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Impact of Vertisol Technology in India

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Abstract

Research on vertisol technology as a package of options began at ICRISAT in 1974. The technology was first tested and demonstrated on farmers' fields in Andhra Pradesh. Later, on-farm trials were conducted in five states — Andhra Pradesh, Karnataka, Gujarat, Maharashtra, and Madhya Pradesh — to understand the dynamics of adoption of various components of the technology, such as summer cultivation, dry seeding, crop protection, improved varieties, proper placement of seed and fertilizer, etc. The survey was conducted in 27 villages, where 500 farmers from low-, medium-, and high-rainfall regions were interviewed using a well-designed questionnaire. This study assesses the extent of adoption of the various components of vertisol technology, identifies the constraints to their adoption, examines farmers' perceptions of the sustainability benefits from it, estimates the on-farm benefits, and details the relative significance of the various components.

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Introduction

Indian agriculture is largely characterized by rainfed farming, with more than 60% of the cropped area being dependent on rainfall. Low yields and high risk are typical of rainfed agriculture. Unless the low yield barrier and high risk are addressed, the country's increasing food needs cannot be met on a sustained basis. Given the prevailing traditional technologies, rainfed farming cannot be improved. The major constraints to agricultural development in the seasonally dry tropics are the lack of suitable technologies and viable crop production systems. Water and nutrient stresses, and degradation of natural resources are pervasive in the rainfed semi-arid tropics (SAT) since there are no opportunities to cultivate two crops a year. Crop intensification has been considered the most effective means of meeting these challenges. Improved technologies offer the potential to considerably improve rainfed farming.

Efforts are on at various research institutes and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop appropriate technologies that increase and stabilize production in the drylands. Developing crop and resource management technologies has been one of ICRISAT's significant contribution to alleviating production constraints and improving the sustainability of natural resources in vertisol areas. An integrated package of options was conceived and developed by a multidisciplinary team of agricultural and social scientists at ICRISAT in 1974 in response to these constraints. This was later known as vertisol technology (El-Swaify et al. 1985; Kampen 1982). The package targeted vertisol areas in regions with relatively dependable rainfall, where land was left fallow during the rainy season (Flower 1994). Vast vertisol areas in India, such as in Madhya Pradesh, Maharashtra, and Andhra Pradesh, are left fallow during the rainy season and sown during the postrainy season using residual moisture (Kampen 1982). It may be feasible to use a package of approaches consisting of several clusters of improved technological options to markedly increase productivity. The prerequisites for the success of the technology are dependable early-season rainfall for dry seeding and soils with sufficient moisture-holding capacity to grow two crops without irrigation. It is estimated that vertisol technology may be suitable over 5-12 million ha in India, largely covering the States of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, and Maharashtra (Ryan et al. 1982). An evaluation of the techno-economic feasibility of the technology at various stages and its superiority over traditional practices is essential for allocating funds on a priority basis. The on-farm trials of the early 1980s provided an opportunity to assess the adoption of the technology after a significant period of time.

History of Vertisol Technology

Vertisol technology research represents a major institutional investment by ICRISAT. The word "vert" in vertisol is derived from the Latin word "verto" meaning invert or turn. Inversion takes place in the soil because of cracking, which is characteristic of vertisol soils. Vertisols are hard when dry, sticky when wet, and have a narrow moisture range during which tillage takes place (Virmani et al. 1989).

At ICRISAT, research on vertisol technology as a package of options started in 1974 with two major experiments. The 'step-in improved technology' was initiated between 1975-76 and 1988. Fourteen cropping systems were evaluated and valuable information was generated. The technology was tested and demonstrated on farmers' fields at Taddanpally, Andhra Pradesh. Later during 1982-83, operational-scale demonstrations were carried out at eight locations. In order to test the performance of the technology outside ICRISAT, on-farm trials were conducted during 1981-84 at Taddanpally and Sultanpur in Andhra Pradesh, Kanzara and Shirapur in Maharashtra, Farhatabad in Karnataka, and Begumgunj in Madhya Pradesh. The trials were collaborative in nature and involved State Departments of Agriculture, the All India Co-ordinated Research Project for Dryland Agriculture, and the Andhra Pradesh Agricultural University (APAU). Walker et al. (1989) assessed the feasibility of the technology at seven different locations and compared the profitability of improved vertisol technology options with that of traditional farming practices from 1979/80 to 1982/83. Marginal rates of return on additional investments in improved technology were found to be negative in initial on-farm tests, but positive during subsequent years (Table 1). Although vertisol technology options generated handsome economic rates of return in on-farm tests in Taddanpally and Sultanpur, the potential of the improved cropping systems was not fully tapped. In 1983/84, on-farm tests were expanded to cover 2000 ha in 28 locations in 5 States.

Table 1. A comparison of the profitability of improved deep vertisol technology options with traditional farm practices in seven watershed tests, 1979/80 to 1982/83 (Walker et al. 1989).

District, State	Year	Area (ha)	Farmers	Soil (rainfall)	Marginal rate of return (%)
Aurepalle (Mahbubnagar,	1979-80	13.5	5	Alfisols	Negative
Andhra Pradesh)	1980-81	11.9		(not assured)	37
Shirapur	1979-80	13.9	8	Vertisols	Negative
(Sholapur, Maharashtra)	1980-81	10.5		(not assured)	113
Kanzara	1979-80	3.7	3	Medium	Negative
(Akola, Maharashtra)	1980-81	10.8		vertisols (assured)	8
Taddanpally	1981-82	14.5	12	Vertisols	244
(Medak, Andhra Pradesh)	1982-83		4	(assured)	381
Sultanpur (Medak, Andhra Pradesh)	1982-83	26.7	12	Vertisols (partly assured)	302
Farhatabad (Gulbarga, Karnataka)	1982-83	17.5	3	Vertisols (partly assured)	3
Begumgunj (Raisen, Madhya Pradesh)	1982-83	24	10	Vertisols (assured)	26

Vertisol Technology

Research in vertisol technology was one of the joint outputs of ICRISAT and the Indian NARS in order to increase agricultural production and productivity by efficient utilization of resources in rainfed areas. The improved technological options addressed the problems of rainy-season cropping on deep black soils with poor drainage. The options developed by ICRISAT for the management of land and water involved the use of moderate inputs and bullock power, and accessibility to small farmers in rainfed SAT. They effectively improved drainage, reduced soil erosion, and increased/stabilized crop productivity, and were based on the concept of a micro-watershed (3 to 25 ha) as the basic natural resource management unit. Following are the essential components of vertisol technology identified by Ryan et al. (1982).

Summer Cultivation

This refers to ploughing land immediately after harvesting the postrainy-season crop, when the soil is not too hard and still contains some moisture. This prevents weeds from setting seed, thus reducing weed survival and multiplication (Shetty at al. 1977). Often, stubble/crop residues remain in the field after harvest, providing shelter to insects during the off-season and then multiplying during cropping. Stubble of many crops such as sorghum, maize, and paddy provide shelter to the stem borer. Most of the weeds in the field act as alternate hosts to pests and diseases during the off-season. Summer cultivation exposes the hibernating egg colonies and pupae of various insects to severe solar heat, thus killing them (Patil and Jawaregowda 2000). It also improves soil fertility, fills cracks, and pulverizes the soil, thereby improving moisture absorption.

Broadbed and Furrow (BBF)

This is a land preparation technique in which 105 cm-wide beds alternate with 45 cm-wide furrows at a gradient of 0.4-0.8% depending on soil type and rainfall. This technique ensures desired plant stand by avoiding stagnation of water/excess moisture in the field, and also economizes on water. Rainfall infiltration increases with BBF and excess water is removed with minimum erosion, thus stabilizing soil moisture conditions. It helps maintain optimum moisture supply in the effective root zone, thereby improving the physical, chemical, and biological properties of the soil, which ultimately results in higher yield (Desai et al. 2000). Sengar (1998) reported the beneficial effects of surface drainage in pigeonpea in Madhya Pradesh. Mamo et al. (1994) reported significantly higher grain yields of gram with BBF than with flat seedbeds. Farmers in some parts of India are adopting BBF for postrainy-season groundnut in order to increase yield and save on labor (Joshi and Bantilan 1996).

Dry Seeding

This option involves sowing rainy-season crops before the monsoon rains. Dry seeding overcomes the constraint of wet sowing and facilitates early germination. It results in early maturity of the crop, which eventually escapes terminal drought. Dry seeding was reported to increase yields of sorghum and cotton by 200-300 kg ha^{-1} (Joshi et al. 1998). Farmers obtained higher yields of sorghum (27%) and cotton (38%) by adopting dry seeding in Maharashtra

(Bhole et al. 1998). It was further reported that cotton seed can remain in the soil for a longer time, and unlike seed of many other crops, is not affected by ants and other insects. Similarly, dry seeding of sorghum enabled farmers to double crop.

Use of Improved Seeds and Moderate Amounts of Fertilizer

Improved varieties are an important component of vertisol technology, and have gained popularity during the last two decades. The genetic potential of improved cultivars is utilized to increase production in vertisols. Labor of both sexes is used more intensively in dry seeding compared to farmers' traditional practices of sowing. It also involves less risk, higher profitability, is more responsive to fertilizers, matures early, and involves less shattering.

Available farmyard manure (FYM) is generally not enough to meet crop requirement and nutrient mining. To improve soil fertility and overcome nutrient mining, vertisol technology recommends the application of moderate amounts of chemical fertilizer that could be complemented by manure. Farmers who apply chemical fertilizer are convinced of the quick results and overcome the supply constraint involved with FYM.

Seed and Fertilizer Placement

Proper placement of seed and fertilizer can increase crop yields substantially. While seed is broadcast in traditional dryland agriculture, in vertisol technology seed and fertilizer are placed together in order to minimize nutrient loss and make optional use of available moisture. Dibbling and using a seed drill are common practices adopted by farmers sowing seed and placing fertilizer, in order to maintain proper row arrangements in cotton and groundnut. Seed drills are commonly used to sow sorghum, wheat, pigeonpea, and chickpea.

Joshi et al. (1998) observed a unique practice in Begumgunj village, where a mixture of seed and fertilizer was placed using either a drill or plough. Although unusual, this modified form of the technology went to prove that farmers accepted the placing of seed and fertilizer together.

Double Cropping

Double cropping involves utilizing land for two growing seasons instead of one. This technology option helps in using the land for production for up to eight months in summer instead of four. In vertisol areas where rainfall is greater than

750 mm year^{-1}, two crops are feasible without irrigation. Double cropping makes effective use of other fixed costs and production resources such as moisture, human labor, bullock time, and cultivation tools. During on-farm testing, several new cropping systems were recommended and verified for feasibility and adaptability.

Both sequential crops and intercrops that require two seasons to mature are considered options; however, farmers view moisture limitation as a major constraint to double cropping. There is, however, an opportunity to increase intensity through an intercrop.

Plant Protection Measures

Since rainfed agriculture is highly prone to diseases and pests, application of modest doses of insecticides/pesticides was advocated to protect plants. With the advent of High-Yielding Varieties (HYVs), the incidence of diseases and insect/pests has increased. Though several insect species attack during various stages of crop growth, those doing so at the reproductive stage are of major economic significance. Since the indiscriminate use of pesticides raises issues of sustainability and environmental pollution, improved plant protection measures are considered one of the essential components of vertisol technology.

The components of vertisol technology are basically a collection of innovations from which a farmer can choose, based on his need and benefit. Farmers may either adopt the complete package or part of it, or even a modified form of its recommendation (Byerlee and Polanco 1986; Ryan and Subramanyam 1975). Despite substantial investments in time, resources, and capital, there is insufficient research on the nature and extent of adoption of vertisol technology, its benefits, and constraints. This study was an attempt in this direction. Its objectives were to:

- Assess the extent of adoption of various components of vertisol technology;
- Identify the constraints to their adoption;
- Study farmers' perceptions about sustainability benefits;
- Estimate the on-farm benefits of different components of the technology; and
- Assess the relative significance of its components.

Hypotheses

- There is greater adoption of different components of vertisol technology in the medium-to-high rainfall region.
- Greater adoption of different components of the technology leads to higher crop intensification, which in turn influences the sustainability of natural resources.

Methodology

Sampling

Since agroclimatic and socioeconomic conditions in India are highly diverse, it was essential to delineate them into homogenous zones so that areas with common biophysical attributes and soil and water conservation problems could be grouped for optimum planning and efficient implementation of soil and water management programs. Since rainfall is the best indicator of several characteristics of a region, the following classification was adopted for this study.

Regions	Rainfall
Low-rainfall region	<750mm
Sholapur (Maharashtra) and Gulbarga (Karnataka)	
Medium-rainfall region	750-950 mm
Panchmahals (Gujarat), and Akola and Buldana (Maharashtra)	
High-rainfall region	>950mm
Medak (Andhra Pradesh), Raisen and Indore (Madhya Pradesh), and Nagpur (Maharashtra)	

Five States were selected to understand the dynamics of adoption of various components of vertisol technology (Figure 1). The survey was conducted in 27 villages selected from 19 blocks in 9 districts. In all, 500 farmers (100 from low rainfall, 190 from medium rainfall, and 210 from high rainfall regions) were surveyed during 1996/97. The sampling distribution is given in Table 2.

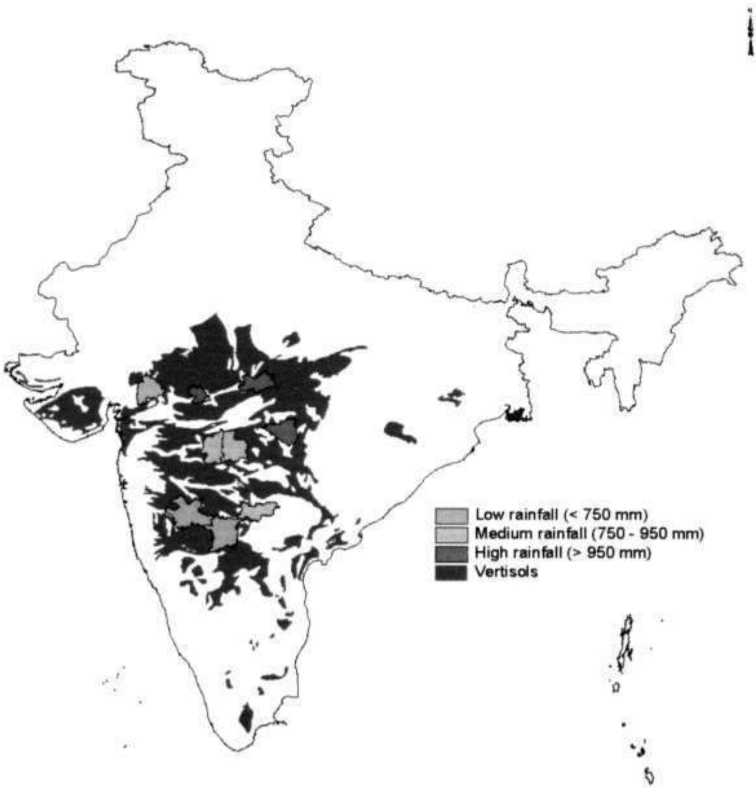

Figure 1. Vertisol areas in India and the study clusters by rainfall.

Data on adoption of various components of vertisol technology, constraints to adoption, farmers' perceptions of the components, etc., were collected by interviewing sample farmers using well-designed and pre-tested questionnaires. This was supported by detailed discussions with agricultural extension personnel, researchers, and agricultural policymakers.

Table 2. Sampling distribution for the vertisol technology survey in India, 1996/97.

State	District	Taluk	Villages	Farmers	Gross cropped area ('000 ha)	Irrigated area (%)	Average annual rainfall (mm)	Major crops
			Low-rainfall region					
Maharashtra	Sholapur	Mohol	Shirapur	20	1147.9	18.9	607	Sorghum, pearl millet
		North Sholapur	Ranmasale	20				
Karnataka	Gulbarga	Gulbarga	Farhatabad	30	1358.1	13.2	730	Sorghum, pigeonpea
		Chitapur	Dandothi	30				
			Medium-rainfall region					
Gujarat	Panch-mahals	Godhra	Rampura, Shivpuri, Sukhpuri	60	580.2	21.5	755	Maize, wheat
		Dahod	Patadungari, Dhamerda, Khared	60				
Maharashtra	Akola	Karanja	Bhadshivan, Palna	20	1022.4	4.4	843	Cotton, sorghum
		Murtizapur	Kanzara	20				
	Buldana	Shegaon	Matargaon	10	830.8	6.6	806	Cotton, sorghum
		Malkapur	Dharangaon	10				
		Motala	Shelpur	10				
			High-rainfall region					
Andhra Pradesh	Medak	Palkal	Sultanpur,Taddanpally	40	447.6	31.7	959	Rice, sorghum
		Andole	Neeridigunta	20				
Madhya Pradesh	Raisen	Begumgunj	Begumgunj	30	492.0	16.7	1330	Soybean
		Gairatgunj	Mudiadheda	30				
	Indore	Indore	Jamburihapsi, Baroli	60	396.0	27.8	980	Soybean
Maharashtra	Nagpur	Saoner	Kodegaon	10	589.6	13.8	1154	Cotton
		Katol	Dorli	10				
		Kalameshwa	Dhapewada	10				
Total				500				

Analytical Framework

It is often difficult to define the term adopters in adoption studies of management-related technologies since some components of the technology are known and adopted even before their introduction. Therefore, information on the first year of adoption of the different components was collected, and a disaggregated analysis was done. In addition farmers are free to choose and adopt any subset of the technology components. To systematically assess the extent of adoption and farmers' perceptions about the benefits of and constraints to vertisol technology, a component-wise tabular analysis was carried out.

The principal components approach was used to assess the relative importance of various components of the technology. The functional form of the principal component model was expressed as:

$$P_1 = a_{11}X_1 + a_{12}X_2 + \dots\dots + a_{1k}X_k$$

$$P_2 = a_{21}X_1 + a_{22}X_2 + \dots\dots + a_{2k}X_k$$

$$P_k = a_{k1}X_1 + a_{k2}X_2 + \dots\dots + a_{kk}X_k$$

This approach aims to construct new variables (P_1) called principal components, out of a set of variables, Xj (j=l,2,...k). The principal components are linear combinations of the Xs. The a, called loading, is chosen so that the constructed principal components satisfy two conditions:

- They are uncorrelated (orthogonal); and
- The first principal component (P_1) absorbs and accounts for the maximum proportion of total variation in the set of all Xs, and the second principal component absorbs the maximum of the remaining variation in the Xs, and so on.

Adoption of Vertisol Technology

Table 3 demonstrates the proportion of farmers who adopted the different components of vertisol technology before and after 1980. Since a few components were adopted by farmers prior to their release, a comparison of component-wise adoption was made between pre-1980 and 1996/97.

Summer Cultivation

The proportion of farmers who adopted summer cultivation before 1980 was highest in the low-rainfall region (39%), followed by the high- (38%) and medium-rainfall (31%) regions. Post-1980, the practice was adopted to a greater extent by farmers in the medium-rainfall region (60%), followed by the low- (42%) and high-rainfall (32%) regions. The wider adoption in the medium-rainfall region could be attributed to fewer irrigation facilities (Table 2). On the other hand, there was adequate moisture in the soil for land preparation and seed germination in the high-rainfall region, where summer cultivation may not be desirable. Many farmers in this region do not depend on rains for tillage since there are better irrigation facilities. It can thus be inferred that medium- and low-rainfall regions could be considered our research target domain for summer cultivation.

Broadbed and Furrow

Broadbed and furrows are used to improve *in situ* moisture conservation and drainage. Under an optimum soil moisture regime, farmers can grow two crops under sequential cropping or add three months to the growing season with intercropping. However, none of the farmers in the low- and high-rainfall regions adopted BBF since they did not face problems of excess water and waterlogging in fields. About 6% of the farmers in the medium-rainfall region adopted BBF, indicating that this component should be considered on a case-by-case basis depending on soil type and gradient rather than as a general recommendation for all farmers. A majority of the farmers followed traditional methods of draining excess water or making furrows between rows. These are more convenient and less expensive to adopt compared to BBF.

Dry Seeding

Dry seeding involves sowing of seed before the onset of monsoon. This practice was adopted only by farmers in the medium-rainfall region; about 16% of them adopted it prior to 1980, whereas 44% adopted it after 1980. It was adopted mainly in cotton and maize, using seeds saved from a previous crop. Nonadoption in the other two regions could mainly be due to its nonsuitability to crops grown in those regions or due to less dependence on rainfall in the early part of the rainy season.

Table 3. Adoption (% farmers) of different components of vertisol technology.

Components of vertisol technology	Before 1980			After 1980		
	Low - rainfall region	Medium-rainfall region	High-rainfall region	Low-rainfall region	Medium-rainfall region	High-rainfall region
Summer cultivation	39	31	38	42	60	32
Broadbed and furrow	0	6	0	2	6	0
Dry seeding	0	16	0	1	44	0
Improved varieties	18	79	9	82	21	62
Fertilizer application	6	69	21	80	32	71
Placement of seed	70	97	58	30	3	42
Placement of fertilizer	3	73	24	68	26	71
Double cropping	0	77	43	24	20	48
Plant protection	8	37	2	82	37	37

Improved Varieties

Improved varieties play a significant role in increasing production in vertisols. It was observed that a majority of the farmers (79%) in the medium-rainfall region had been growing improved varieties prior to 1980, whereas the proportion who adopted them in the low- and high-rainfall regions increased only after 1980. A similar situation was observed for fertilizer application. It was perceived that improved varieties responded better to fertilizer than did landraces.

Nutrient Management

Proper placement of seed and fertilizer were essential to the technology package to ensure the utilization of soil moisture and nutrients, and minimize nutrient loss. It was observed that placing seed and fertilizers using a plough was a common practice in all the three regions. This shows that the farmers were fully convinced about the benefits of sowing in rows and placing fertilizer along with seeds. A majority of the sample farmers used dibbling and maintained proper row arrangements for cotton, while seed drills were commonly used to sow sorghum, wheat, pigeonpea, and chickpea.

Double Cropping

Double cropping refers to both sequential crops and intercrops, which require two seasons to mature. It was recognized that the production potential of vertisols could be increased by introducing double cropping and utilizing underutilized resources. Despite this, it was not adopted in the low-rainfall region prior to 1980, while adoption was only 24% post-1980. There was greater adoption of double cropping in the medium- and high-rainfall regions even prior to 1980. Appropriate technologies, a conducive policy environment in terms of remunerative prices for important crops, and better marketing facilities could enhance the adoption of double cropping in the low-rainfall region.

Crop Protection

Since crop protection measures are imperative to protect the extra investments made on resources, their adoption pattern was assessed. It was found that insecticide/pesticide use increased substantially after 1980 (82%), particularly in the low-rainfall region, whereas prior to 1980, they were used by only 8% of the farmers. Over the years, the need to apply insecticides/pesticides has arisen

Table 4. Intensity[1] of adoption of vertisol technology.

Components of vertisol technology	Low rainfall	Medium rainfall	High rainfall	All
Summer cultivation	***	***	**	**
Broadbed and furrow	-	+	-	+
Dry seeding	+	**	-	+
Improved varieties	***	***	**	***
Fertilizer application	***	***	***	***
Placement of seed and fertilizer	***	***	***	***
Double cropping	+	***	***	**
Plant protection	***	**	*	*

1.*** = Very high adoption (>75%), ** = high adoption (51 to 75%), * = moderate adoption (26 to 50%), + = low adoption (up to 25%), and - = no adoption.

due to the high incidence of insects/pests, particularly in pigeonpea and pearl millet. Though an increase in their use by farmers in the high-rainfall region was noticed, its proportion was the lowest among all the three regions.

Intensity of Adoption

Table 4 details the intensity of adoption of different components of vertisol technology. Adoption was very high in the case of placement of seed and fertilizer, fertilizer application, and improved varieties in all the three rainfall regions and also for the pooled data. While the rate of adoption of double cropping in the medium- and high-rainfall regions was very high, the intensity of adoption of summer cultivation was high in low- and medium-rainfall regions. The low adoption of double cropping in the low-rainfall region suggests that intercropping of more than one crop having different periods of maturity increases the efficiency of rain water use and the productivity of available resources. A majority of the farmers in the low-rainfall region used plant protection measures. Those in the low-rainfall region of Gulbarga faced the problem of *Helicoverpa* in pigeonpea; thus higher use of pesticides was reported. Contrary to this, major crops in the high-rainfall region, such as soybean and rice, had no insect/pest problem; therefore adoption of plant protection measures was low. Time series data were compiled on region-wise crop intensity, area under HYVs, and total fertilizer consumption from 1980 to 1994 in the selected districts. The data were correlated with year-wise data on

Table 5. Correlation coefficients among select components of vertisol technology.

Components of vertisol technology	DC	CRPINT	IV	HYV area	FA	TFC
Low-rainfall region						
Double cropping (DC)	1					
Crop intensity (CRPINT)	0.7023	1				
Improved varieties (IV)	0.8627	0.7147	1			
HYV area	0.9176	0.6603	0.8806	1		
Fertilizer application (FA)	0.9418	0.7422	0.9808	0.9198	1	
Total fertilizer consumption (TFC)	0.8653	0.7736	0.9170	0.9312	0.9253	1
Medium-rainfall region						
Double cropping (DC)	1					
Crop intensity (CRPINT)	0.8621	1				
Improved varieties (IV)	0.9894	0.8537	1			
HYV area	0.6396	0.5396	0.6416	1		
Fertilizer application (FA)	0.9851	0.8357	0.9953	0.5376	1	
Total fertilizer consumption (TFC)	0.8942	0.9509	0.8905	0.5822	0.8899	1
High-rainfall region						
Double cropping (DC)	1					
Crop intensity (CRPINT)	0.9023	1				
Improved varieties (IV)	0.9895	0.9007	1			
HYV area	0.8117	0.8042	0.8462	1		
Fertilizer application (FA)	0.9744	0.8784	0.9928	0.8748	1	
Total fertilizer consumption (TFC)	0.8667	0.7656	0.8277	0.7377	0.8153	1

adoption of the respective components of vertisol technology by sample farmers of the regions. A correlation matrix is given in Table 5. A positive association was observed between adoption of double cropping and crop intensity, between adoption of improved varieties and area, and between adoption of fertilizer application and total fertilizer consumption in all the three regions. This implies that the samples selected duly represented the respective regions. It was also observed that these three components of the technology were highly correlated among themselves in all the regions.

Table 6. Adoption of vertisol technology by farm size (% farmers).

Components of vertisol technology	Small farm (1 to 2.5 ha)	Medium farm (2.5 to 5 ha)	Large farm (>5 ha)	All
Summer cultivation	65	64	90	71
Broadbed and furrow	1	1	4	2
Dry seeding	10	15	20	14
Improved varieties	73	68	90	75
Fertilizer application	85	93	99	89
Placement of seed and fertilizer	81	90	97	85
Double cropping	71	77	64	70
Plant protection	45	45	71	50

Farm Size and Vertisol Technology

Adoption of the different components of vertisol technology by farm size was assessed (Table 6). It was found that all the components of the technology, except double cropping, were widely adopted by large farmers, followed by medium and small farmers, suggesting that farm size was positively correlated with adoption of technology. Large farmers could afford to adopt different components of the technology while small farmers faced several resource constraints. Since India has a large proportion of small and marginal farmers, special government programs are needed to ensure easy accessibility to vertisol technology.

Principal Component of Vertisol Technology

The adoption of vertisol technology is influenced by many components but the variations are governed by a few underlying factors. Identifying and assessing the magnitude of these factors provides a deeper insight into the phenomenon, and helps in formulating appropriate policies. Therefore, this study used the principal component analysis model.

A principal component analysis (Table 7) revealed four underlying dimensions in the adoption of the technology, which together explained about 74% of the variation in the configuration. Improved varieties, fertilizer application, proper placement of seed and fertilizer, summer cultivation, and plant protection measures were the key components in the first dimension, which explained about 31% of the total variation. Dry seeding was the major component in the second dimension, explaining nearly 16% of the total variation. The important component in the third dimension was double cropping, which accounted for 14% of the total variation. The least preferred practice was BBF, the fourth

Table 7. Factor patterns with technology adoption components.

Technology	Factor 1	Factor 2	Factor 3	Factor 4
Improved cultivars	.519	.102	-.218	-.163
Placement of seed and fertilizer	.473	-.359	.246	.097
Fertilizer application	.451	-.436	.210	.155
Summer cultivation	.390	.365	-.164	-.399
Plant protection	.363	.210	-.277	.130
Dry seeding	.099	.629	.299	.060
Double cropping	.390	.143	.807	-.236
Broadbed and furrow	.095	.278	.061	.839
% variation explained	31.3	15.6	14.3	12.5
Cumulative % variation explained	31.3	46.9	61.2	73.7

dimension. Researchers and policy planners should focus on technology components with higher loading values in the first dimension while least weightage should be given to components with low loading values. However, area needs have to be kept in mind vis-a-vis soil depth, percentage of clay, total rainfall, duration and intensity of rainfall, etc.

Rainfall

Vertisols are traditionally left fallow in the rainy season and cropped in the postrainy season on stored soil moisture. In 1981, 26 million ha of agricultural land was left fallow during the rainy season. Traditional fallowing exposes vertisols to severe erosion and leads to the underutilization of their production potential. The long-term operational-scale experiments at ICRISAT gave an excellent opportunity to validate the hypothesis that improved systems as a whole increase crop growth, crop production, carrying capacity of the land, improve soil quality, and carbon sequestration. Improper management of land and water adversely affects the adoption of vertisol technology. Vertisols improved management practices like BBF and also cropping systems. Integrated Pest Management (IPM) could record increased productivity which was mainly due to increased rainfall use efficiency (Singh 2001). It may thus be concluded that adoption of vertisol technology is higher in the medium-rainfall region.

Constraints to Adoption

Among the major constraints to adoption (Tables 8, 9, and 10) lack of awareness about benefits accruing from all the components figured

Table 8. Constraints to the adoption of vertisol technology in the low- rainfall region (% farmers).

Constraints	Summer cultivation	Double cropping	Dry seeding	Improved varieties	Fertilizer application	BBF	Plant Protection
Nonavailability of bullocks	20	-	-	-	-	-	-
Labor shortage	11	31	-	-	-	-	-
Lack of knowledge	6	9		31	19	69	26
Low germination	-	-	18	-	-	-	-
Lack of irrigation facilities	2	62	-	22	3	-	-
Waterlogging during rainy season	-	14	-	-	-	-	-
Lack of credit	3	14	-	16	45	-	32
Hard soil	-	-	-	-	-	-	-
Dry spell/ insufficient rainfall	-	46	48	-	30	-	-
Nonavailability of implements/ fertilizers/seed/insecticides/pesticides, etc.	-	-	-	31	14	26	18
Higher cost of labor/implements/ fertilizers/seed/insecticides/pesticides, etc.	-	-	-	24	40	13	31
Loss of seed due to late rainfall	-	-	30	-	-	-	-
Weeds	-	-	22	-	-	-	-
Gap filling	-	-	10	-	-	-	-
Seed damage by ants, insects, etc.	-	-	24	-	-	-	-
Loss of seed due to cracks in soil	-	-	8	-	-	-	-
Reduction in cultivated area	-	-	-	-	-	21	-
Preparing BBF every year	-	-	-	-	-	16	-
Maintaining BBF during heavy rains	-	-	-	-	-	14	-
No visible marginal rate of return	-	-	11	-	21	20	9
Poor grain quality and low market price	-	6	-	-	-	-	-

Table 9. Constraints to the adoption of vertisol technology in the medium-rainfall region (% farmers).

Constraints	Summer cultivation	Double cropping	Dry seeding	Improved varieties	Fertilizer application	BBF	Plant protection
Nonavailability of bullocks	12	-	-	-	-	-	-
Labor shortage	6	14	-	-	-	-	-
Lack of knowledge	8	4	14	24	8	63	22
Low germination	-	-	12	-	-	-	-
Lack of irrigation facilities	10	46	-	17	6	-	-
Waterlogging during rainy season	-	30	-	-	-	-	-
Lack of credit	-	10	-	12	29	11	15
Hard soil	5	-	-	-	-	-	-
Dry spell/insufficient rainfall	-	41	-	-	30	-	-
Nonavailability of implements/ fertilizers/seed/insecticides/ pesticides, etc.	-	11	-	29	11	32	24
Higher cost of labor/implements/ fertilizers/seed/insecticides/ pesticides, etc.	-	-	-	21	37	18	21
Loss of seed due to late rainfall			24				
Weeds			21				
Gap filling	-	-	11	-	-	-	-
Seed damage by ants, insects, etc.	-	-	16	-	-	-	-
Loss of seed due to cracks in soil	-	-	15	-	-	-	-
Reduction in cultivated area	-	-	-	-	-	28	-
Preparing BBF every year	-	-	-	-	-	31	-
Maintaining BBF	-	-	-	-	-	32	-
No visible marginal rate of return	-	-	-	-	17	11	8
Poor grain quality and low market price	-	5	-	-	-	-	-

Table 10. Constraints to the adoption of vertisol technology in the high-rainfall region (% farmers).

Constraints	Summer cultivation	Double cropping	Dry seeding	Improved varieties	Fertilizer application	BBF	Plant protection
Nonavailability of bullocks	12	-	-	-	-	-	-
Labor shortage	-	19	-	-	-	-	-
Lack of knowledge	9	-	23	27	12	66	12
Low germination	-	-	24	-	-	-	-
Lack of irrigation facilities	-	27	-	32	20	-	-
Waterlogging during rainy season	-	23	-	-	-	-	-
Lack of credit	10	17	-	21	17	26	19
Hard soil	24	-	-	-	-	-	-
Dry spell/ insufficient rainfall	-	14	-	-	17	-	-
Nonavailability of implements/ fertilizers/seed/insecticides/pesticides, etc.	-	9	-	41	28	31	24
Higher cost of labor/implements/ fertilizers/seed/insecticides/pesticides, etc.	-	-	-	30	29	34	22
Loss of seed due to late rainfall	-	-	37	-	-	-	-
Weeds	-	-	28	-	-	-	-
Gap filling	-	-	9	-	-	-	-
Seed damage by ants, insects, etc.	-	-	18	-	-	-	-
Loss of seed due to cracks in soil	-	-	-	-	-	-	-
Reduction in cultivated area	-	-	-	-	-	29	-
Preparing BBF every year	-	-	-	-	-	34	-
Maintaining BBF	-	-	-	-	-	31	-
No visible marginal rate of return	-	-	-	-	12	-	12
Poor grain quality and low market price	-	11	-	-	-	28	-

prominently in all the three rainfall regions. Results suggest the need for strong technology dissemination methods to convince farmers of the benefits of improved production and management technology options. Inadequate credit facilities too have restricted the adoption of many components of the technology. Timely and adequate supply of credit through Self-Help Groups (SGHs) would help. Farmers also faced problems of higher price and nonavailability of inputs like improved seed, fertilizers, implements, insecticides/pesticides, etc., which could be resolved by joint efforts by seed companies, agricultural scientists, extension workers, and other voluntary organizations. Some of the farmers had dug their own wells, but had no oil engines or electric motors to irrigate the postrainy-season or long-duration crop. A majority of the farmers was unaware of banking procedures. If farmers were to be educated and made aware of the bank loans available to purchase agricultural implements, a larger area can be expected to be covered under double cropping and improved varieties. No visible marginal rate of return was observed from fertilizer application, and the use of BBF and plant protection measures.

Wide infestation of weeds in fields sown just ahead of the monsoon was a major constraint to adopting dry seeding. With the onset of the monsoon, weeds grow in conjunction with the crop. So rapid is weed growth that weed control costs are a financial burden on the farmer. The other constraints to adopting dry seeding were loss of seed due to late rainfall and soil cracks; seed damage by ants, birds, insects, etc., and gap filling due to failure of seeds in some field plots, calling for further research on alternatives to dry seeding. Lack of knowledge, fall in cultivated area, and annual preparation of BBF and its maintenance during heavy rains were the constraints which resulted in very low adoption of BBF. As a result, most farmers followed traditional methods of draining excess water. Districts like Sholapur and Gulbarga did not face waterlogging, implying that the technology may be targeted for the needy areas.

Benefits of Vertisol Technology

On-farm Benefits

To assess the on-farm benefits of adopting vertisol technology, input and output data on adopters and nonadopters was collected with a focus on components such as summer cultivation, dry seeding, and BBF. The data sets were confined to the medium-rainfall region where adoption was quite impressive. The components were evaluated for all the three crops — maize, pigeonpea, and paddy. Details of the cost and returns from these crops in relation to the different components of vertisol technology are given in Tables 11 ,12 and 13.

Maize

Maize is an important crop which attracted the adoption of different components of vertisol technology. Farmers could harvest an impressive 43% higher yield by merely adopting summer cultivation in contrast to their counterparts who adopted no component of the technology (Table 11). The net income from maize was to the tune of Rs 5776 ha^{-1} in the case of adopters whereas it was only Rs 2428 ha^{-1} in the case of nonadopters. Adopting summer cultivation reduced unit cost of production by about 30%. A large share of the decline in cost may be ascribed to the reduced cost of weeding (by about 28%) due to summer cultivation.

The on-farm benefits of dry seeding in maize are summarized in Table 11. There was a nearly 16% gain in maize yield due to adoption of dry seeding. In a study in Vidarbha region of Maharashtra, Bhole et al. (1998) reported about 27 % higher yields in cotton due to dry seeding and 38% in sorghum. The net income per hectare of maize cultivated was more than double in the case of adopters compared to nonadopters. The relatively higher price of maize due to early harvesting, better yield, and lower cost of cultivation was responsible for the higher net incomes of adopters. Higher yields and lower total cost of cultivation also resulted in a 24% fall in unit cost of production. However, an increase in the cost of weeding (4%) was warranted. Severe weed problems were reported by Joshi et al. (1998) in plots that were dry seeded. More agronomic and entomological research is therefore called for to control weed infestation. The participation of female labor in marketing was noticed. It can therefore be inferred that dry seeding is not a constraint in economic terms, even though many farmers avoid it due to the risk of losing their seeds and weed infestation. The cost of weeding on dry sown fields was 4% higher than on normally sown fields. In Madhya Pradesh, Foster et al. (1987) observed higher costs due to gap filling and intensive weed management in dry sown fields. Nonavailability of labor for manual weeding during the peak season discouraged farmers from adopting dry seeding on a large scale. Therefore, alternative methods like hand weeding, mechanical weeding, and chemical control are required. If the weed problems originating in dry seeding are overcome, the payoffs could be in the form of substantial increases in area.

Summer cultivation followed by dry seeding enhanced maize yields by 39%. Together, these two components increased net income threefold. There was a 36% reduction in unit cost and 9% decline in cost of weeding. The declining weeding cost could be attributed to summer cultivation.

The economic feasibility of BBF in the existing cropping system was also assessed. None of the maize growers adopted BBF alone; it always followed summer cultivation. Only two farmers adopted BBF. Nonadoption was because surface waterlogging was not a serious constraint in the study area. BBF yielded positive benefits wherever drainage problems arose. Results revealed that adoption of summer cultivation and BBF increased maize yield by about 18%. Similarly, the net income per hectare of maize cultivated was nearly double that of the nonadopting farmers. The unit cost of production fell to 27% and the cost of weeding to 20%. Despite these benefits, farmers did not adopt this method due to lack of awareness. It was also found that the BBF system is difficult to maintain through the rainy season. However, an in-depth study of its contribution to improving the sustainability of soil and water resources is needed. In terms of relative profitability of maize, the adoption of summer cultivation and dry seeding together showed the highest net income (Rs 7433 ha^{-1}) compared to all other technology options.

Pigeonpea

Table 12 presents the comparative economics of pigeonpea using different components of vertisol technology. A very limited number of farmers adopted the different components of the technology since there were fewer pigeonpea growers. Since none of the pigeonpea growers was a nonadopter of even one component, a comparison of profitability was made between different components of the technology. There was no significant difference in pigeonpea yield between the adopters of summer cultivation and those of dry seeding. However, adopting dry seeding was more profitable as it gave 6% higher net income with a 10% reduction in unit cost of production. On the

Table 11. On-farm benefits of various components of vertisol technology in maize.

Components of vertisol technology	Yield (kg ha^{-1})	Price (Rs kg^{-1})	Gross returns (Rs ha^{-1})	Cost (Rs ha^{-1})	Net income (Rs ha^{-1})	Unit cost (Rs t^{-1})	Human labor cost (Rs ha^{-1})	Female labor cost for marketing (Rs ha^{-1})	Cost of weeding (Rs ha^{-1})
Summer cultivation	1939	5.37	12955	7179	5776	3703	1152	11.39	139
Dry seeding	1572	5.61	11520	6340	5180	4032	1066	2.06	200
Summer cultivation + dry seeding	1885	5.81	13790	6356	7433	3373	930	3.53	176
Summer cultivation + BBF	1605	5.11	10904	6180	4725	3851	965	2.08	154
None	1357	5.44	9624	7196	2428	5304	1363	-	193

Table 12. On-farm benefits of various components of vertisol technology in pigeonpea.

Components of vertisol technology	Yield (kg ha^{-1})	Price (Rs kg^{-1})	Gross returns (Rs ha^{-1})	Cost (Rs ha^{-1})	Net income (Rs ha^{-1})	Unit cost (Rs t^{-1})	Human labor cost (Rs ha^{-1})	Female labor cost for marketing (Rs ha^{-1})
Summer cultivation	867	18.01	15808	7239	8570	8347	1172	9.86
Dry seeding	881	17.69	15729	6647	9082	7544	1017	5.93
Summer cultivation + dry seeding	823	18.13	15101	7439	7662	9035	1373	9.88
Summer cultivation + BBF	694	16.61	11700	8026	3675	11564	1302	14.82

other hand, farmers adopting summer cultivation experienced a 39% reduction in weeding cost. The findings are in conformity with the results obtained in maize, and with farmers' perceptions of the constraints to summer cultivation and dry seeding. Surprisingly, pigeonpea growers found only summer cultivation economical, rather than summer cultivation and dry seeding together. A study of a larger sample of pigeonpea growers would give more meaningful results. Adopting only summer cultivation provided higher yields (by 25%), net income (by 133%), and a reduction in unit cost of production (by 28%) compared to the sequential adoption of summer cultivation followed by BBF. However, it was found that adopting these two components together reduced weeding cost by 6%. Introducing BBF could have reduced weeding cost, since similar results were obtained in the case of maize. It can thus be concluded that the problem of weeds can be greatly minimized by adopting BBF. Based on their three-year research station experiment in Gujarat, Desai et al. (2000) concluded that providing one furrow after four rows of pigeonpea recorded significantly higher yields compared to flatbed cultivation. Foster et al. (1987) found that the profits from fields with BBF were not significantly different from those from plots cultivated flat-on-grade. Ryan el al. (1980) reported that using the BBF system on vertisol watersheds with an intercrop of maize/pigeonpea was about 20% more profitable than using the flatbed system. Since BBF benefits areas that are excessively waterlogged, its use should be assessed in the long run, covering techno-economic feasibility and sustainability issues under different intercrops and crop sequences.

Dry seeding alone contributed the most in terms of yield, net income, and unit cost reduction compared to summer cultivation + dry seeding or summer cultivation + BBF. However, weed infestation was found to be high when dry seeding alone was adopted.

Comparing summer cultivation + dry seeding with summer cultivation + BBF in pigeonpea revealed that the former was more profitable. Summer cultivation + dry seeding gave significantly higher yields and net income per hectare, and reduced unit cost of production compared to summer cultivation + BBF. However, weeding cost was about 35% higher in the former compared to the other group of components. This was obviously because of adopting dry seeding.

Table 13. On-farm benefits of various components of vertisol technology in paddy.

Components of vertisol technology	Yield ($kg\ ha^{-1}$)	Price ($Rs\ kg^{-1}$)	Gross returns ($Rs\ ha^{-1}$)	Cost ($Rs\ ha^{-1}$)	Net income ($Rs\ ha^{-1}$)	Unit cost ($Rs\ t^{-1}$)	Human labor cost ($Rs\ ha^{-1}$)	Cost of weeding ($Rs\ ha^{-1}$)
Summer cultivation	2729	5.25	14475	12466	2009	4569	2138	309
None	2519	4.90	12508	11504	1004	4567	2111	422

Paddy

In the case of paddy, none of the components except summer cultivation was adopted by the respondents. About 44% of the paddy growers followed it. The results of on-farm benefits of summer cultivation in paddy are presented in Table 13. An 8% gain in paddy yield was realized due to summer cultivation, whereas the net income per hectare of paddy for adopters of summer cultivation was two times that of nonadopters. Both price and yield of paddy contributed higher net incomes to the adopters. No significant reduction in unit cost of production was noticed with the adoption of summer cultivation. This was because the cost of land, seedbed preparation as well as the expenditure on chemical fertilizers were significantly higher, resulting in higher cost of cultivation.

Sustainability Benefits

Vertisol technology has many sustainability benefits apart from the direct economic ones which accure to farmers. Tables 14, 15, and 16 reveal farmers' perceptions about the sustainability benefits of different components of the technology. Improving soil and water conservation by adopting summer cultivation was advocated by 52-64% of the farmers, and 6-25% of them were in favor of BBF in the three different regions. Many farmers felt that summer cultivation, double cropping, and BBF would enhance soil fertility. Similarly, effective use of rainwater by adopting double cropping, dry seeding, BBF, and proper placement of seed and fertilizers was reported. About 35% of the farmers in the low-rainfall region and 46% in the medium-rainfall region opined that if seeds and fertilizer were properly placed, it would help in enhancing fertilizer use efficiency and good crop stand establishment. About 13% (low-rainfall region) to 32% (medium-rainfall region) of the farmers felt that double cropping helps prevent soil erosion. Many farmers observed higher yields/profits by adopting different components of vertisol technology. This suggests that its impact on the output marketing system may be studied to anticipate any drastic price effects and also to improve marketing facilities. Collaborative research is required to quantify soil benefits from soil and water conservation.

Conclusions and Lessons for the Future

Though it was observed that some of the components of vertisol technology were known to the farmers even prior to 1980, the extent of adoption was much

Table 14. Sustainability benefits from components of vertisol technology in the low -rainfall region (% farmers).

Sustainability benefits	Summer cultivation	Double cropping	Dry seeding	BBF	Proper placement of seed and fertilizers
Improves soil and water conservation	64	-	-	6	-
Increases soil fertility	35	23	-	10	-
Effective use of rain water	-	28	22	18	24
Prevents nutrient mining	-	-	-	-	35
Prevents soil erosion	19	13	-	-	-
Reduces soilborne diseases/ pests, etc.	22	-	-	-	-
Controls weeds	30	-	-	-	11
Higher yield/profit	16	41	19	-	20

Table 15. Sustainability benefits from components of vertisol technology in the medium- rainfall region (% farmers).

Sustainability benefits	Summer cultivation	Double cropping	Dry seeding	BBF	Proper placement of seed and fertilizers
Improves soil and water conservation	55	-	-	25	-
Increases soil fertility	32	26	-	13	-
Effective use of rain water	-	21	45	17	15
Prevents nutrient mining	-	-	-	-	46
Prevents soil erosion	23	32	-	-	-
Reduces soilborne diseases/ pests, etc.	26	-	-	-	-
Controls weeds	27	-	-	-	14
Higher yield/profit	13	29	22	10	23

Table 16. Sustainability benefits from components of vertisol technology in the high-rainfall region (% farmers).

Sustainability benefits	Summer cultivation	Double cropping	Dry seeding	BBF	Proper placement of seed and fertilizers
Improves soil and water conservation	52	-	-	8	-
Increases soil fertility	21	19	-	-	-
Effective use of rain water	-	34	5	6	18
Prevents nutrient mining	-	-	-	-	33
Prevents soil erosion	9	20	-	-	-
Reduces soilborne diseases/ pests, etc.	23	-	-	-	-
Controls weeds	25	-	-	-	10
Higher yield/profit	14	33	-	-	15

higher only after 1980. In general, farmers of the medium-rainfall region were found to-be early adopters; the proportion of farmers who adopted different components of the technology too was relatively higher in this region. This implies that earmarking appropriate ecoregions for a given technology would ensure its wider adoption. Among the most important and widely adopted components were placement of seed and fertilizer, improved varieties, fertilizer application, and summer cultivation. The adoption of dry seeding and BBF was reported only in the medium-rainfall region. BBF was used only by farmers with drainage problems in their fields. Future research on dry seeding and BBF should concentrate on the ecoregion where the specific problems exist.

Vertisol technology was found to favor large farmers since only they could afford it; small farmers faced several resource constraints. Future research should therefore focus on the small farmer in order to make the technology more accessible.

Vertisol technology as a complete package was not adopted by the sample farmers; only its components were widely adopted by different groups of farmers at different locations. Similar findings were reported by Joshi et al. (1998). A stepwise adoption of various technology options was also observed.

The several constraints to the adoption of different components of the technology need attention in order to ensure widespread adoption of the technology. The NARS and the State Department of Agriculture may provide appropriate technology domains by identifying the existing constraints in different regions.

Many sustainability benefits were reported; however they may only contribute to enhancing yields in the long run. So future research will have to address the reassessment of such benefits, covering techno-economic feasibility and the sustainability issues under different rainfall regions.

Farmers adopting either summer cultivation or dry seeding enjoyed better yields, higher net incomes, and a reduction in unit cost of production compared to their counterparts. The relatively higher cost of weeding due to dry seeding suggests the need for collaborative research by agronomists, entemologists, and plant pathologists to overcome weed infestation. Summer cultivation followed by dry seeding was found more profitable than summer cultivation followed by BBF. This implies that dry seeding has a greater bearing on crop yields in dryland areas compared to BBF.

Results of the principal components analysis indicated the existence of four underlying dimensions in the adoption of vertisol technology. Improved varieties, fertilizer application, proper placement of seed and fertilizers, etc., were the key components in the first dimension. Constraints to their adoption could be eliminated with the help of technical improvements. Some constraints like the nonavailability of fertilizers and seeds of improved varieties require intervention from public agencies. Voluntary organizations may take the lead in helping farmers of dryland agriculture.

The future research agenda will have to include impact assessment in terms of transforming technology and its implications on food security and poverty alleviation. Quantifying the social benefits from vertisol technology would be important, as it would justify incentives and policy initiatives to enhance adoption. Refinement of technology and policy research by NARS in collaboration with ICRISAT are called for.

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