the land. Cooperative research programs must be strengthened so that integration of new technology is emphasized, inter-disciplinary research is facilitated, farmers are involved in technology development, and group action problems are solved. Training of scientists and development workers in holistic approaches-is essential. Only sustained, integrated development programs—executed by well-trained, dedicated professionals and supported by problem-oriented, applied research projects—will have the desired impact. No short-term, miracle solutions should be expected.

The transfer and early implementation of watershed, management technology will depend upon three major factors : (1) development of efficient research methodologies aimed at the generation of new farming systems; (2) involvement of national and regional research and extension agencies' in developing viable technology and effective transfer methods through cooperative research programs at research centres and on farms; and (3) assistance to preparing the manpower to initiate and guide gigantic training programs aimed not only at technicians but also at farmers.

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