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Abstract

Deep Vertisol regions in India with dependable rainfall are characterized by the widest gap between actual and potential production among dryland farming regions. This paper provides an updated economic assessment of a set of technological options targetted for those regions. Investing in such dryland technological options may be much more socially profitable than inveting in larger irrigation schemes in these regions.

The assessment is based on results of watershed-based verification trials and tests carried out collaboratively by ICRISAT, state departments of agriculture, and other institutions in Andhra Pradesh, Karnataka, and Madhya Pradesh during 1979-83. The profitability of traditional and improved technology options are compared, and the untapped economic potentials of some cropping systems are illustrated.

Issues relating to technology generation and transfer are also examined with information from the verification trials. Several questions have to be answered before these technology options can find a home in farmers' fields. Most require input from economists and several specific interdisciplinary research studies are described. The paper concludes by pointing out institutional changed that are needed to accommodate a watershed approach to technology testing and transfer in these high production potential dryland cropping regions.

The Economics of Deep Vertisols Technology Options: Implications for Design, Testing, and Transfer*

T.S. Walker, J.G. Ryan, K.G. Kshirsagar, and **

Introduction

One of the greatest challenges for agricultural researchers, extensionists, bankers, and policymakers in India is to develop, adapt, and transfer technologies to the rainfall-assured, deep Vertisol regions, which we believe are characterized by the widest gap between potential and actual production of any dryland farming region in India. This paper provides an updated economic assessment of one set of technological options, which were initially developed and tested at ICRISAT Center in the 1970s and which are targeted for those regions1. A detailed description and analysis of the that production environment, the improved technological options, their performance in ICRISAT Center and in an on-farm verification trials in 1981-82, and related policy

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issues are contained in Ryan, Virmani, and Swindale (1982). Our presentation supplements their discussion and is based largely on results from on-farm watershed-based trials and tests of the technological options during 1979-84.

We briefly describe the wet deep Vertisol production environment and the technological options in the next section. We then analyze economic aspects of the on-farm verification trials and tests, and go on to evaluate farmer participation. Implications for technological design and for investment alternatives, testing, and transfer are then presented. We conclude by identifying several problem areas for further economic research.

Potential of the Deep Vertisol Production Environment and the Improved Technological Options

The improved technological options are an outcome of research that addresses the problem of rainy season (kharif) fallowing on deep black, shrink-swell soils, scientifically called Vertisols[2]. Kharif fallowing on deep Vertisols may be due to too much or too little rain. Virmani et al. (1981) have divided Vertisols into (1) wetter areas with relatively dependable rainfall, usually meaning an average annual rainfall of over 750 mm; and (2) drier areas with relatively unreliable rainfall, usually implying a mean annual rainfall less than 750 mm.

The improved technological options for the wetter regions are based on the premise that poor field surface drainage on deep Vertisols in medium and high rainfall areas is a severe constraint to kharif cropping. An investment in land leveling, and in field and community drains, together with cultivation on graded broadbeds and furrows, should result in improved drainage and better in situ moisture conservation. These measures allow farmers to grow two crops instead of one with sequential cropping, or add three months to the growing season with intercropping. A social benefit accruing from more kharif cropping is reduced soil erosion. Two other prerequisites for the success of the improved technology are dependable early-season rainfall for dry seeding, and deep soils with enough water-holding capacity to produce two crops without irrigation.

Although there are no reliable data on the size of the deep Vertisol regions with dependable rainfall, Ryan et al. (1982) estimate that it ranges in India from 5 to 12 million ha. It covers large areas of Madhya Pradesh and parts of Andhra Pradesh, Maharashtra, and Karnataka.

The improved technology is carried out on small watersheds, generally ranging from 3 to 25 ha. The package of improved technological options includes the following components:

1. postharvest cultivation following the postrainy season rabi crop;

2. land smoothing and shaping, construction of field and

community drains, and the use of graded broadbeds and furrows;

3. dry seeding before the monsoon;

4. use of improved cultivars and moderate amounts of fertilizer;

5. improved placement of seeds and fertilizer; and

6. timely plant protection.

Most of these practices are implemented with a bullock-drawn wheeled tool carrier. Therefore, engineering, agronomic, biological, and mechanical components comprise the package, which is complex but flexible enough to adjust to location-specific conditions.

The production potential of the higher rainfall deep Vertisol regions is reflected in the economic data reported in Table 1, which is based on 1981-82 results of a long-term, operational-scale experiment to assess the performance of cropping systems under different soils at ICRISAT Center under two fertility regimes (ICRISAT 1983). Based on past results and experience, the most promising cropping systems were selected for testing in operational-scale plots. On average, the "best-bet" cropping systems grown in deep Vertisols gave net returns 20 and 30% higher under medium and low fertility than their nearest competitors planted in medium deep Vertisols. In terms of economic productivity, one ha of deep Vertisols in 1981-82 at ICRISAT Center was worth about 1.50 ha of Alfisols under low fertility, and 1.85 ha under medium fertility. Nine of the 11 cropping systems planted in deep Vertisols with medium fertility gave net returns that exceeded Rs 4000/ha (Table 1). Similar comparative results across soils were obtained at ICRISAT Center in 1982/83[3].

The operational significance of the unexploited production potential of the Vertisol region with dependable rainfall is that it may be feasible to use a package approach with several clusters of improved technological options to markedly increase productivity. Such opportunities are rare in dryland agriculture in the SAT.

Economic Results from On-Farm Verification Trials and Tests

The on-farm verification of the technological options on deep Vertisols can be divided into three stages. The initial on-farm tests in 1979-80 and 1980-81 were conducted across a fairly wide range of soil, rainfall, and crop environments in three villages, where the Economics Program had initiated socioeconomic enquiries and posted resident investigators since 1975-76. Succeeding verification efforts focused on a few sites in deep Vertisol regions. These trials are carried out collaboratively by ICRISAT, state departments of agriculture, and other institutions in Andhra Pradesh, Karnataka, and Madhya Pradesh. On their own initiative, the state departments of agriculture in Andhra Pradesh, Karnataka, and Maharashtra started tests in 1982-83.

Table 1. Production potential in net returns (Rs/ha) of different soils under medium and low fertility in operational-scale plots at ICRISAT Center, rainy and postrainy seasons 1981/82.

Production potential	Resource base: Deep Vertisols L[1]	Deep Vertisols M[2]	Medium-deep Vertisols L[1]	Medium-deep Vertisols M[2]	Shallow Vertisols L[1]	Shallow Vertisols M[2]	Alfisols L[1]	Alfisols M[2]
Average net returns (Rs/ha)	2836	4326	1981	3614	1378	2503	1916	2342
Number of cropping systems tested	11		6		6		10	
Number of cropping systems where average net returns								
> 2000 (Rs/ha)	9	11	3	5	2	3	4	5
> 3000 (Rs/ha)	4	10	3	3	1	2	2	3
> 4000 (Rs/ha)	1	9	0	3	0	1	1	1

1. Low fertility refers to N-P_2O_5-K of 0-0-0.

2. Medium fertility refers to N-P_2O_5-K of 60-30-0.

Source: Data adapted from ICRISAT 1983, Annual report 1982.

ICRISAT offered technical help on one site in each state. In 1983, the testing program was expanded to sites in 28 districts of Andhra Pradesh, Karnataka, Maharashtra, and Madhya Pradesh (Naidu 1983).

Comparing Profitability of Improved and Traditional Technology Options

The early on-farm tests in Aurepalle, Kanzara, and Shirapur provided information on where the improved technological options best suit regional soil and rainfall conditions. Although some components, such as high yielding varieties (HYVs) and precision placement of fertilizer, significantly increased yields in some sites, particularly in the Alfisols of Aurepalle, the complete package of practices was not remunerative in the initial on-farm tests (Sarin and Ryan 1983). In 1979-80, marginal rates of return on additional investment with the improved technology were negative (Table 2); in 1980-81 marginal returns were positive but not attractive. Kharif cropping is widely practiced in Aurepalle and Kanzara, where drainage is not a constraint. In contrast, kharif fallowing is common in Shirapur, even though rainfall is low and undependable. Subsequent base data analysis (Binswanger, Virmani, and Kampen 1981) shows that kharif cropping is too risky to be economically attractive in the Sholapur region[4].

Table 2. Comparing the profitability of improved deep Vertisol technology options with traditional farm practices in seven watershed tests from 1979-80 to 1982-83.

Watershed test site description					Comparative profitability						
					Weighted average profits[1]			Operational cost			Marginal rate of return %
Village (District, State)	Year	Area (ha)	Farmers (no.)	Soil (Rainfall)	Improved	Traditional	Difference	Improved	Traditional	Difference	
Aurepalle (Mahbubnagar, Andhra Pradesh)	1979-80 1980-81	13.5 11.9	5	Alfisols (Unassured)	299 373	318 123	-19 250	898 953	251 284	647 669	Negative 37
Shirapur (Sholapur, Maharashtra)	1979-80 1980-81	13.9 10.5	8	Deep Vertisols (Unassured)	211 1345	355 619	-144 726	1313 912	220 269	1093 643	Negative 113
Kanzara (Akola, Maharashtra)	1979-80 1980-81	3.7 10.8	3	Medium deep Vertisols (Assured)	539 343	976 268	-437 75	1418 1480	643 588	775 892	Negative 8
Taddanpally (Medak, Andhra Pradesh)	1981-82 1982-83	14.5	12 4	Deep Vertisols (Assured)	3055 3957	1625 1722	1430 2235	1181 1035	595 448	586 587	244 381
Sultanpur (Medak, Andhra Pradesh)	1982-83	26.7	12	Deep Vertisols (Assured)	3576	1722	1854	1062	448	614	302
Farhatabad (Gulbarga, Karnataka)	1982-83	17.5	3	Deep Vertisols (Semiassured)	3323	2186	1137	1194	1142	52	-[3]
Begumgunj (Raisen, Madhya Pradesh)	1982-83	24.0	10	Deep Vertisols (Assured)	1172	786	386	2348	866	1482	26

1. For the first three test sites, profitability is measured in net profits where the initial development costs of the watershed are amortized and deducted from weighted average gross profits (Sarin and Ryan 1981). For the last four sites, profitability is measured in gross profits. Because development costs range from only Rs 200 to 1000 per hectare, use of net or gross profits gives about the same results.

2. Detailed results by cropping systems are found in Appendix Tables 1,2,3, and 4. For Aurepalle, Shirapur, and Kanzara results by cropping system are given in Sarin and Ryan (1983). See Ryan et al. (1982) for cropping systems results for Taddanpally 1981-82.

3. Differences in operational cost too meager to make a meaningful comparison.

Based on this and other information, later verification efforts focused on the higher rainfall deep Vertisol fallow regions where rainy season cropping is likely to be constrained by poor drainage. In the Taddanpally and Sultanpur test sites, the improved technological options performed well. An additional investment in operating cost of about Rs 600/ha generated incremental returns of between Rs 1500 and Rs 2000/ha during 1981-82 and 1982-83 (Table 2). The technology also performed well in Anthwar, another watershed test site in Medak district, where the Andhra Pradesh State Department of Agriculture carried out a verification trial with seven farmers in 1982-83. The Anthwar verification test was expanded to 45 farmers in 1983-84.

Despite their low relative profitability, the improved technological options showed considerable promise in the Begumgunj watershed in Madhya Pradesh during 1982-83. An early season drought in late June and early July, followed by uninterrupted rain in mid- to late-July and August, led to poor stand establishment and ineffective weed control; it was also not possible to top-dress fertilizer (Heinrich and Sangle 1983). Yet, several encouraging signals emerged from the Madhya Pradesh experience in 1982-83. First, some cropping systems, particularly the soybean/pigeonpea intercrop, performed well with profits over Rs 3300/ha (Appendix Table 4). Secondly, grain yields in a companion cropping systems experiment ranged from 3 to 4 t/ha in some treatments (Heinrich and Sangle 1983, courtesy M.S. Reddy). Thirdly, farmers netted profits of only about Rs 800/ha with their traditional practices in 1982-83; profits from the use of traditional practices in the other watershed sites were much higher in Andhra Pradesh and Karnataka (Table 2 and Appendix Tables 1,2, and 3). Hence, there appears to be a substantial margin for improvement in the dependable rainfall, deep Vertisol regions of Madhya Pradesh, compared to similar agroclimatic and soil areas in Andhra Pradesh and Karnataka. Lastly, 8 of the 10 farmers in the verification test during 1982-83 decided to participate in these trials during 1983-84[5]. To realize this potential, a greater investment in adaptive research is needed over space and time.

Exploiting Cropping Systems Potential

Although the deep Vertisol technology options generated handsome economic rates of return in the Taddanpally and Sultanpur tests, the potential of the improved cropping systems was not fully tapped. The most important determinant of profitability in the improved cereal/pigeonpea intercrop in Andhra Pradesh is effective *Heliothis* (pod borer) control. Farmers in Taddanpally and Sultanpur relying on existing support service sprayed endosulfan several times to control a heavy *Heliothis* infestation and averaged a yield of about 450 kg/ha of pigeonpea. Researchers in a large field trial in the watershed compared the effectiveness of *Heliothis* control with three different types of sprayers (Pulse Entomology 1983). Timely spraying with only two applications of endosulfan reduced losses from *Heliothis*, as yields ranged from 1150 to 1250 kg/ha across the three types of sprayers. These results suggest that poor control of *Heliothis*

Table 3. Cropping pattern chosen by farmers in Sultanpur and Taddanpally watersheds during the first, second, and third year of participation in the on-farm tests.

Year of participation	Cropping pattern: Kharif cereal plus intercrop or rabi sequential crop	Kharif pulse plus rabi sorghum[1]	Noncereal-based cropping system[2]
	———% of total land in the watershed test———		
First year[3]	65	14	21
Second year[4]	17	47	36
Third year[5]	0	39	61

1. Refers to mung bean or black gram.
2. Includes fallow-chillies, black gram/pigeonpea intercrop, mung bean-chickpea sequence, mung bean-chillies sequence, and mung bean-safflower sequence.
3. Refers to Taddanpally 1981-82 and Sultanpur 1982-83.
4. Refers to Taddanpally 1982-83 and Sultanpur 1983-84.
5. Refers to mung bean or black gram.

pod borer reduced yields by 700 to 800 kg/ha, which is equivalent to a loss of about Rs 2500/ha in profits at 1983-84 prices.

A less explicit source of untapped economic potential concerns the choice of cropping system. In the first year of the watershed test in Taddanpally and Sultanpur, farmers planted 65% of the watershed to systems that featured a kharif cereal, usually sorghum, that was either intercropped or sequentially sole cropped with a kharif pulse (Table 3). In the second and third year, farmers reverted to their more traditional practice of planting rabi sorghum or sowed a noncereal-based crop, usually a kharif fallow-chillies sequence.

Considerations of crop rotation may have played a role in conditioning the choice of rabi sorghum and chillies during the last few years, but we believe that there is a fundamental difference in perception between researchers and farmers on the relative profitability of kharif cereal and more traditional rabi-based cropping systems. In operational scale trials at ICRISAT, kharif cereal-based cropping systems have consistently performed better than other cropping systems on deep Vertisols. For example, in 1981-82, under medium fertility, eight kharif cereal-based cropping systems generated returns that averaged Rs 4600/ha (ICRISAT, 1983). In contrast, sequential cropping of mungbean-rabi sorghum yielded returns of Rs 2600/ha, while that of mungbean-chilles yielded Rs 3,400/ha. These differences were also reflected in the Taddanpally and Sultanpur watersheds. On an average, profits from kharif cereal-based cropping systems exceeded profits from other, usually more traditional, cropping systems by 25%. Apparently, the perceptions economists and agronomists have of the relative profitablity of alternative deep Vertisol cropping systems are not shared by farmers in Taddanpally and Sultanpur.

Assessing Risk

The appropriate yardstick for assessing risk in the improved deep Vertisols technology options is the measurement of fluctuations in relative profitablity over time. Such measurement from ICRISAT Center shows that the standard deviation of profits increased with the improved system, compared to the traditional practices of farmers, but the coefficient of variation (CV) of profits fell from 55 to 25% (Ryan et al. 1982). Thus, the improved technological options tried out at ICRISAT Center were not relatively more risky than the farmers' traditional practices. We do not have enough observations in the same watershed to carry out a risk assessment over time; however, farmers may equate risk with field-to-field variability they observe in the improved watershed plots within the same cropping year. From the estimated CVs in Table 4, we see that the improved technological options compared favorably with farmer practices in three of the four watershed X cropping year combinations.

The exception was the Begumgunj verification site, where plot-to-plot variability in profits was more than in neighboring farmers' fields. Farmers in this watershed also stood a greater

Table 4. Risk assessment between improved watershed plots and traditional farmers' fields in watershed test sites.

Watershed	Cropping year	Number of fields		CV of gross profits	
		Improved watershed	Tradi-tional	Improved watershed	Tradi-tional
Taddanpally	1981-82	26	17	45	61
Taddanpally and Sultanpur	1982-83	35	13	37	32
Farhadabad	1982-83	8	15	22	30
Begumgunj	1982-83	17	21	102	83

chance of incurring losses than neighboring farmers who practiced kharif fallowing. Although the improved technology options were on average more profitable, they were also more risky. The relative riskiness of tested sequential cropping systems in 1982-83 probably partially explains the popularity of the improved soybean/pigeonpea intercropping system in 1983-84. For the seven fields planted to soybean sequential crop systems, the CV of gross profits was 345%; for the ten fields planted to the intercrops, the CV of gross profits was 35%. In 1982-83, intercrops accounted for about 50% of the total area planted in the watershed; in 1983-84, soybean and pigeonpea were intercropped on 64% of the watershed area. This potential conflict between risk and profitability further highlights the need for more adaptive cropping systems research in Madhya Pradesh.

Developing the Watershed

The development cost of the on-farm watershed test sites ranged from about Rs 200 to 1000/ha (Table 5). The higher cost in Begumgunj in Madhya Pradesh reflected the need for greater drainage associated with a higher rainfall environment and the substitution of more expensive tractors for cheaper bullocks in forming the watershed. Even at Rs 1000/ha the cost of watershed development is attractive when compared to an investment in irrigation, as the Sixth Plan envisages an average capital cost (at 1979/80 prices) of about Rs 15000/ha to provide surface irrigation (Abbie et al. 1982).

Table 5. Development costs incurred in the first year of the test watershed sites.

Watershed test site	Cost Component (Rs/ha) Land smoothing	Main and field drains	Forming broadbeds and furrows	Surveying and other expenses	Total
Aurepalle	76	64	156	-[1]	296
Shirapur	126	211	91	-[1]	428
Kanzara	32	27	150	-[1]	209
Taddanpally	9	96	92	57	254
Sultanpur	39	105	28	50	222
Farhatabad	45	13	114	10	182
Begumgunj	153	487	320	75	1035

1. Not computed as this activity was carried out by ICRISAT.

Farmer Participation in Testing the Technology Options for Deep Vertisols

The watershed verification tests provide a forum for farmers to express their beliefs on the relative performance of the improved technological options in their fields. Participation each year in the verification test is voluntary, and the perceptions of farmers on how well the tested technology performs are expected to significantly influence decisions on participation[6].

Levels of Participation

It is too much to expect that every farmer will remain in the verification test each year, just as it is too much to hope that every participant will accept every component of the tested technology. There are no hard and fast guidelines about a desirable rate of technology acceptance based on verification tests; however, Hildebrand considers that a technology should be recommended if 25% of the farmers in on-farm verification tests use the improved technology on at least 25% of their land in the following year[7]. In the three larger verification trials in the dependable rainfall, deep Vertisol regions, 16 of the original 31 decisionmaking participants have continued in the trial in the succeeding year (Table 6). A 50% level of participation suggests that there is scope for wider diffusion of the technology.

Determinants of Participation

Table 6. Farmer participation in the watershed tests.

Test site	Year	Participation			
		Farmers		Land	
		Number	% of total[1]	Total area owned (%)	% of total[1] land in the watershed
Taddanpally	1982-83	4	36	5.50	38
Taddanpally	1983-84	4	36	5.50	38
Sultanpur	1983-84	4	33	7.08	27
Begumgunj	1983-84	8	80	16.20	68

1. Based on the number of farmers and area covered in the first year of development of the watershed.

contributes to kharif fallowing. Therefore, it is important to assess the perceptions of farmers on field drainage before and after the improved technology is tested in the watershed. Results from an early acceptance study (Sarin and Walker 1982) of the Taddanpally watershed illustrate the relative importance of their perceptions on drainage. There were 18 plots in the Taddanpally watershed in 1981-82; before watershed work started in 1981-82, farmers perceived that poor drainage was more of a problem in some plots than in others. All farmers agreed that the new land-and water-management practices improved field drainage on all their plots. But not all farmers felt that poor drainage in the past had been a major problem on some of the plots. We expected that participation in 1982-83 would be greater for those farmers who believed that poor field drainage was a constraint to rainy-season cropping on their individual plots. This expectation was tested with the simple decision model presented in Figure 1.

For 10 of the 18 plots, farmers said that drainage was not a constraint to rainy-season cropping. We predicted that farmers owning these plots had less incentive to participate in 1982-83 and 1983-84 than farmers cultivating fields where they thought drainage was a problem. A negative response to the drainage question in Figure 1 was associated with nonparticipation for 8 of the 10 fields. The other two plots belonged to participants who perceived that drainage was inadequate in their other plots in the watershed. For an affirmative response, we further queried whether management practices taken in previous years were

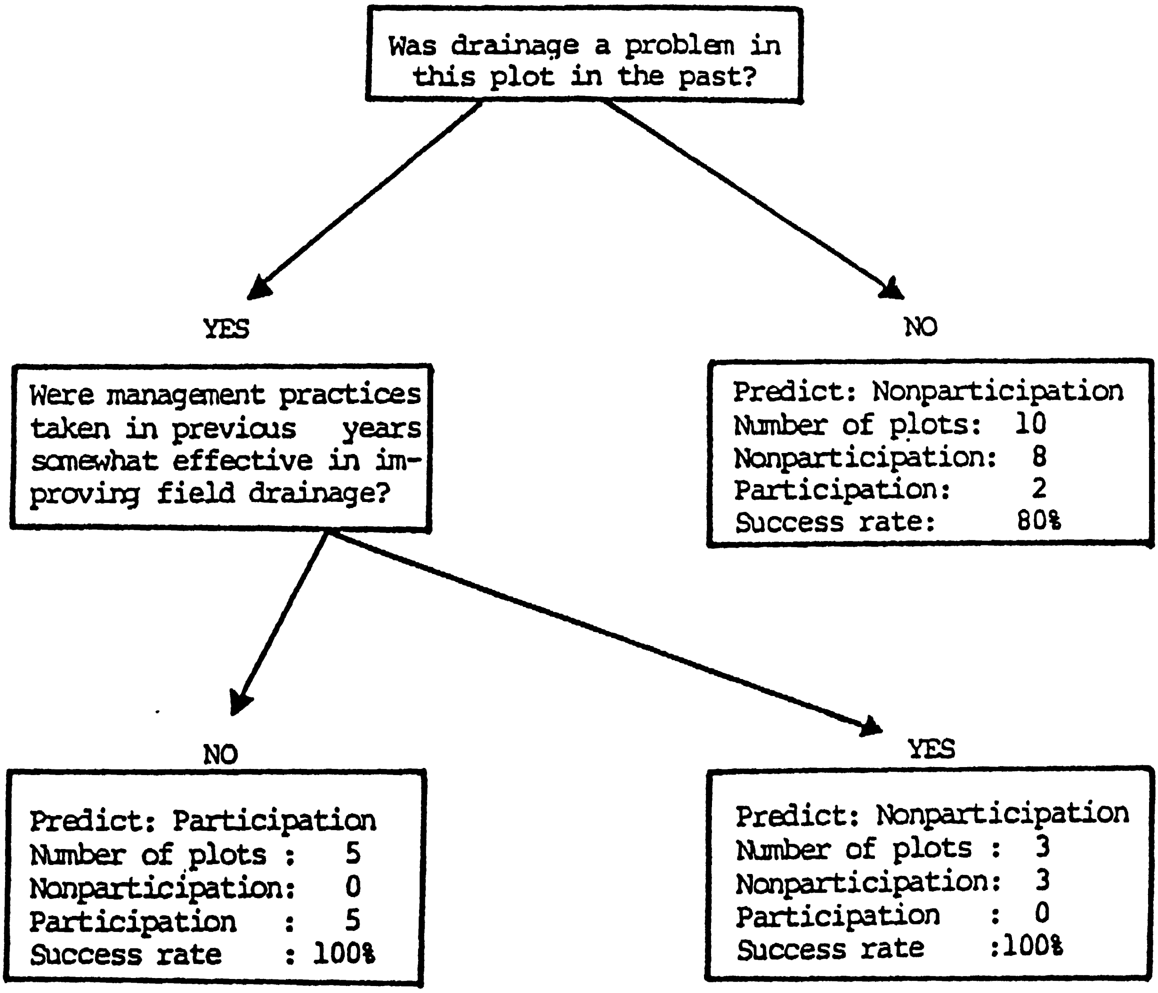

Figure 1. Perceptions on field drainage and participation in 1982-83.

Source: Sarin and Walker (1982).

partially effective in improving field drainage. A positive reply was seen to be consistent with a prediction of nonparticipation, while a negative response suggested participation. For these eight plots, predictions were consistent with the decisions on participation.

Based on this model, we could successfully predict participation on 16 of the 18 plots. These results strongly suggest that participation in 1982-83 was influenced by the farmers' perception of the status of field drainage in the past. While nonparticipants thought that drainage was not a problem, participants believed it was.

Participants were also quick to point out that poor field drainage was not the only, or even the most important, constraint to rainy-season cropping. Inadequate field drainage may have caused rainy-season fallowing, but other constraints, such as weed and insect management problems, may have been more limiting.

Economic Input into Design Questions

One of the principal aims of involving economists in interdisciplinary farming systems research is to improve the quantity and quality of information flowing from farmers to researchers, so that technological options are designed and modified according to farmers' circumstances. With regard to the deep Vertisol technological options, economists have carried out baseline surveys featuring watershed plot histories, partial budgets comparing the profitability of improved options and traditional farm practices (Sarin and Ryan 1983), early acceptance studies monitoring farmer participation in the watershed (Sarin and Walker 1982), and in-depth economic assessments focusing on specific issues, such as reasons why farmers practice kharif fallowing in wet deep Vertisol regions (Michaels 1981). Some topics--which merit more attention from economists and relate to the design of deep Vertisol technology options--are discussed in this section under component research, cropping systems research, and watershed management research.

Component Research

Information from verification trials and related on-farm research can be extremely useful in partially establishing priorities for component research. For example, the results in 1981-82 from the Taddanpally test highlighted the importance of effective *Striga* and pod borer control. At present, there are several areas in which economists can supply decisionmakers with information on component research.

Steps in Technology Trials

The first issue centers on the often-asked question of how much each component separately contributes to increased productivity of the package. This question is usually asked about the broadbed-and-furrow management system and the wheeled tool carrier. There is a consensus that broadbeds and furrows on deep Vertisols provide long-term benefits in the form of reduced soil erosion and better tilth (Binswanger et al. 1980). There is less agreement on how much the broadbed-and-furrow system directly increases productivity in the short run. Similar questions are raised about the wheeled tool carrier, which is costly but may give considerably higher and stabler yields from better seed and fertilizer placement.

Economic analysis of steps in technology experiments planted on deep Vertisols in 1976-77 and 1977-78 at ICRISAT Center shows that with improved varieties and fertilizer, the improved soil- and crop-management steps can increase net benefits by more than Rs 1000/ha, compared to treatments featuring improved varieties, fertilizer, and traditional soil- and crop-management practices (Ryan et al. 1980). In this comparison, the improved soil- and crop-management practices not only include the broadbed-and-furrow system with the wheeled tool carrier, but also entail postharvest cultivation and effective plant protection. Too many components change between the improved and traditional soil- and crop-management practices to allow identification of the contribution made by the wheeled tool carrier and the broadbed-and-furrow system.

Partitioning the contribution of the deep Vertisols technological package to its components is thus beset by a number of problems. These include the inadequacy of small-scale plot research in drawing implications about outcomes from watershed-based treatments, the sensitivity of results over time and the consequent need for multiyear trials, the difficulty in simulating farmer management conditions with regard to timeliness and other variables (in ICRISAT experiments), and the absence of homogeneous operator skills in the management of wheeled tool carriers and traditional bullock-drawn implements. Combining experimental results with base data analysis and whole farm modeling could help overcome some of these obstacles. In 1982-83, when rainfall was normal and evenly distributed, and drainage was not a problem, use of the wheeled tool carrier with flat-on-grade land management gave higher profits than competing implement and land- and water-management treatments in a sorghum/pigeonpea intercrop and a maize-chickpea sequence (Nishimura and Heinrich 1983). These results should be viewed with caution in the light of problems associated with partitioning the contribution of the deep Vertisols technological package, but such technology trials do furnish richer technical information for decisionmaking. Seldom, if ever, do farmers adopt a whole package unless they believe that each cost component effectively contributes to enhanced productivity.

Demand for Wheeled Tool Carrier[8]

Few farmers have purchased a wheeled tool carrier at nonsubsidized prices. A production engineer's report (Barwell 1981) estimated that a complete machine with most implements should cost about Rs 9000[9]. Most of the demand has been institutional, primarily by state departments of agriculture.

In the three initial test sites, ICRISAT made the tool carrier available on a rental of Rs 15/day over two cropping years. Three to four farmers in each village used the machine for some operations--particularly seeding--for a few days each year. Most farmers were unwilling to pay Rs 15/day to hire the wheeled tool carrier.

Under an energy conservation project, the Maharashtra government subsidized 80% of the purchase price of wheeled tool carriers. More than 400 tool carriers were programmed for distibution in 1983 in two taluks (Kshirsagar and Mayende 1983). Irrespective of the deep Vertisols technological options, a follow-up study on tool carriers, particularly those purchased by farmers, is needed to establish what uses they are being put to, their impact, and how effectively local artisans are servicing machines that have been manufactured without strict quality control. Data on market purchase and resale prices would be valuable. Such a study could generate more specific information on what farmers are willing to pay for wheeled tool carriers in different locations.

It is unlikely that a marginal reduction of 15 to 20% in the cost of the tool carrier will be accompanied by a significant increase in orders. It is critically important that we find out if tool carriers, as presently designed, have a future. It is presumptuous to think that one study can provide definitive answers to this question, but information is urgently needed on demand parameters for wheeled tool carriers in different environments. A review of recent trends in wages especially for plowmen and full-time farm labor would also help in estimating the demand for wheeled tool carriers and the prices that farmers are likely to pay for them.

The Economics of *Heliothis* Pod Borer Control

More information is also needed to pin down the cause of poor pod borer control by farmers in SAT India. Most economic studies on the adoption of plant protection measures suggest the following multiple and interrelated reasons why SAT farmers find it difficult to control insect pests (Rastogi and Annamalai 1981): (1) lack of timely information on when and how to control infestations that have usually exceeded economic threshold levels, (2) unavailability of sprayers and recommended insecticides on a timely basis, (3) prohibitive cost of some insecticides, and (4) limited supplies of water for spraying. Therefore, inefficient pest control may be because of constraints on the generation and diffusion of technical information, on input supplies, and on capital to invest in materials.

In traditional farming systems, it simply may not be profitable to spray insecticide for *Heliothis* (pod borer). With the improved deep Vertisol options, it should be profitable for many farmers to make the transition from an unprotected to a protected pigeonpea crop. If this transition is not made, economic incentives for rainy-season (kharif) cropping will be noticeably dampened. This change will increase the demand for monitoring pod borer populations and for technical information on when and how to spray, particularly in Andhra Pradesh where infestation is often severe. This in turn will place heightened demands on the research and delivery systems to generate and diffuse timely information on pod borer control measures. As an alternative strategy to chemical control, promising cultivars with some *Heliothis* resistance should also be tested in the verification trials as soon as possible.

Incongruent Perceptions

Economics also has a role to play in diagnosing the source of differing perceptions between researchers and farmers on the relative profitability of alternative cropping systems. The reluctance of farmers to adopt what seem to be profitable kharif cereal-based cropping systems and their preference for mungbean-rabi sorghum and fallow-chillies sequences may be based on an implicit discounting of the quality of hybrid sorghum grain and fodder relative to rabi sorghum. Or perhaps farmers believe that hybrid sorghum production entails greater yield risk from reducers such as *Striga*, shoot fly, and head bugs than rabi sorghum production. Farmers may also consider the price risk from uncertain maize markets and price reductions from grain mold attack precipitated by September and October rainfall on sorghum hybrids. They may also attach a higher implicit price to the production of rabi sorghum, which is their subsistence staple. Whatever the case, the issue is not trivial. If farmers continue with traditional practices in the absence of further improvements in the profitability of noncereal-based cropping systems, our