FARMING SYSTEMS RESEARCH IN A WATERSHED FRAMEWORK: EXPERIENCE RELATIVE TO VERTISOL MANAGEMENT IN SEMI-ARID TROPICAL INDIA

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The need for farming systems research (FSR) is universally recognized in modern agriculture. It is particularly important for the drylands in semi-arid tropics (SAT) where farming systems are diversified, crop yields are low and unstable, and ecological balance is fragile. To be useful, such research must draw upon expertise from an array of sciences. Therefore, there is considerable discussion on the kinds of activities that FSR should encompass, the strategy it should adopt for the development and transfer of improved technologies, and the way it should be conducted (Gilbert, et al. 1980, ICRISAT, 1983).

In the semi-arid tropical regions improved rain water management is critical to increase and stabilize crop production because the rainfall distribution is erratic and its amount is less than the potential evapotranspiration demand. ICRISAT's work in improved management of Vertisols has shown that an integrated plan for land-, water-, and crop-management through the watershed approach offers scope for a substantial improvement in productivity. A watershed is the land area from which water drains to a single outlet. Different parts of a watershed are treated as interlinked components of a single hydrologic unit; interfarm and intrafarm development activities are coordinated.

The Farming Systems Research and Extension (FSR/E) methodology generally assumes that the physical resources of the farm are fixed (Zandstra, 1978. Appendix Table 1) and that increases in productivity are realized through the manipulation of crops/ cropping systems, fertilizer, labor and other related management inputs. The approach we have found useful for increasing the productivity of the SAT focuses on a hydrologic unit (watershed) where both farming and landless labor households reside. According to Gilbert et al (1980) the conventional model of FSR/E has been based on the individual farming family; the link to societal needs has not been well established either conceptually or operationally. Should FSR/E be conducted within a framework that views the natural resource environment as fixed or variable? More specifically, should FSR/E be carried out within a watershed management approach? Should watershed management projects use some aspects of FSR/E? Is it desirable and feasible to wed a watershed management approach (WMA) to FSR/E concepts and methodologies? These are crucial questions for agro-technology development and transfer in the tropics. In this paper, we discuss several of their dimensions. To supplement this discussion we review our experience in the generation and diffusion of ICRISAT's Vertisol Technology which in many ways represents a blend of WMA and FSR/E concepts.

COMPARING WMA AND FSR/E CONCEPTS

A watershed management approach broadly aims at protection, development and management of land and water resources in an area bounded by a drainage divide. Watershed-based resource utilization involves the optimum use of an area's precipitation for the improvement and stabilization of agriculture on the watershed through better water, soil, and crop management (Kampen, 1979). Thus the primary thrust of WMA is improvement of the watershed area and its productivity; secondarily individual farmers owning land in the watershed are mostly benefitted. This point is also reflected in the criteria for evaluating watershed management plans. According to Gil (1979) economic evaluation of watershed plans should be carried out in steps for each work component separately and then be combined for all components. These steps are:

* determining project benefits for each component and alternative.

* determining project costs for each component and alternative.

* determining national profitability criteria for each component and alternative.

* eliminating alternatives that are uneconomic.

* ranking of alternatives according to internal rate of return and choice of the optimal economic alternative.

* attaching intangible and "external" benefits and costs to all components.

* summing areas, all components, social benefits and costs to obtain a measured total social profitability.

Thus it is possible to imagine a successful watershed management project wherein some individual farmers may not benefit as much as others or a few may even lose.

FSR/E represents a farmer-directed philosophy of technology development and transfer. A strong and meaningful interaction among a multidisciplinary team of researchers, farmers and extension workers at the local level is essential. Thus FSR/E focuses more directly on problems facing farmers as individuals. The goals/objectives of the (individual) farming household tend to take precedence in the progress of designing improvement measures (Gilbert et al. 1980). Adoption of FSR/E based technology by farmers is completely voluntary. The main premise of FSR/E lies in generating technologies that could be "self-sustaining" and "self-replicating" depending primarily on farmers' initiative.

In summary, both WMA and FSR are approaches for problem solving and involve communication and cooperation among several disciplines. But WMA stresses more on the management of physical resources for their optimized utilization whereas conventional FSR/E features biological, agronomic and human aspects of the problem. WMA recognizes a watershed (hydrological unit) as a system; FSR/E views the farming household (farming unit) as a system. WMA is traditionally more concerned with hydrological processes with long-term effects and both tangible and intangible benefits; the goals, aspirations and perceptions of individual farmers seldom receive adequate consideration in this methodology. In contrast, a narrower FSR/E methodology is conditioned primarily by farmers' goals and these may not take full cognizance of long-term, intangible, interfarm and group dimensions of development problems.

A blend of WMA and FSR/E is desirable, and perhaps even essential in ecological situations where natural resource constraints can be cost effectively broken by improved land and water management practices and where interactions among such practices and other farming systems components are likely to be significant. We can cite three examples of such situations in Indian agriculture. First, in mountainous regions where soil losses are potentially high with resulting downstream silting and sedimentation of reservoirs, a watershed management approach has yielded handsome dividends (Bhumbla et al., 1980). Secondly, in wet rainy season cultivated fallow, Vertisol regions of India, improved watershed management can add 90 days to the cropping season, reduce soil loss, and improve rain utilization (JNKVV,1980; ICRISAT, 1983). Without a watershed management approach an FSR/E program would primarily limit itself to postrainy season cropping alternatives. Thirdly, in the hard rock areas of peninsular India, by judicious watershed management it may be feasible to significantly enhance ground water recharge which increases the options for intensified cropping (von Oppen et al. 1983).

FEATURES OF IMPROVED WATERSHED MANAGEMENT

Interfarm Improvements in Watershed Management

An important feature of watershed management projects is interfarm improvement components which relate to and affect more than one farm. Some common examples of interfarm improvements are:

a. Diverting runoff and seepage from upper regions to protect lower regions.

b. Ground water recharge and exploitation.

c. Runoff control and drainage improvements in an area.

d. Runoff collection, storage, and use.

e. Erosion control through integrated use of mechanical measures and land use planning.

The benefits and cost of these measures are generally not distributed uniformly to all parts of the watershed. Often cost has to be incurred in the upper reaches that result in benefits to the lower reaches. This leads to a divergence of benefits and costs among individual farmers when different parts of a watershed are under different ownership.

For promoting motivation and participation of farmers in interfarm practices, mechanisms should be developed to facilitate equitable distribution of benefits among all farmers either through voluntary sharing by them or through Governmental action. In many watershed management projects in developing countries the cost of interfarm improvements is borne by the Government. While it simplifies the financing of the project, this practice increases the dependency of farmers on external initiative.

Size of Watershed

The size of the watershed may be decided by the following factors:

a. Topographic and physiographic features.

b. Nature of the hydrologic problem and size adequacy for problem solving.

c. Number of cooperators and scope for cooperation.

d. Composition and attributes of development agency/agencies involved in watershed management program.

As far as possible planning and development should move from smaller to bigger and from simpler to more complex watershed units. In general, watersheds of smaller size have advantages of involving a small number of farmers and less diverse land uses. It is, therefore, relatively easier to improve their management. But at the same time the size must be adequate for solving the problem at hand.

This point may be better explained by a few examples. If it is desired to improve ground water availability in a given area by constructing percolation tanks or similar land use modifications, a watershed of 5-30 ha size is too small. Similarly, if flooding of crop lands due to runoff from neighboring hills and upland areas is a problem, a small watershed will in general not be effective.

But where a major drainage network is already available for an area, and where the main aim of development is to improve the local surface drainage and guide the runoff to available outlets, a 5 - 30 ha watershed is quite adequate. Fortunately, the topography of peninsular India permits demarcation of such watersheds. ICRISAT's Vertisol technology described briefly in the next section has been verified at several locations in very small watersheds units, as such small sizes are considered adequate to improve *in situ* drainage. In contrast, the Indo-UK Dry Farming Project in Indore (India) selected a watershed of about 2700 ha for practices such as diversion of upland runoff, gully control, and integrated land use planning (JNKVV, 1980).

Steps in Watershed Planning

The following steps are usually involved in planning for WMA (Jaiswal and Kolte, 1981):

- Preparation of base maps for carrying out surveys.

- Reconnaissance survey of the watershed for overall development.

- Assessing rainfall characteristics.

- Preparation of soil maps and classification of lands for different uses according to capability for agriculture, forestry, pasture, horticulture, etc.

- Preparation of inventory of existing land uses, and farm sizes.

- Appraisal of agricultural production patterns and potentials; present and potential markets and possible group action arrangements.

- Carrying out topographic and hydrologic surveys for engineering.

- Geo-hydrological survey to delineate areas suitable for ground water development.

- Formulation of an integrated time-bound plan for land and moisture conservation, ground water recharge, development of productive and protective afforestation, agriculture production, grass lands and horticulture.

* Assigning of priorities for the implementation of the project.

* Assessing social costs and benefits.

CASE STUDIES OF WATERSHED BASED MANAGEMENT

ICRISAT Vertisol Technology: FSR/E in a WMA Framework

Background: Vertisols are cracking clay soils characterized by low saturated hydraulic conductivity and imperfect drainage. They are very hard in a dry state and sticky in a wet condition. On the Vertisols of Peninsular India crop yields are quite low under traditional farming systems. In a large part of Vertisol area in India the land is left fallow during the rainy season in order to raise a postrainy season crop based on residual soil moisture; the land is cultivated repeatedly during the rainy season to control weeds. ICRISAT identified the replacement of this practice by more productive technology as an early goal (Binswanger et al. 1980).

Stages in technology development: The stages listed below give an idea of range of activities involved. However, these are not necessarily sequential as there were overlapping and repetition of several activities:

* Analysis of soil, climatic and crop yield data;

* Researchers' identification and evaluation of reasons for low productivity and resource degradation in an ecological zone and potential for improvement;

* Review and analysis of existing research results; component research on research station;

* Conceptualization of prospective technology options; operational-scale evaluation of promising options in watersheds at research station by a multidisciplinary team; understanding of agronomic, economic and hydrologic features of selected options; cooperative research at selected national research stations.

* Seminar and training sessions to have a dialogue with research and extension workers, and policy-makers of national system, and to identify cooperators for on-farm verification studies.

* On-farm verification studies to:

    a) involve farmers in technology testing and adaptation.

b) identify the potential for productivity gains in real farm setting.
c) identify the institutional and policy constraints.
d) provide a feedback to research station for further studies.

Technological description: Through the experimental studies at ICRISAT a small watershed integrated approach for Vertisol management was evolved. The key components of this approach are:

* Cultivating the land immediately after the previous postrainy-season crop when the soil is not too dry for working.

* Improved drainage through provision of community drains, field drains, and use of graded broadbeds and furrows (Fig.1).

* Dry-seeding of rainy-season crops before the monsoon rains arrive;

* Planting of postrainy-season crops in the stubbles of rainy season crops after a shallow cultivation;

* The use of improved seeds and moderate amounts of fertilizers;

* Improved placement of seed and fertilizers;

* Timely interculture and weed control; and

* Timely plant protection

On-station operational research extending over 5 years (1976-77 to 1980-81) has shown that this improved watershed management approach including such cropping systems as maize intercropped with pigeonpea can increase profits by about 600% compared with a traditional system based on a rainy season fallow followed by postrainy season sorghum or chickpea. This represents a rate of return on the added operating expenditures of 250% (Ryan and Sarin 1981). In addition to improving the productivity, this approach has substantial resource conservation benefits as shown in Table 1. It is evident that runoff is reduced by about 50% and soil loss by over 80%.

On-farm verification: Site selection criteria for on-farm verification trials include:

a) Anticipated applicability of technology options and untapped productivity potential. Rainfed deep Vertisols in 750-1250 mm rainfall zone, land slope 0.4 - 3%, pH of soil<8.5, availability of small watershed with safe and efficient outlet, primarily upland annual cropping and existing low productivity.

b) Representative land ownership pattern.

c) Interest shown by farmers.

d) Interest of national research extension, and credit insititutions.

The on-farm verification studies with a relatively better understanding of the potential ecological zone of this technology started in 1981-82 on a 14.5 ha watershed in a village called Taddanpally (Andhra Pradesh). In 1982-83 similar studies were taken up in Sultanpur (Andhra Pradesh), Begumganj (Madhya Pradesh), and Farhatabad (Karnataka). These trials are carried out collaboratively by ICRISAT, State Department of Agriculture, and other institutions. The State Departments of Agriculture in Andhra Pradesh, Karnataka and Maharashtra on their own initiative started tests in 1982-83 in four sites. In 1983, the states expanded their testing program to several sites in 28 districts of Andhra Pradesh, Karnataka, Maharashtra and Madhya Pradesh. ICRISAT has facilitated this process by organizing seminars and training programs and by providing technical backstopping.

Interest shown by farmers was one of the criteria for choosing watershed sites for on-farm verification. In the first year, community drains, field drains, land shaping, and broadbed and furrows were planned and laid out on the entire watershed area.

Fertilizers, seeds, pesticides, petrol, hired labor and bullocks had to be paid for by the cooperating farmers. The elements that were provided free of cost to them but those which normally they would be expected to pay for in full or in part were:

* Surveying and planning the watershed layout.

* Construction of community drainage channel.

* Use of wheeled tool carriers and improved implements which accompany them.

* Use of power sprayers.

* Rodent control.

A useful device to enlist farmers' cooperation was a guarantee from ICRISAT that participant farmers would not earn less than they would expect from crops grown under traditional management. In addition to monitoring inputs/outputs on improved watershed plots, we also monitored plots selected to be representative of traditional cropping patterns and management.

Farmers were encouraged to choose cropping systems of their preference; however, agroeconomic and hydrologic advantages of rainy season cropping and early vegetative cover (based on results at ICRISAT-Center) were explained to them. Most of the participating farmers used the recommended technology in the first year.

The improved technology options have demonstrated their high profitability in the on-farm verification trials (Ryan et al. 1982; Walker et al. 1983). The marginal rate of return ranged from 26 to 381% (Table 2). In the three larger verification trials in the succeeding year 16 of the original 31 decision making farmers continued their participation (Table 3). Since the subsidies provided are small and the farmers must carry out the operations themselves, a 50% level of participation suggests that there is scope for wider diffusion of the technology (Walker et al. 1983).

A MORE CONVENTIONAL WMA EXPERIENCE WITHOUT FSR/E

Jaiswal and Kolte (1981) conducted a case study of implementation and effectiveness of G.R. Halli Watershed Project located in Chitradurga district, Karnataka (India). This 314 ha watershed was developed as a model to serve as an example of watershed development efforts in drought-prone areas. The watershed plan was drawn up by subject-matter specialists and handed over to the Project Director, Drought Prone Area Program for implementation. Jaiswal and Kolte state that:

a) Almost all the officials of the project blamed the farmers for their negative attitude towards the recommended practices of watershed plan. In their view it was the main problem that led to the failure of the program.

b) The farmers did not appreciate several aspects of the project as they were not involved in the planning. They were not convinced about the utility of recommended practices either.

c) There was lack of proper coordination amongst the different development agencies.

d) Farmers did not receive adequate credit support primarily due to procedural difficulties.

These findings are typical of planning at the top without the involvement of the lower functionaries and the farmers (Jodha, 1983). Many of these weaknesses could have been eliminated or at least reduced through a judicious FSR/E orientation of the project.

WATERSHED MANAGEMENT PROGRAM FOR RAINFED AREAS IN INDIA

In recognition of the need for natural resource development and management, an extensive program has been launched in India to improve the productivity of rainfed areas through integrated planning on the basis of microwatersheds. More than 4000 such watersheds have been identified throughout India and an integrated program covering crop and plant technology, land and water conservation and re-use measures, and extension, cooperation and credit support, is being pursued.

Forty-two model watersheds are being developed with collaboration from the Indian Council of Agricultural Research and Indian agricultural universities which will serve as demonstration cum-training centers. These watersheds will be monitored intensively in a number of technical and socioeconomic dimensions which will provide indications for taking up further steps to develop such areas (Das, 1983).

In the light of our experience in watershed based Vertisol management technology we feel that effectiveness of this program could be increased by using a blend of FSR/E and WMA concepts.

STRENGTH AND WEAKNESSES OF WATERSHED BASED FSR/E

Attributes of Watershed Based FSR/E

The distinguishing and positive attributes of watershed based FSR/E are:

* It seeks to strike a balance between natural resource management and human aspects of problem solving. Thus it recognizes the role of physical, biological and social scientists in all phases of research and development.

* It explicitly recognizes two levels (tier) of system integration - one at the farmer level and the other at the watershed level; planning and evaluation are made at both levels.

* It also sees complementarity and conflict between the two levels of integration and seeks to harmonize them wherever possible. Policies for agricultural development should seek a convergence of individual and societal needs and goals.

* It recognizes that although it may be possible to develop technically optimal technology for a natural resource situation, it is to be used by individual farmers and their groups. They may have a primary role in properly maintaining the assets created. Therefore, technology should be flexible enough to be adapted and modified at the local level. Thus on-farm verification and adaptation is a key element of watershed based FSR. Farmers in cooperation

with extension workers and investigators determine what is the best technology for their situation by exploring a range of technology options through a process of inquiry and self-discovery rather than through force-feeding of ready-made solutions. This is particularly true for intrafarm components.

* It relies primarily on farmers' voluntary participation and initiative. Thus it relies largely on the 'extension approach of technology diffusion.

* It seeks to institutionalize equitable distribution of benefits and costs in all parts of a watershed. Ideally speaking it should seek to institutionalize measures favorable to resource-poor farmers, landless laborers, and other groups in a rural society.

Limitations of Watershed based FSR/E

When deciding whether or not to carry out FSR/E in a watershed management framework, strengths should be evaluated against weaknesses. In theory a watershed management approach is robust, but it can be difficult to carry out in practice.

Research on land and water management practices is more intensive in its demand for land than in the more conventional FSR which features small-plot cropping systems trials. Land and water management practices seldom truly express themselves unless plot size is reasonably large; this means that fewer treatments and replications are possible for a given level of research expenditure. For example, in on-farm testing, verification watersheds may range from 5 to 30 hectares. Although component testing within the watershed is desirable it still requires sufficient area for full expression of effects. Therefore it may take more time and be more costly to divide a watershed technology package into its economic components to measure separate contributions from components or clusters of components.

A watershed approach is not self-replicating because it requires government investment on a project basis much like the construction of irrigation command areas. If the government is constrained in implementing projects, farming systems research contingent on natural resource improvement may not find its way to farmers' fields. In particular, soil and water conservation staff are the key extension personnel in a watershed management based FSR/E approach. If they are not trained, diffusion will be slow and ineffective.

A watershed-based approach places greater reliance on beneficiaries being able to socially organize themselves to construct and maintain community works. The requirements for group action can be lessened through a more flexible and pragmatic approach to technology generation and diffusion. In the Vertisol technology options, field boundaries of farmers are respected and farmers are free to choose cropping systems. Moreover, we have not found supplemental irrigation profitable in wet Vertisol regions. Therefore, we do not recommend construction of on-farm ponds whose management can be intensive in its demand for social organization (Doherty et al. 1982). Nevertheless, effective watershed development still requires a minimum level of social organization. For example, in the Vertisol technology options, it is highly desirable, if not essential, that all farmers participate in the first year when main and field drains are completed and when the watershed is developed. But we find that many farmers in the watershed will have previously defaulted on loans and therefore are poor credit risks which institutionally limits the scope for group action (Walker et al. 1983). By concentrating on what is optimal a watershed-based FSR/E may bypass more rapid but less significant longer-term gains forthcoming from a more narrower FSR/E approach. By including land and water management engineers and soil conservation staffs within FSR/E there may be a tendency to concentrate on those environments where payoffs to land and water management are high but where investment costs are also high. Potential technological opportunities may be overlooked in regions where natural resource constraints do not limit agricultural productivity and where less comprehensive measures are needed.

Lastly, watershed management investments such as on-farm ponds and percolation tanks are themselves susceptible to "social leakages" if they are heavily subsidized by the government. To comply with targets, project staff often select projects that can easily be administered and carried out. Administrative ease may not be in the social interest, particularly if subsidies make it profitable for political factions to lobby for a scheme for their constituents.

CONCLUDING COMMENTS

In many areas of the SAT, improved management of land and water resources is crucial for future agricultural development. The farm family based model of FSR/E is inadequate for development and transfer of integrated technologies that include land and water management components having interfarm implications. Watershed units provide a logical framework for diagnosis and for alleviation of land and water related problems.

FSR/E can more substantially contribute to agricultural development in the SAT if it is conducted within overall WMA framework. This suggests a need for blending the WMA and FSR/E concepts and methodologies. We emphasize that the optimal blend of the WMA and FSR/E depends upon analysis of the problem and availability of trained manpower.

At this point in time there may be a relatively small number of developing countries that have the requisite institutional capacity to carry out FSR/E within a watershed management framework. But such a capacity should gradually develop over the next decade or so. For this reason, it is important to carefully monitor and analyze specific experiences like those in India where FSR/E is being carried out within a watershed management framework.

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Table 1. Runoff and soil loss under two differently treated Vertisol watersheds at ICRISAT Center.

Year	Rainfall (mm) (seasonal)	Broadbed and furrow layout with improved crop management system		Traditional flat with bunds, rainy season fallow system	
		Runoff (mm)	Soil loss tonnes/ha	Runoff (mm)	Soil loss tonnes/ha
1976-77	688	73	0.80	238	9.20
1977-78	586	1.4	0.04	52.7	1.68
1978-79	1125	273	3.40	410	9.70
1979-80	690	73	0.70	202	9.47
1980-81	730	116	0.90	166	4.58
Mean	763.8	107.3	1.17	213.8	6.93

(Source: Miranda, et al. 1982).

Appendix Table 1. Difference in the way various research activities treat factors influencing crop production.

Research activity	Physical resources			Economic resources (power, cash, labor)			Crop	Management
	To farm	Within farm	Within crop production	To farm	Within farm	Within crop production		
Resource management	^	^	^=	=	=	=	=	=
Farming systems	=	^	^	=	^	^	^	=^
Cropping systems	=	=	^	=	=	^	^	^
Institutional constraints	=	=	=	^	^	^	=	=
Agronomy	=	=	=	=	=	=	=	^

Source: Zandstra, H.G. 1978

^ - treated as variable
= - treated invariant

Table 2. Comparing the profitability of improved deep Vertisol technology options with farmers' traditional practices in several watershed tests from 1981-82 and 1982-83.

Watershed test site description				Comparative profitability						
				Weighted average profits (Rs/ha)*			Operational cost (Rs/ha)*			Marginal rate of return%
Village (District) (State)	Year	Area ha	No. of farmers	Improved	Traditional	Difference	Improved	Traditional	Difference	
Taddanpally (Medak) (Andhra Pradesh)	1981-82	14.5	12	3055	1625	1430	1181	595	586	244
	1982-83		4	3957	1722	2235	1035	448	587	381
Sultanpur (Medak) (Andhra Pradesh)	1982-83	26.7	12	3576	1722	1854	1062	448	614	302
Farhatabad (Gulbarga) (Karnataka)	1982-83	17.5	3	3323	2186	1137	1194	1142	52	a
Begumganj (Raisen) (Madhya Pradesh)	1992-83	24.0	10	1172	786	386	2348	866	1482	26

(Adapted from Walker et al. 1983)

*Rs.10 = 1 US $ (Approx)

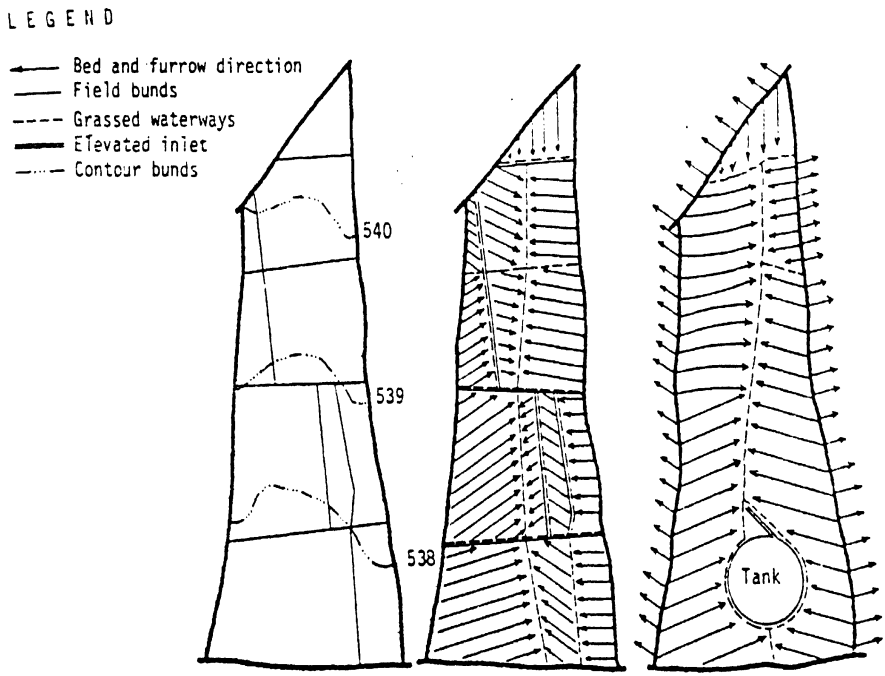
[a]The differences in operational cost are too meager to make a meaningful comparison.

Table 3. Farmer participation in the watershed tests.

Watershed test site	Year	Participation			
		Farmers		Land	
		Number	% of total[a]	Area owned by participants (ha)	% of total[a] 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

Source: Walker et al. 1983)

[a] Based on the number of farmers and area covered in the first year of the development of the watershed.



a. Contour bunds

b. Broadbed and furrow system at 0.6% within field boundaries.

c. Broadbed and furrow system at 0.6% with grassed waterways and a tank.

Figure 1. A vertisol watershed with three alternative soil and water conservation and management practices.