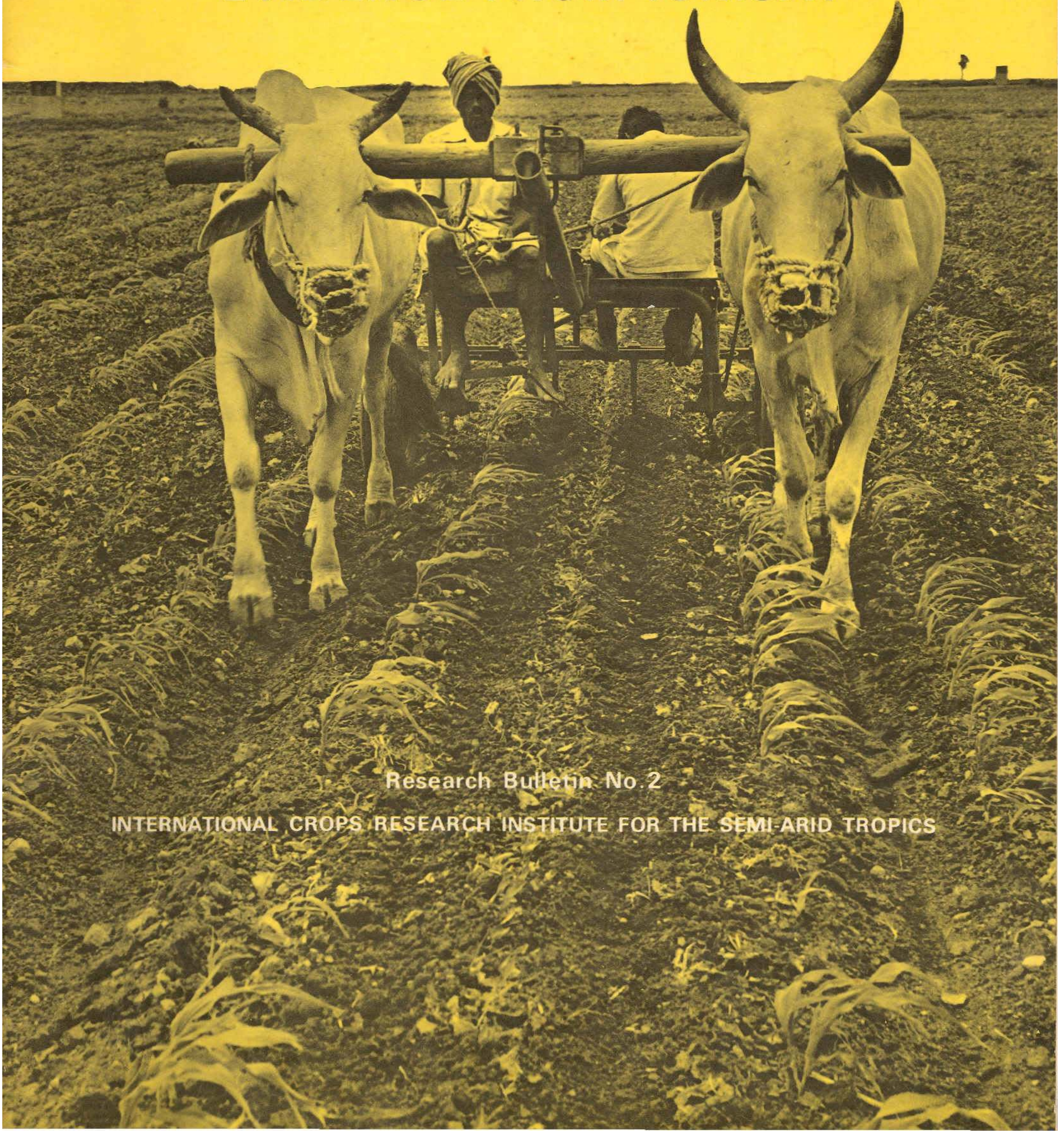
FARMING SYSTEMS COMPONENTS FOR SELECTED AREAS IN INDIA: EVIDENCE FROM ICRISAT



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INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

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FOREWORD

This Research Bulletin summarizes conclusions that can be drawn from 7 years of soil and water management research in the Farming Systems Program of ICRISAT, as well as selected conclusions from our other programs and subprograms. It clearly states findings that need to be evaluated on farmers' fields; it also indicates areas of further research that need continuing intensive investigations and evaluation.

The paper has had a substantial impact on the program and research direction of the Institute, and we hope that it will be useful to other researchers and to policymakers as well. Farming systems research is still in its initial phases of development, and basic issues of how to approach research on a whole-systems basis are still not fully settled within ICRISAT and outside. This bulletin is part of the continuing process of defining how best to do farming systems research and transfer its results to researchers and farmers across locations.

J.S. Kanwar
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Contents

FARMING SYSTEMS COMPONENTS FOR SELECTED AREAS IN INDIA: EVIDENCE FROM ICRISAT

H.P. Binswanger, S.M. Virmani, and J. Kampen

Operational-scale research on natural watersheds at the ICRISAT research center has demonstrated that substantial profits (after deduction of all costs, including those related to capital investments) can be earned by more input-intensive farming systems than those currently used by farmers.[7] For the best systems on deep Vertlsols at ICRISAT, profits are in the range of Rs 3000 per hectare, while for the Alfisols they are of the order of Rs 2000 per hectare.[2] However, these systems are complex and require several inputs; before transfer to farmers, we need to ask if essential components of these systems can be identified. We must also more precisely describe the agroclimatic and socio-economic conditions where specific components may be most appropriate.

We attempt to use the massive evidence accumulated in the various subprograms of the Farming Systems Research Program (FSRP) and in the Economics Program to present a series of generalizations. Some of these generalizations may sound obvious to the specialists since they form part of their disciplinary backgrounds. Other generalizations are tentative because they rest on fragmentary evidence. The geographic limits for which these generalizations hold must yet be more clearly defined. However, we believe that generalizations of the nature proposed here, once fully stated, are useful for several purposes:

1. They lead to further questions and sharpened hypotheses for new inquiries at ICRISAT. They may serve similar purposes at the research planning stage at regional research centers, particularly when scientists engage in new research fields.[3]

2. They may assist scientists at regional research centers and at ICRISAT

1. Research results that lead to similar conclusions are available from Indian research institutions (e.g., the All India Coordinated Research Project for Dryland Agriculture-AICRPDA). However, we have not yet reviewed these data systematically.

2. See Ryan, Sarin, and Pereira (1979, Table 3 and p. 9).

3. We recognize that the generalizations and tentative predictions presented here may often be too general to be useful to the informed regional or local scientist who may have arrived at them in a more detailed manner by his own previous work. Furthermore, one must be more precise than, for example, to say that in a particular soil and rainfall region "intercropping appears a good practice to investigate." Cooperating scientists at regional research centers often know fairly well what they ought to do.

in interpreting a variety of research results on a comparative basis across locations.

3. Once the geographic limits of the generalizations are known and are otherwise confirmed, they can become useful to action and funding agencies at the project identification level and possibly in actual planning. However, at the planning stage and especially in the execution stage, more site-specific knowledge will inevitably be required.

It is therefore important to realize that our generalizations are not "development prescriptions"; this is particularly true for our "predicted farming systems." Given the specific characteristics of each area in the semi-arid tropics (SAT), few handbook-type solutions can be expected to evolve (Kampen 1979). Although the principles for natural resource development and use may be clear, the ultimate task of finding appropriate, site-specific solutions for the special problems encountered in a given area will have to be assigned to local researchers, technicians, extension agents, and, finally, to farmers. To fulfill their responsibilities effectively, those charged with agricultural development will have to acquire the ability to invent the most suitable solutions to each particular situation rather than apply a given set of rules. Thus, training programs will be required to increase understanding of the limitations, constraints, and potentials of present farming systems and the requirements of improved production technologies, as well as the adaptation and application of such technologies.

This paper is based on evidence from many different types of inquiries. The diverse methods used and their results are not discussed in detail; however, the original sources of the generalizations are given so that they can be easily verified.

Each individual piece of evidence has of necessity been derived to attain specific objectives under a given set of conditions and with simplifying assumptions. These can always be used to put the evidence in question; for example, large-scale experiments usually have few replicates, sample surveys may be of modest size, runoff and soil moisture models may require further refinements to achieve greater accuracy, etc. Nevertheless, it is our contention that such questioning is rather inappropriate as long as evidence from different studies, each one with its own limitations, is not contradictory and leads to essentially similar conclusions. In such cases, the sum of the evidence is robust in the sense that minor changes in assumptions or approaches do not affect the generalizations that can be drawn from them. On the other hand, when different studies contradict each other, one may arrive at more sharply defined hypotheses to be further tested.

In this paper, we first present generalizations and further hypotheses or suggestions for research related to soil management, runoff collection, and rainy-season fallow, respectively. We then attempt to predict—subject to further confirmation—what the essential components of more input intensive farming systems would be in four different environments. The final section reflects on broader issues of ICRISAT research strategy. Appendix 1 brings together the specific research suggestions identified. Some of the data used as a basis for our generalizations have been summarized in the Appendix Tables.

Cultivated Rainy-Season Fallow on Deep Vertisols

Cultivated fallow in the rainy season, popularly known as kharif fallow,[4] consists of leaving the land fallow during the rainy season in order to raise a postrainy-season crop based on stored soil moisture; the land is harrowed repeatedly during the monsoon to control weeds. This practice is frequently encountered on deep[5] Vertisols. ICRISAT identified the replacement of this practice by more effective land management techniques as an early goal.

Krantz and Russell (1971) and Kampen et al. (1974) have discussed reasons for kharif fallow in the high rainfall zone where the fallowing cannot be explained by the lack or the unreliability of soil moisture during the rainy season. Kampen et al. (1975) and Kampen (1976) stressed undependability of the early rainy season and risk evasion as important causes of the kharif fallow in low rainfall areas such as Bijapur and Sholapur.

Recent mapping work suggests that the important kharif fallow areas indeed fall into two clearly distinct groups: (1) the low-rainfall kharif fallow found parallel to the Western Ghats through Maharashtra and Karnataka, and (2) the high-rainfall kharif fallow concentrated primarily in Madhya Pradesh. A rainy-season cropping belt is found in between the two zones.[6] We want to demonstrate that this distinction is vital for further work on trying to develop improved technology for the kharif fallow regions.

We believe the low-rainfall kharif fallow can be fully explained by the unreliability of soil moisture. Table 1 presents probabilities of crops having fully adequate soil moisture regimes.[7] As the footnotes of this table amply demonstrate, these probabilities are calculated on the basis of definitions of required moisture that can be questioned at every stage. For example, with

4. Kharif cropping is a term used in India for rainy season cropping; *rabi* cropping denotes growing a crop in the postrainy season, primarily on moisture accumulated earlier in the soil profile.

5. On Vertisols, four depth classes—related to moisture-holding capacity and, therefore, to stability and productivity--are generally distinguished: deep Vertisols> 90 cm, medium-deep Vertisols 45 to 90 cm, medium Vertisols 22.5 to 45 cm, shallow Vertisols < 22.5 cm.

6. These conclusions are evident from data collected by G. Michaels in a study on the principal reasons for the *kharif* fallow.

7. These data are based on the results of weather-driven, process-based soil moisture simulation models for the surface layers of the profile and for the entire rooted profile. The models predict the daily soil moisture status of defined layers and thereby the moisture availability to a crop. For details see Reddy 1979.

Table 1. Reliability of a 90-day kharif crop on Vertisols of three areas (probabilities expressed in percent of years).[a]

Soils[b] Location and Type	Probability of emergence before 15 July	Probability of seedling survival		Probability of adequate soil moisture through vegetative growing period		Probability of adequate moisture in seed-set stage	Probability of good growth condition throughout	Probability of adequate moisture for rabi sorghum after kharif crop	Probability of adequate soil moisture after kharif fallow
		Conditional[c]	Total[d]	Conditional	Total	Conditional	Total	Total	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sholapur deep Vertisols	65	76	49	84	41	80	33	60 (80)	80 (93)
Hyderabad deep Vertisols	85	90	76	90	69	90	62	50 (73)	83 (96)
Akola medium Vertisols	92	87	80	92	74	90	66	n. a.	n. a.

a. "Reliability" in this table has been defined as the probability of a fully adequate moisture supply (equal to potential evapotranspiration). If one assumes for example that covering 75% of the potential evapotranspiration will still result in a satisfactory crop, the probability values given in parentheses in column 8 and 9 are arrived at. These probabilities could, for example, apply to a chickpea crop.

b. Water-holding capacity for deep and medium deep Vertisols is assumed at 230 mm and 120 mm, respectively.

c. Conditional probability is conditional on successfully meeting all prior conditions.

d. Total probability is the product of conditional and prior probabilities, i.e., it is the total probability to successfully complete the stage and refers to all years

n. a. = Not applicable

<u>NOTES TO COLUMN:</u> (1) Assuming dry seeding and using 1 inch of rainfall as sufficient for emergence. (2) and (3) No water stress in top soil layer for 2 weeks after emergence. (4) and (5) Soil moisture more than 50 mm during all weeks. (6) Soil moisture more than 100 mm during seed-setting period. (7) Probability of fulfilling all previous conditions. (8) Total probability of having more than 150 mm of stored water from mid-September to mid-October after growing a kharif crop. (9) As (8) but with kharif fallow.

evidence from ICRISAT watersheds on deep Vertisols of a successful rabi crop after a kharif crop in 7 successive years, the estimated 50% success rate seems rather low, and the figures in parentheses represent probabilities based on less stringent requirements that could, for example, be sufficient for a chickpea crop. Nevertheless, the probabilities represent orders of magnitude of potential and risk that can be compared across locations and lead to clear inferences. However, much remains to be done to improve the estimates for each location in an absolute sense.

Column 7 of Table 1 shows the total probability of a 90-day kharif crop encountering good growth conditions throughout the growth period. At Sholapur, in the low-rainfall kharif fallow region, this is the case only in roughly one-third of the years. For similar Vertisols in Hyderabad and for medium Vertisols in the higher rainfall zone represented by Akola, this is the case in two-thirds of the years. The most serious setback in Sholapur arises from a much lower probability of successful crop emergence before 15 July, which is probable in only two-thirds of the years. However, all subsequent conditional probabilities also show that the plant is at a higher risk in Sholapur than in the other two areas at every growth stage, even after it has completed the earlier stages successfully. A 33% probability of a favorable soil moisture regime is too low a basis for encouraging rainy-season cropping on a normal annual basis. The loss of seed and cultivation expenses in some years and the low returns in other years would almost certainly reduce average profits of any crop to zero or result in losses.

The probabilities of adequate soil moisture for a postrainy-season crop after kharif fallow (column 9) are high at Sholapur (80%); this level of probability exceeds that for good growth conditions for the rainy-season crop in Hyderabad or Akola (column 7). However, if a rainy-season crop is taken in Sholapur, the chances of the rabi crops are reduced by 20%. Not only would consistent rainy-season cropping often not be profitable; it would probably endanger the profitability of the more important postrainy-season crop. We, therefore, emphasize strongly the importance of breeding for high yield potential postrainy-season sorghums for these and similar regions.[8]

One possibility for rainy-season cropping in low rainfall regions remains to be investigated: the establishment of decision rules based on observed soil moisture in the early rainy season to sow a low-input, short-duration crop that primarily provides cover to prevent erosion and also produces some yield in those years when it can be left on the land until maturity. If high rainfall in the early rainy season is correlated with above-normal rainfall later, the farmer

8. We do realize that it may remain difficult to use high rates of chemical fertilizer effectively in postrainy-season cropping when the surface soil is usually dry. However, it appears that temperature and possibly other factors are also related to the low payoff from improved sorghums in the postrainy season.

may protect the soil during those years when it is most endangered and get a modest return in some years. We recommend that further work on rainy-season cropping (simulation and actual experiments) in the low-rainfall kharif fallow areas be oriented to explore this option. However, most emphasis on replacing the kharif fallow by rainy-season cropping must be concentrated in the high rainfall regions.

In several areas in the low-rainfall kharif fallow zone, there may be scope for advancing the sowing dates of rabi sorghum if problems related to shoot fly attack can be overcome and if surface drainage of the deep Vertisols can be improved. The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) Research Centers in this zone generally recommend earlier sowing dates, but farmers experience problems with this recommendation, partly because of the risk of inadequate soil aeration—and even flooding—late in the rainy season. Potentials for improved soil management systems to remedy this situation (see next section) must be investigated.

Soil Management, Runoff and Erosion Control

The Experiments, the Data, and the Analyses

The experimental data[9] are of three types: the "Steps in Improved Technology" experiments (SIIT), the replicated field-scale comparisons of alternative soil management techniques (FSMT), and the operational-scale research on small natural watersheds (WBR).[10] The SIIT and WBR have been analyzed for profitability and stability.[11]

Steps in Improved Technology Studies (SIIT). In 1975, the SIIT experimentation was started by the Production Agronomy subprogram in cooperation with other ICRISAT programs. The primary goal was to investigate the effects of step-by-step introduction of improved technology on the Alflsols and Vertisols at ICRISAT Center, and to perform complete economic analyses of these steps. The development and implementation of improved technology was thought to involve many steps or facets. An attempt to research the separate effects of each individual phase in a complex system would amount to an unmanageably large number of combinations; also, the effects of many individual facets were thought to have been thoroughly investigated previously. Thus, the many steps were grouped into four phases or factors in a complete factorial design: variety, fertilization levels, soil-, crop-, and fertility-management methods, and supplemental water

9. Unpublished and some earlier published data have been summarized in Appendix Tables 1 to 9 to facilitate easy reference.

10. See ICRISAT Annual Reports, Farming Systems 1973/74-1978/79 (ARFS).

11. See Ryan, Sarin, and Pereira 1979.

(if required). Each factor was applied at two levels, traditional and improved. The cropping systems used have been rotated to avoid a buildup of diseases and insects and to provide information on a range of crops. Medium-scale (450 m^2), replicated plots were used to make bullock-drawn operations feasible with both improved and local implements and to facilitate the economic analysis.

In the SIIT, the precision and timeliness of operations is similar to that of small-scale experiments. More attention can be given to attaining uniform and optimum stands, adequate weed control, rapid turnover between crops, etc.[12]

Field-Scale Land Management Trials (FSMT). The basic goal of the FSMT investigations, which were started by the Land and Water Management subprogram in 1975, has been to evolve improved approaches towards in situ soil and water management for Alfisols and Vertisols. Field-scale plots (>.4 ha) were used as replicates, and differences in soil tillage—essentially comparing the graded broadbed-and-furrow system (BBF)[13] and flat cultivation—were the only variable. Large plots are essential for this type of research, because runoff, erosion, and drainage do not express themselves on small plots. These experimental areas, in terms of operational precision, timeliness, and control, do not meet the performance levels of the SIIT but are superior to the WBR.

Watershed-Based Research (WBR). Research on natural watersheds on deep Vertisols at ICRISAT was initiated In 1973 by the Land and Water Management subprogram with three main objectives: (1) investigations of the hydrologic effects of alternative land and water management techniques, (2) research on the integration of new technology components into improved farming systems, and (3) an overall economic evaluation of different farming systems. In the WBR we try to estimate the levels to which productivity can be further increased when crop varieties of high-yield potential and improved crop and fertility management are combined with in situ soil and moisture conservation—with and without supplemental irrigation from collected runoff or locally available groundwater. The precision, timeliness, and accuracy attained on the research watersheds are, of all farming systems experimentation at ICRISAT, probably most similar to what might be attained on real farms. Thus, significant differences in productivity

12. For a precise description of the treatments, see the ICRISAT Annual Reports, Farming Systems, 1973-74, 1978-79. Although the SIIT experiment is not a formal cooperative project with AICRPDA, a very similar set of experiments has been conducted by several regional centers of AICRPDA since 1978. Also, steps in technology experiments are being carried out by scientists in cooperative research projects in West Africa and Northeast Brazil.

13. The normal dimensions of the BBF system initially experimented with at ICRISAT are a distance of 150 cm between furrows that are relatively sharp and have a depth of about 15 cm; the broad bed between the furrows is relatively flat. Many alternative configurations of the BBF system are feasible and may be more appropriate under particular conditions.

and stability observed here may also be expected to be evident in on-farm situations under similar agroclimatic and economic conditions.[14]

Analysis through simulation models. Ryan and Pereira have used the hydrologic data collected between 1973 and 1977 on ICRISAT Center watersheds on Alfisols and deep Vertisols and 30 years of small plot data for shallow to medium-deep Vertisols from the Sholapur research station of AICRPDA, to derive a regression model of the runoff process, based on daily rainfall and soil characteristics. Krishna (1979) developed a parametric model on the basis of watershed hydrologic data collected at ICRISAT between 1973 and 1976 to predict runoff and to estimate the water balances.

The Ryan-Pereira work has been used to simulate a watershed with runoff storage in order to evaluate the supplemental irrigation potential (from collected runoff) for different watershed sizes in the two regions. Based on historic rainfall data, the model first computes cumulative runoff (total and as a percentage of seasonal rainfall) between 1 June and 31 October. This information can be used directly to evaluate the impact of a practice on infiltration of water into the soil. The cumulative runoff is then adjusted for losses due to excess water disposal via spillways and evaporation and seepage from the reservoir, to arrive at the "available" runoff on 31 October. This information is used to judge the physical potential for supplementary irrigation in the postrainy season. Finally, based on the quantities of available runoff in every year when some water is available for a 5-cm supplementary irrigation, and on the costs of constructing and operating the system, the yield increment of a coarse cereal crop (e.g., sorghum) that would have to be achieved in order to pay for the system is computed. This is the break-even yield to avoid long-term financial losses. This information is then used to evaluate the economic potential of the system.

Generalizations for the Deep and Medium-Deep Vertisols

Rich documentation is available from the research watersheds on deep Vertisols

14. The watershed-based studies were later expanded to the medium-deep to shallow Vertisols and Alfisols at ICRISAT Center and are now conducted in cooperation with regional research centers of the AICRPDA. The main characteristics of alternative farming systems and resource management methods presently investigated in WBR are:
    a. Existing technology: Flat cultivation (without land smoothing), planting with local farm equipment, traditional, long-duration varieties, common levels of farmyard manure.
    b. Improved technology: Varieties of high yield potential, recommended levels of chemical fertilizers. Seeding, fertilizer application, and all cultural operations executed by means of animal-drawn precision equipment, regionally accepted land development techniques (e.g., field, contour or graded bunding, but no land smoothing or cultivation strictly parallel to bunds).
    c. Improved technology: Similar to (b) but with land smoothing and graded broadbed-and-furrow systems or other regionally developed land management methods, grassed waterways, etc.
    d. Improved technology: Similar to (c) but in addition, supplemental irrigation of crops from collected runoff water or other sources.

and from one of the FSMT located on medium-deep Vertisols/[5] The results of these two types of experiments generally reinforce each other. Since rainy-season fallow is an important issue on these soils, generalizations should be made comparing soil management systems under cropped and under fallow conditions. This is what has been attempted in Table 2.

Intercropping of maize and pigeonpea is the most profitable cropping pattern at ICRISAT Center[26] (Generalization 1). Although sequential maize and chickpea were also grown, most of the later comparisons are made on the basis of the intercrop results.

Crop cover in the rainy season reduces runoff (regardless of soil treatment) and therefore also frequently reduces erosion to acceptable and safe levels (Generalization 2). Early vegetative cover reduces the erosion hazard primarily to the crop establishment period; wherever feasible, some crop cover should therefore be established in the rainy season.

Generalization 3a on contour bunds implies that they are an inappropriate technology wherever cropping during the monsoon season is feasible or where drainage problems prevent monsoon cropping. They are therefore not recommended for the deep and medium-deep Vertisols where drainage problems caused by this system have long been recognized. Graded or "guide" bunds[17] are more appropriate in these situations since they have been shown to also reduce watershed erosion. Such guide bunds have less impact on watershed runoff, but they do provide a controlled excess water disposal system without causing drainage problems.

BBF reduce runoff under fallow and cropped conditions (Generalizations 4 and 5) but, except in the early growing season, they appear to have a substantial impact on soil loss only under fallow conditions because crop cover already is good erosion protection. BBF thus appear to be a method to increase in situ

15. We will continue to distinguish among (a) deep, (b) medium-deep, and (c) medium and shallow Vertisols because the water-holding capacity of the soil has a major impact on cropping possibilities and on potential benefits from irrigation. This distinction will, as we shall see, also be useful in considering benefits from soil surface treatments.

16. Other locations more suitable to chickpea or other postrainy-season crops will have different optimum cropping systems and so will those areas where factor or product price relationships are substantially different. For example, probability calculations need to be made for stations in Madhya Pradesh, in the high-rainfall kharif fallow area, to see whether the potentials and returns for sequential cropping are better there. Cropping systems work in cooperation with regional centers should increasingly take account of the results of simulation models.

17. Graded or guide bunds are small bunds that have one or both of the following two purposes: (1) to control the flow of runoff water where drainage of point rows is required because of changes in the direction of cultivation; (2) to indicate the direction of cultivation, in particular where nonpermanent BBF or flat, graded cultivation systems are used to control in situ runoff and erosion. They are similar to conventional graded bunds, although they are often much smaller,

Table 2. The effects of land treatments on runoff, soil erosion, and gross and net returns on deep and medium-deep Vertisols.

Generalizations	Source
From WBR and FSMT:	
1. Intercropping of maize/pigeonpea is more profitable than maize/chickpea sequential cropping.	ARFS 77-78 Table 103 ARFS 76-77 Table 71 RSP Table 3 Appendix Table 2 (FSMT)
2a. Crop cover reduces cumulative and available runoff by at least 10% and more than that in low rainfall years; this is true for both the flat cultivated and the BBF watersheds.	ARFS 76-77 Table 65 BW4C vs BW3B vs BW1, 2, 3A RP Table 3 and 5 regression coefficients RSP Table 5 long-term simulation JHK (1979)
2b. Crop cover greatly reduces soil erosion, often to less than one-fourth of the fallow treatment. With early vegetative cover, soil losses seem well within acceptable limits.	Appendix Table 2 BW4C vs others ARFS 76-77 Table 68 and page 184 BW4C and BW5B vs all others
3a. Contour bunds lead to losses in the monsoon and postmonsoon crops by causing waterlogging near the bund and by loss of cultivated land. They are not necessary if rainy-season crops are grown (see 2b).	- ARFS 76-77 - ARFS 77-78
3b. Under cropped and fallow conditions, contour bunds reduce watershed runoff by storing it temporarily above the bunds; water may evaporate or add to groundwater recharge (in situ runoff may not be reduced).	ARFS 76-77 Table 65 BW6B vs BW5BS and BW4C
3c. Well-designed and maintained contour bunds reduce watershed erosion, (in situ erosion may not be reduced).	

Continued

Table 2 continued

	Generalizations	Source
4a.	BBF reduces runoff under fallow conditions.	AFRS 76-77 Table 65 BW5BS vs BW4C ARFS 77-78 Page 219 BW5B vs BW4C
5a.	Under cropped conditions BBF reduces cumulative and available runoff by atleast 30% compared with flat cultivation.	ARFS 76-77 Table 66 (1976 data only), Table 50. RP Table 3 Table 5 pp 12, 13 regression coefficients RSP table 5 long-term simulation Appendix Table 2 (FSMT)
5b.	Under cropped conditions BBF may further reduce soil losses compared with flat cultivation, particularly if high intensity rainfall occurs early in the rainy season.	ARFS 76-77 Table 50 Appendix Table 2 BW3B vs BW3A
6a.	Under cropped conditions BBF give higher gross returns than flat planting (roughly 15%).	ARFS 76-77 Table 71 BW1, 2, 3A, vs BW3B, 4B ARFS 77-78 Table 103 BW1, 2, 3A vs BW3B, 4B Appendix Table 5 BW1, 2, 3, 7A vs BW3B, 4B
6b.	Under cropped conditions BBF give higher profits than flat planting (roughly Rs 600/ha).	- RSP, Table 3 BW1, 2, 3A, 7A vs BW3B, 4B
7.	BBF lead to savings in bullock time required for primary tillage but not in other operations, compared with flat cultivation.	- Appendix Table 1
8.	Operating within field boundaries may not lead to substantially lower gross returns and profits for either BBF or flat cultivation.	- RSP Fig. 8 BW2 vs BW1, BW7A - Appendix Table 6 BW2 vs BW1, BW7A OR BW2 vs BW1, BW3

Continued

Table 2 continued

	Generalizations	Source
9.	Management of cropping patterns and crops across field boundaries is extremely difficult for small groups.	- VSD Village experience 1979
10.	Short term group action to implement improved soil and water management systems appears feasible.	- Village experience 1979

Abbreviations:
ARFS = ICRISAT Annual Report, Farming Systems section
BBF = Broadbeds and furrows
Flat = Flat Planting System
FSMT = Field-Scale Land Management Techniques
JHK = Krishna (1979)
RP = Ryan and Pereira (1978)
RSP = Ryan, Sarin, and Pereira (1979)
VOSR = von Oppen and Subba Rao (1980)
VSD = Doherty (1979)
WBR = Watershed-Based Research

Cumulative runoff = The total annual runoff or total runoff up to 31 October.

Available runoff = Based on the RSP long-run simulation study and refers to runoff available on 31 October after adjustment for tank spillway flow and evaporation.

profile water infiltration on these soils regardless of whether they are cropped or fallow.[18] Particularly under fallow conditions, broadbeds and furrows combined with a system of graded or guide bunds may be capable of minimizing runoff and attaining control of erosion within fields and across watersheds.

Furthermore, under cropped conditions, the present system of BBF gives higher gross returns and profits than flat planting (Generalization 6). For primary tillage BBF lead to savings in bullock time compared to flat cultivation[19] (Generalization 7). Improved surface drainage is probably the major cause of increased

18. When the profile is already filled to capacity such increased infiltration may result in increased groundwater recharge rather than being usable by the crop. Evidence suggests that most runoff on these soils may indeed occur when they are already filled to capacity.

19. Both systems operated with wheeled tool carriers.

yields with BBF in this soil type. Other evidence and experience indeed suggest that the BBF-type system should be viewed primarily as a means to improve in situ surface drainage where that is a problem, even in soils other than the deep Vertisols. This should be kept in mind when studying the results of BBF on shallow soils.

For extension and implementation purposes (but not research) it is convenient to divide the system of farming into two parts: (1) soil- and water-management techniques; and (2) cropping patterns and agronomic practices. Soil- and water-management techniques designed to control runoff to dispose of excess water and to minimize erosion—frequently including direction of cultivation—have to be planned and implemented on a whole-watershed basis since guidance of water from plot to plot is crucial. On the other hand, cropping pattern decisions and agronomic practices should be adapted to the watershed topography only if the benefits of such group action are sufficient. The WBR allow us to test whether this may be the case. BBF and improved agronomic practices were introduced in BW2 in a way that respected the original field boundaries (i. e., each farmer in this situation could presumably adopt the BBF without changing the field boundaries and without affecting his neighbor). Comparing this watershed with the others (in particular BW1 and BW3 and/or BW7) suggests that watershed-based adaptation of field boundaries to graded cultivation may result in modest increases of gross returns (Generalization 8). However, it is doubtful that the gains to be realized from adjusting present field boundaries to BBF cultivation are sufficient to actually motivate farmers to exchange land on a voluntary basis.

Evidence from cross-cultural anthropological research suggests that small groups, such as the farmers on a watershed, can be brought to act as a group more easily to execute one task in a short period rather than to manage a whole host of decisions for a long period of time (Generalizations 9 and 10). The implementation of a system of bunds and BBF on a watershed seems to be such a specific, short-duration task, while crop management across field boundaries is not. Except for the Sholapur situation, the experience in the village watersheds in 1979 bears out these generalizations fairly well.[20] We therefore suggest that watershed work in the villages should be directed to watershed-based systems of drainage and runoff and erosion control but that the existing field boundaries in many situations can be respected without major adverse effects on the goals to be attained. Ongoing land consolidation programs, however, may provide opportunities for field boundary adjustments that should then be based on

20. Adhering to field boundaries in the Sholapur village would have resulted in taking out of production a relatively large area for field drains and bunds. Such an approach might well make the experiment unacceptable to the cooperating farmers because presently no field bunds exist. Evidently the local topography and property boundaries can, in selected cases, be such that respecting them both might make watershed-based implementation of erosion and drainage control systems very difficult.

watershed development principles. Where the topography and field boundaries are such that inordinate losses would occur if original boundaries were respected, land consolidation programs may even be considered a prerequisite to improving - the land resource on a watershed basis.

Generalizations for the Medium and Shallow Vertisols

Reporting of findings from watershed-based research on the medium and shallow Vertisols is less advanced because work on these soils was initiated later than that on deep and medium-deep Vertisols; they have also been less intensively monitored. Unfortunately, on a watershed scale, no contiguous areas of such Vertisols exist at ICRESAT allowing for uniform comparisons. On the other hand, SIIT experiments have been conducted on medium to shallow Vertisols[21] since 1975. One of the field-scale land management trials is located mostly on shallow Vertisols (BW8B).

Many of the tentative generalizations on these soils are similar to those derived earlier for the deep Vertisols (Table 3, Generalizations 1, 3, and 4). As expected, intercropping relative to sequential cropping is even more attractive on these soils of lower water storage potential because postrainy-season cropping is often not at all feasible on the medium and shallow Vertisols (Generalization 2). On these soils the presence of vegetative cover during the rainy season also has a major impact on runoff and erosion. Contour bunds are now common on these soils.[22]

Regression and simulation modeling of runoff has not been done separately for the medium to shallow Vertisols. This is because most analysis in the past assumed that one could expect deep and less-deep Vertisols to behave similarly with respect to runoff and soil loss, which are primarily soil surface phenomena. However, hydrologic data collected on soils of different depths during the past few years in the FSMT indicate that runoff potential (and therefore erosion) decreases as one moves to shallower soils (Generalization 5). Thus resource conservation may be a less critical issue on these soils.

21. The SIIT on Vertisols were conducted on the lower portion of BW8C, an area characterized during the rainy season by shallow groundwater and therefore by frequent inadequate drainage.

22. On medium and shallow Vertisols in low-rainfall kharif fallow areas, contour bunds may not be as easily dismissed as on deep Vertisols. While these soils must be cropped in the rainy season because of insufficient water storage capacity for postrainy-season cropping, the crop cover will often be poor in low-rainfall years providing insufficient erosion protection. Contour bunds do not of course affect in situ erosion but they do decrease watershed erosion. This might be a desirable objective in areas where erosion from contributing catchments threatens the efficient operation of irrigation reservoirs. (But bunds would also reduce runoff that may adversely affect existing reservoirs.) Water stagnation near the bunds will lead to losses to the rainy-season crop in high-rainfall years. Infiltration benefits near the bunds can be expected in low-rainfall years without high intensity, long-duration storms. Probability calculations are required to see under which condition waterlogging losses are offset by infiltration benefits. But even on these soils, guide bunds of low slope may often be more effective than contour bunds.

Table 3. The effects of land treatments on runoff, soil erosion, gross and net returns on medium and shallow Vertisols.[a]

	Generalizations	Source
	From WBR and FSMT:	
1.	Intercropping of maize/pigeonpea is higher yielding and more profitable than maize/ chickpea sequential cropping.	ARFS 77-78 Table 103 BW7B, C, D vs BW6C, ARFS 76-77 Table 72
2.	Cropping based on residual moisture in the post-monsoon is impossible.	Too small moisture storage capacity
3a.	Crop cover reduces cumulative and available runoff by at least 10% and by more in low rainfall years.	RP Table 3 and 5 regression coefficients RSP Table 5 long-term simulation
3b.	The crop cover effect on soil loss is not assembled separately but probably reduces losses to acceptable levels for all soil treatments.	
4.	Contour bunds lead to substantial waterlogging losses to rainy-season crops especially on medium Vertisols. Generalization 3b implies that they are not necessary.	
5a.	Runoff on ICRISAT Vertisols is lower the shallower the soils.	- Appendix Table 3 FSMT
5b.	Soil loss on ICRISAT Vertisols is lower the shallower the soils.	Appendix Table 3, FSMT BW8 vs BW5
6.	BBF do not affect runoff and erosion significantly.	- Appendix Table 3 FSMT
7.	BBF do not result in substantial yield, gross return, or profit increases.	Appendix Table 4 FSMT ARFS 77-78 Table 103 BW7B, C, D, vs BW6C, D Appendix Table 4 RSP Table 3, BW7B, 7C, 7D vs BW6C, 6D

Continued

Table 3 continued

Generalizations	Source
From SIIT	
8a. Soil and crop management (including BBF) leads to yield and profit increases.	- RSP 1979 Fig. 1 - ARFS 1976-77 Table 61 - ARFS 1977-78 Table 100
8b. The BBF system has its highest payoff when fertilizer level and/or variety are improved.	

a. Abbreviations are explained in Table 2.

b. The source table incorrectly designates BW6C, 6D as BW3B, 4B.

In Table 3, a key difference with the deeper Vertisols (based on WBR and FSMT data) appears to be that on medium and shallow Vertisols BBF do not affect runoff or erosion (Generalization 6) nor substantially increase yields or profits (Generalization 7). Our intuitive explanation and hypothesis is that this difference is caused by the absence of serious surface and subsurface drainage problems on the medium and shallow Vertisols used for experimentation in WBR and FSMT and that some situations may exist where BBF would be profitable because they solve specific drainage problems.

This tentative hypothesis is strengthened by the results of the SIIT experiments on these soils; they apparently contradict findings from research watersheds and FSMT by suggesting that management (including BBF) leads to higher yields and profits (Generalization 8a). "Management," as defined in the SIIT experiments includes broadbeds and furrows, improved weed control, and differences in equipment to perform seed and fertilizer placement (as well as some other operations). In BW8C, inadequate surface drainage conditions and shallow groundwater may further complicate the issue. We hypothesize that these confounding factors may be the reason for the apparent contradiction and suggest de-emphasizing the SIIT evidence on BBF with regard to well-drained, medium and shallow Vertisols.

We suggest that the difference in the effects of BBF on medium to shallow Vertisols, compared to medium-deep and deep Vertisols, requires urgent scientific resolution, to be done by careful analysis of existing data and, if necessary, by specifically directed experiments, .and that the already initiated research on alternative soil configurations be further strengthened. We also recommend an urgent search for more effective means to utilize the total available rainfall on these soils (e.g., through mulches and improved residue management).

Generalizations for the Alfisols

Most generalizations in Table 4 are concerned with BBF. The conclusions from WBR and the FSMT are that the presently used BBF generally increase runoff, do not reduce soil loss, and do not increase yields, gross returns, or profits. If one were interested in increasing runoff to store such water in a tank for breaking droughts in the rainy season or for postrainy-season use, one might advocate this system.[23] Also, in case one wanted to irrigate crops supplementally, graded furrows may be needed for applying the water. For most situations, however, alternative soil management techniques would seem required, and work is in progress to develop them. This research needs to be intensified, especially for situations where surface drainage problems are encountered.

As on the medium to shallow Vertisols, the SIIT experiments on Alfisols suggest an apparent contradiction in that they find improved management to result in higher yields and profits.[24] Management in the SIIT experiments on Alfisols included the same factors as on medium to shallow Vertisols; specifically the effects of improved equipment and BBF cannot be separated from one another. Under WBR and in the FSMT, broadbed-and-furrow and flat cultivation are both planted with the same equipment. We may hypothesize, therefore, that an important reason for the apparent contradiction between results from the watersheds and SIIT experiments is the better seed and fertilizer placement attained in BBF in the SIIT experiment. This hypothesis seems supported by 1978-79 tillage experiments in villages (Appendix Table 9) and from the literature on the effects of precision seed and fertilizer placement. We also note that conclusion 3b (Table 4) shows a strong interaction between management and fertilizer levels, which is consistent with our hypothesis. However, improved soil and crop management without the application of chemical fertilizer also increases SIIT yields both in case of traditional and high-yield-potential varieties (as in the Vertisol situation). Inadequate surface drainage is not expected to have been a significant factor in the SIIT experiments on Alfisols (contrary to the situation in medium to shallow Vertisols SIIT experiments). Thus, it is important to resolve the apparent contradiction between SIIT results and the WBR and FSMT-based evaluations of BBF on Alfisols.

23. Increasing runoff may also increase the risk to rainy-season crops if runoff occurs under conditions of a partially filled profile. However, most runoff comes from high-intensity storms during which the relatively low-water-storage capacity of the soil would be filled anyway.

24. The SIIT during the years selected for comparison were executed on a relatively deep Alfisol; WBR and FSMT were located on shallow to medium-deep Alfisols.

Table 4. The effects of soil treatments on runoff, soil erosion, and gross and net returns on Alfisols.[a]

Generalizations	Source
From WBR and FSMT:	
1a. Under cropped conditions, the present BBF usually increase cumulative or available runoff. At grades between 4 and 8% of BBF, cumulative and available runoff are substantially higher than under flat cultivation.	RP 1978 Table 7 regression coefficients RSP 1979 Table 5 simulation ARFS 1976-77 Table 67 RW1 D RW2 B vs RW1 C ARFS 1975-76 Tables 56,73 RW1D, RW2 B vs RW1 C Appendix Table 5 FSMT
1b. The present BBF may substantially increase soil loss.	ARFS 1975-76 Table 56 ARFS 1976-77 Table 68 RW1D, RW2B vs RW1C
1c. Different yields and gross returns are not substantial with BBF compared to flat cultivation.	RSP 1979 page 19 Appendix Table 5 FSMT
1d. Therefore profits are not expected to be higher for present BBF compared to flat cultivation under rainfed conditions.	
2a. Contour bunds reduce watershed runoff (but not in situ runoff) while graded bunds do not.	ARFS 1976-77 Table 67 RW1E vs RW1C
2b. Contour bunds reduce watershed soil loss (but not in situ loss).	ARFS 1976-77 Table 68 RW1E vs RW1C
From SIIT	
3a. Soil and crop management (including BBF) leads to yield and profit increases. (These increases are less than on medium to shallow Vertisols.)	RSP 1979 Fig. 4 ARFS 1976-77 Table 60 ARFS 1977-78 Table 101
3b. The BBF system has its highest payoff when seed and fertilizer are also improved.	

Continued

Table 4 continued

Generalizations	Source
3c. Even without the application of chemical fertilizers, improved soil and crop management results in improved yields.	

a. Abbreviations are explained in Table 2.

Storing Runoff for Supplementary Irrigation

The idea of runoff collection and use for supplemental irrigation presupposes that the potentials for using the available root profile storage more efficiently to buffer discontinuities in rainfall have been fully utilized. It is more efficient and cheaper to store water in the soil than in a tank. It must also be realized that runoff will frequently be least available in those years of erratic and low rainfall when the payoffs from supplemental water would presumably be largest. On any given soil type, the potential for supplementary irrigation from stored runoff is influenced strongly by the rainfall patterns (Generalizations 2b and 4b in Table 5) and by subsoil conditions (Generalization 4a). The actual feasibility of this technique will therefore always be highly location-specific.

Benefits from supplemental irrigation from stored water on small watersheds are more likely on the Alfisols than on deep to medium-deep Vertisols because: (1) Alfisols, at ICRISAT Center, have a higher runoff potential (Generalization 2a); and (2) Alfisols have a lower water-storage capacity and therefore a likely higher payoff from supplemental water. It also appears that medium to shallow Vertisols (at ICRISAT Center) have a lower runoff potential than the deep Vertisols (Generalization 2c). Benefits from storing runoff for supplementary irrigation on small catchments may therefore be low on shallow Vertisols, despite the fact that these soils have a limited water storage capacity. We recommend that the runoff potential on medium and shallow Vertisols in different climatic zcnes and toposequences be analyzed separately from the deep and medium-deep Vertisols.

On all deep and medium-deep Vertisols, storing water for supplementary irrigation of the rainy-season crop has little potential.[25]

25. We note that supplementary irrigation of postrainy-season crops on deep and medium-deep Vertisols may have potential under conditions of rainfall as high as Hyderabad or higher (RSP, Table 6), provided that water responses in that season can be shown to be large enough on a year after year basis.

Table 5. Runoff potentials and payoffs from stored water for Vertisols and Alfisols.[a]

Generalizations	Source
For <u>runoff collection</u>	
1. Watershed runoff increases less than proportionately with size of catchments.	- RSP Table 5
2a. Alfisols at ICRISAT have greater cumulative and available runoff than Vertisols.	RP Table 2 RSP Table 5 APFS 76-77 tables 65 and 66 APFS 75-76 tables 72 and 73
2b. Runoff potential on Hyderabad deep Vertisols is higher than on medium to shallow Vertisols at Sholapur.	RP Table 2 RSP Table 5
2c. On Hyderabad Vertisols, runoff potential increases with soil depth.	Appendix Table 3 BW5 vs BW8 (FSMT)
3. Larger catchments have a higher potential for profitable use of runoff water	- RSP Table 5
<u>For irrigation and organization</u>	
4a. Traditional tanks are concentrated on soils with low moisture retention capacity and in areas with granitic subsoils.	VOSR Vol. 1 Fig. 1 and Table 6 (regression coefficients)
4b. Traditional tanks are concentrated in low rainfall areas and especially where postrainy-season rains are substantial.	VOSR Vol. 1 Fig. 1 and Table 6 (regression coefficients)
5. Existing tanks in Alfisol areas are more profitable than in Vertisol areas. They are also better utilized.	VOSR Vol 2 Table 5 Appendix Table 7
6. Tank construction costs per unit of stored water tend to decrease with size of tank.	- Appendix Table 8

Continued

Table 5 continued

Generalizations	Source
7. Gravity flow can be used in larger tanks; small dug tanks require pumping, which may increase costs.	
8. Larger tanks have larger ratios of settled command area to submerged area. Therefore, they probably have lower relative evaporation losses.	- VOSR (Vol 2) Table 2
9. Larger tanks and groups of people can be supported by administrative systems while small ones depend more frequently on spontaneous group action.	- VSD
10. Supplemental irrigation from runoff collection on small watersheds is not profitable on medium and shallow Vertisols in Sholapur even for the postrainy-season crops.	- RSP Table 4 - RSP Table 6, 7 and page 26, 30
11. Supplemental irrigation from small-scale runoff collected may be profitable on Alfisols, especially if applied to high value crops.	- ARFS 75-76 page 202 - RSP table 4 - RSP table 8 and page 30

a. Abbreviations are explained in Table 2.

We further suggest that future research on supplemental irrigation of rainfed crops for Vertisols in the low rainfall zones be based primarily on lifting from rivers, large irrigation schemes, or well water rather than from stored small watershed runoff. On Alfisols all sources of water may be considered. Potential on a small scale may exist, especially for high-value upland crops.[26]

We recommend that an attempt be made to use existing information and the existing methodologies for mapping the semi-arid tropics of India into three zones: (1) where benefits from storing runoff for supplementary irrigation on

26. ICRISAT will have to decide whether research on supplementary irrigation from sources other than runoff collected on small agricultural watersheds and applied to crops other than its mandate crops, falls within its purview.

small watersheds are likely; (2) where such benefits are in question; and (3) where they are unlikely. To achieve this for countries other than India in the SAT, and to narrow down the "questionable" zone, will require specific focusing, of data-collection programs and more precise modeling exercises based on current research.

Generalizations 1, 3, 6, 7, 8, and 9 tend to suggest that for the "likely" zone, runoff collection may have to concentrate on improved water utilization in larger watersheds. The FSRP is already investigating water-use efficiency and potential improvements in traditional tank irrigation systems; the Economics Program has also done considerable research on management practices in such systems and on how to improve them (von Oppen and Subba Rao 1979).

These economies of scale have been realized from the early stages of research on the feasibility of storing water for supplementary irrigation in small catchments. However, shifting attention to larger-scale water collection and supplemental irrigation means a move down the toposequences, i. e., the benefits of the irrigation will tend to be concentrated on the deeper soils while the shallower upper reaches receive no benefits. Unless farmers have land at different points in the toposequence, such a move towards larger-scale reservoirs implies a distribution of benefits away from those with the poorest resources and to those with an already richer resource base. This potential tradeoff between equity and efficiency needs further investigation in particular because ICRISAT's mandate also relates to the farmers with the poorest resources.

Predicted Systems for Selected Areas

The variability encountered in the agroclimatic, soil, and socioeconomic environments makes attempts towards broad generalizations and prediction difficult; we refer back to the introduction on this issue.

The predicted systems (Table 6) are subject to further research and hinge on testing or confirming some of the hypotheses expressed in the earlier sections. We offer them as an integrative device.

With regard to the proposed cropping systems, it is realized that intercropping systems are most attractive only for a particular range of crops. Particularly in terms of rainy-season crop growth extended into the postrainy season, crops such as pigeonpea, cotton, and castor seem the most suitable. Postrainy-season cereals or legumes can often only be grown as sequential crops.

Relative to the deep and medium-deep Vertisol situations we can rule out small-scale watershed-based runoff collection for supplementary irrigation of rainy-season crops. For postrainy-season crops, such a system will not be

Table 6. Predicted farming systems for selected regions and soil types.

	Kharif Fallow				
	Sholapur (low rainfall) Deep Vertisols	Madhya Pradesh (high rainfall) Deep Vertisols	Hyderabad Deep Vertisols	Hyderabad Alfisols	Akola Medium to shallow Vertisols
Soil water management	Broadbeds and furrows Guide bunds Land smoothing Grassed waterways Emphasis on erosion control and infiltration	Guide bunds Broadbeds and furrows to be tested Land smoothing Grassed waterways Emphasis on drainage	Broadbeds and furrows Guide bunds Land smoothing Grassed waterways	Flat cultivation, except where supplemental water is available Guide bunds Land smoothing	Guide bunds Land smoothing Grassed waterways Cultivation and tillage to be investigated
Cropping system	Rainy-season fallow (possibly short duration low input rainy-season crop in some years)	Potential for rainy-season cropping to be investigated	Preferably rainy-season crops with intercrops	Rainy-season crops with intercrop	Rainy-season crop with intercrop
Runoff collection for supplementary irrigation	No	Not for rainy-season crops[a]	Not for rainy-season crops	Promising for high valued crops	Not for rainy-season crops[a]
Supplementary irrigation from other sources	To be investigated (if water is available)				
Group action	Confined to establishment and maintenance of the soil and water management system				

a. Potential may be explored for collecting runoff for supplemental irrigation of postrainy-season crops.

attractive in the Sholapur situation, but it may be attractive as one moves to higher rainfall zones.

We further note that we cannot extrapolate the findings from the low-rainfall kharif fallow zone to the high-rainfall kharif fallow zone without first gaining a better understanding of what the basic causes of the rainy-season fallow are. It is clear that in the high-rainfall kharif fallow area, most components are still poorly understood.

Where Table 6 indicates flat cultivation systems, the benefits of graded flat systems need to be investigated. With respect to possible flat cultivation systems, implements other than the wheeled tool carrier should be considered. Low cost precision seeding with fertilizer application may be essential if our earlier hypothesis on the importance of seed-fertilizer placement is confirmed.

On Alfisols receiving supplementary irrigation, some type of broadbed-and-furrow system may be required to effectively guide the water. Village experience suggests that farmers often use similar systems when irrigating crops such as chillies.

With respect to grassed waterways, experience is very positive on all soil types at ICRESAT Center. Whether grasses can survive the dry season under grazing pressure is currently being investigated for the different soil types in our on-farm studies.

Broader Implications for ICRISAT Research

Our specific suggestions for research are summarized in Appendix 1. Such a list will be a revolving one as current issues are solved and new hypotheses suggest themselves. Here we focus on broader implications.

Based primarily upon a priori reasoning, it was suggested in an earlier paper (Binswanger et al., 1976) that farming systems research at ICRISAT should focus on:

1. Assembling and interpreting existing base-line data in the areas of climatology, soil science, water management, plant protection, and economics.

2. International assembly and communication of basic and applied research results.

3. Basic or supportive research on research methodology, agronomy,

physiology, crop competition, land and water management, hydrology, soil science, etc.

4. Simulation or systems-analysis studies based on climate, soil, and economic information to predict potential performances of cropping patterns, and cultivation or soil-and water-management practices.

5. Organization of international cooperative trials and networks.

6. Training of researchers for national research institutes.

7. Development of applicable farming systems at benchmark locations.

In recognizing the striking location specificity of the predicted farming systems, we believe that the experience gained in the past few years clearly supports such a distribution of emphasis. Taking into account what has happened since then, we note:

1. The continued need for more emphasis on comparative evaluation of research done elsewhere and at ICRISAT and for the dissemination of results from such reviews.

2. The requirement for rapid publication of the valuable data and evidence from watershed-based and other resource-management research, the supporting evidence from the Economics Program, and the evidence from the tank studies of the Farming Systems Research Program and the Economics Program.

3. The value of science-oriented research that enabled the improvement of simple soil moisture, runoff, and tank irrigation models on which the essential conclusions of this paper are based.

4. A need for the widespread use of simple models to test as many alternative hypotheses as possible.

5. A need for maps based on review and simulation work for various production techniques such as that for dry seeding (Fig. 1).

6. An urgent need to determine uniform data sets to be collected in multipurpose or omnibus experiments in order: (1) to characterize the environment of the experiments from all agronomically relevant points of view; and (2) to generate data sets to test and improve components of systems models.

7. An increased effort in cooperative research programs at research

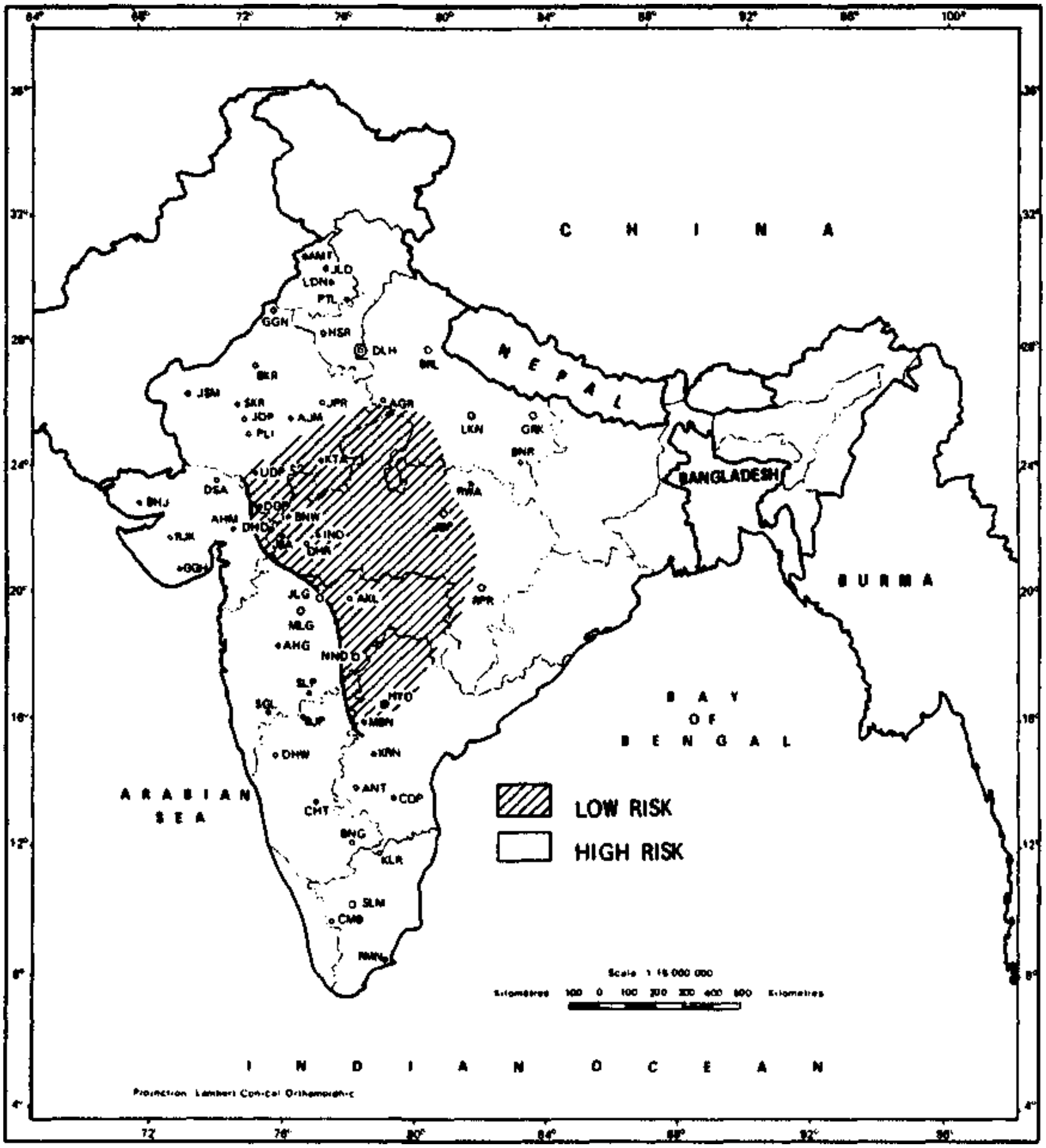

Figure 1. Possibilities of dry seeding on Vertisol.

Source: Virmani, S. M., "Climatic Approach for Transfer of Farming Systems Technology in the Semi-Arid Tropics," ICRISAT, August 1979.

centers and on farms to rapidly generate the required uniform data sets and to facilitate local adaptation of broad principles.[27]

8. An increased emphasis on looking at the farming systems as consisting of components to be assembled differently for distinct regions according to their profitabilities, costs, and local preferences.

We note that it would be impossible to maintain the quantity of experimental effort implied in these suggestions at ICRISAT Center with present staffing levels. Review of evidence from many diverse sources and interpretation and publication of research results take considerable time. Emphasis on cooperative research at national research stations and in villages (where much of the ultimate assembly and evaluation of systems would take place), is similarly time-consuming and often more challenging than research at a single experiment station. The importance of research at ICRISAT Center is in no way diminished by our suggestions; such research has to be focused on testing specific crucial hypotheses and/or on improving basic knowledge to improve model components and individual technology components of the system.

27. In the area of land and water management two cooperative research efforts started in 1978 in collaboration with AICRPDA research stations. The first focuses on resource development, conservation, and utilization with respect to soil and water (similar to FSMT). It currently involves research at 16 stations. The second consists of a set of hydrological studies to improve land and water utilization in small agricultural watersheds earlier described as WBR. It currently involves four locations. Cooperation with AICRPDA in on-farm studies is presently limited to the three villages of Aurepalle, Shirapur, and Kanzara.

Appendix 1. A Summary of Research Suggestions

The research suggestions below are not a list of research topics for the entire Farming Systems Research Program but are confined to the areas covered in this paper. They include suggestions for crop improvement research and support of crop improvement research. They often may require review work, or cooperative research, rather than research at the Center.

We divide them into two sets: "Immediate objectives" are research projects required to firm up the evidence on which the generalizations are based, to more clearly define their geographic scope and/or to refine specific components of the predicted farming systems; "Intermediate and long-run objectives" relate to opportunities arising from the generalizations where we feel that ICRISAT now has methodologies and comparative advantage, but where refinements and/or additional data gathering may be required.

Immediate Objectives

	Programs/Subprograms
1. Resolve the question why BBF improve yield and profits on deep Vertisols but less or not at all on medium to shallow Vertisols.	E. Physics L & W. Management
2. Review existing data to see how much BBF reduce erosion and improve infiltration and/or drainage under fallow conditions on Vertisols (for irreducible kharif fallow areas).	L & W. Management
3. Test BBF in high-rainfall kharif fallow areas on medium-deep and deep Vertisols.	L & W. Management
4. Determine through survey and soil sampling techniques the factors <u>most</u> responsible for high rainfall/kharif fallow and how they can be overcome.	L & W. Management E. Physics Agroclimatology Economics
Investigate which factors are responsible for low-yield and low-fertilizer responsiveness of rabi sorghum (such as temperature, soil moisture, and nutrient availability) and how they can be overcome.	Breeding Physiology S. Chem & Fert.

6.	Review and compare the impact of better seed and fertilizer placement on yields by soil type and fertility level.	Machinery S. Chem & Fert. L & W. Management
7.	Identify and test technical minimum machinery packages necessary to achieve the sometimes considerable management effects identified in SET and on-farm research, with special emphasis on the effects of seed-fertilizer placement.	Machinery Production Agronomy
8.	Explore and evolve institutional and legal alternatives to implement and maintain soil-water management systems on a watershed basis respecting or only slightly modifying existing field boundaries.	Economics L & W. Management
9.	Review experiment station evidence on cropping systems and conduct probability-based model exercises of alternative systems for selected locations of current or future ICRISAT involvement.	Cropping Systems Agroclimatology E. Physics

Medium and Long-Range Objectives

Farming systems work must emphasize comparative classifications of the SAT. into promising, unpromising, and questionable zones for specific production techniques or subsystems. The classification schemes cannot be general but must be specific to the production technique or subsystem studied. The topics are not listed in order of priority.

A. Classifications that can probably be done on the basis of currently existing methodologies (but for which additional data may be required):

1.	Runoff collection for supplementary irrigation	L & W. Management Agroclimatology E. Physics Economics
2.	Dry seeding	Agroclimatology Production Agronomy
3.	Low-rainfall kharif fallow zone	Agroclimatology E. Physics

4. Subzones of major ICRISAT crop-growing zones by optimal length of crop growth cycle[a]	Agroclimatology Breeding

B. For ICRISAT to do similar mapping for other techniques, more research is required along the following lines:

1. Summarize existing knowledge on cropping systems by agroclimatic zone and explore ways in which to predict optimal combinations for different locations.	Cr. Systems Agroclimatology Agronomy
2. Explore potential of deriving optimal decision rules for cropping patterns based on observed soil moisture at the beginning of the kharif and/or rabi seasons.[b]	Agroclimatology E. Physics
3. Explore the potential of clustering techniques to group together distant locations with similar agroclimatic conditions to facilitate research planning and technology transfer.[c]	Agroclimatology E. Physics
4. Develop a rainfall-driven, process-based model enabling the mapping of the SAT into areas where photosensitive genotypes are required.	Breeding Agroclimatology E. Physics
5. Explore potentials of converting existing tanks for supplying supplementary irrigation of dry crops,[d]	L & W. Management Agroclimatology Prod. Agronomy Economics
6. Intensify research on more effective land management systems by studying alternatives to BBF on Alfisols and medium to deep Vertisols.	L & W. Management Production Agronomy E. Physics
7. Explore cropping systems for medium and shallow Vertisols in low-rainfall kharif fallow areas.	Cr. Systems Agronomy Agroclimatology

a. For example, questions such as "how large is the zone that would benefit from a 60-day sorghum in Africa," etc.

6. Special emphasis on kharif fallow belt.

c. Based on soil moisture and possibly temperature.

d. Emphasis on Indian Alfisol areas and possibly shallow Vertisols.

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Appendix Table 1. Field capacity of one bullock pair with wheeled tool carrier for various operations on broadbeds and furrows and flat planted fields (1978-79).

Management	Broadbeds and Furrows			Flat			
Watershed	BW1	BW2		RW1E	BW4A	BW4B	
Area	3.25	3.46	Average	1.46	2.75	2.16	Average
Operations							
Cultivation or	0.27	0.46	0.36	0.30	0.14		0.22
disking						0.17	0.17
Sowing	0.30	0.23	0.26	0.38	0.33	0.38	0.36
Interrow							
cultivation I	0.32	0.16	0.24	0.37	0.14	-	0.25
cultivation II	0.45	0.33	0.39				
Total bullock pair hours per ha[a]	25.9	29.8		24.3	32.4	18.8	

Source: Courtesy of G. E. Thierstein

a. Includes other operations not listed.

Note: On broadbeds and furrows a substantial increase in field capacity, or alternatively bullock saving, appears possible for the field preparation, but not for other operations. Overall the evidence does not suggest appreciable bullock saving by broadbeds and furrows.

Appendix Table 2. Runoff and soil loss data from watersheds (kindly provided on comparable basis by Mr. P. Pathak).

Year	Watershed	Runoff		Soil loss	
		Comparable total in mm[a]	Year total in mm	Comparable total in tonnes[a]	Year total in tonnes
1976	BW1 BBF 0.6% cropped	46	73	.596	.851
	BW2 BBF 0.6% cropped field bunds	28	53	.118	.332
	BW3A BBF 0.4% cropped	33	51	.197	.285
	BW3B flat cropped	70	n.a	.475	n.a
	BW4C flat fallow[b]	143	238	1.77	9.195
1977	BW1	1		.073	
	BW2	0		0	
	BW3A	0.4		.048	
	BW3B	0.05		.008	
	BW4C	53		1.68	
1978	BW1	31	272	.919	3.411
	BW2	9	185	.091	1.705
	BW3A	19	195	.945	3.626
	BW3B	52	n.a	.385	n.a
	BW4C	102	410	2.500	9.693
Three years totals	BW1	78	346	1.588	4.335
	BW2	37	238	.209	2.037
	BW3A	52	246	1.19	3.959
	BW3B	122	n.a	.868	n.a
	BW4C	298	701	5.95	20.568

a. Runoff and soil loss measurements were beset with problems in BW3B during 1976 and 1978. Therefore, for comparisons with BW3B only the comparable total should be used which, for all watersheds, measures only runoff and soil loss for those storms for which measurements are available for BW3B.

b. Fallow means fallow during the kharif season only but cropped during the rabi season. Cropped watersheds are cropped during both seasons.

Appendix Table 3. Runoff and soil loss estimation under different treatments in Field-Scale Management Trials.

Deep Vertisols, BW5

Year	Runoff (mm)		Soil loss (tonnes/ha)	
	Flat	Beds	Flat	Beds
1976	141.1	109.9	2.40	1.70
1977	0.8	0.6	0.04	0.04
1978 a. seasonal	240.8	250.6	2.10	1.38
b. excluding storms of 14-15 Aug.	132.0	96.9	1.81	0.86
1979	63.4	53.9	0.84	0.73
Totals (excluding 14-15 Aug.)	337.0	261.0	5.19	3.33

Shallow Vertisols, BW8

Year	Runoff (mm)		Soil loss (tonnes/ha)	
	Flat	Beds	Flat	Beds
1976	14.1	16.9	0.12	0.23
1977	2.1	5.9	0.07	0.25
1978 a. seasonal	147.9	ND	1.43	ND
b. excluding the storm of 14-15 Aug.	45.3	65.3	0.61	0.81
1979	21.5	21.2	0.16	0.23
Totals (excluding 14-15 Aug.)	83.0	109.0	0.95	1.52

ND=no data: the recorder clock did not work on 14-15 August.

Appendix Table 4. Yields (kg/ha) and gross returns (Rs/ha) on flat versus broadbeds and furrows in 1976, 1977, and 1978 Field-Scale Management Trials.

Medium-Deep Vertisols

Treatment	Maize			Chickpea				Produce values[b]			
	1976	1977	1978	1976		1977	1978	1976		1977	1978
				Dry	Irr[a]			Dry	Irr[a]		
Flat	2430	2640	1790	410	580	840	980	2970	3160	4290	3856
Beds	3490	2420	2100	800	1060	960	1100	4320	4640	4360	4405

Medium to Shallow Vertisols

Treatment	Maize			P. P	Ch. P	Saff.	P. P	Produce values[b]		
	1976	1977	1978	1976	1977	1977	1978	1976	1977	1978
Flat	2690	2260	670	510	220	480	510	3800	2880	1963
Beds	3040	2100	980	620	170	380	610	4320	2560	2505

a. One irrigation was applied at planting time in 1976 in two replications.
b. Prices used are market prices from Hyderabad.

Appendix Table 5. Yields, runoff and soil loss under different treatments in Field-Scale Management Trials.

	Alfisols									
	1976		1977		1978		1979		All years	
	Flat	BBF[a]	Flat	BBF	Flat	BBF	Flat	BBF	Flat	BBF
Sorghum (kg/ha)	2790	2300	700	1280	2920	2420	2940	2460	9350	8460
Ratoon Sorghum (kg/ha)	680	570								
Pigeonpea (kg/ha)			230	500	880	910	230	70	1340	1480
Runoff (% of R. F.)	5.4	13.4	4.3	6.3	ND	ND	12.0	14.5	21.7	34.2
Soil loss (T/ha)	0.2	1.0	0.4	0.4	ND	ND	0.4	0.7	1.0	2.1

a. BBF = broadbeds and furrows.
ND = no reliable data available.

Appendix Table 6. Comparison of gross returns and profits (Rs/ha) under broadbeds and furrows operations within and across field boundaries.[a]

Crop year	1976-77		1977-78		1978-79		Average	
Crop system	Inter crop	Seq. crop	Inter crop	Seq. crop	Inter crop	Seq. crop	Inter crop	Seq. crop
A. Gross Returns[b]								
BW2 (within boundaries)	5319	4325	5358	5732	4737	4552	5138	4870
BW1 (across boundaries)	4885	4480	4974	5652	5126	4766	4995	4966
BW3A (across boundaries)	4946	4538	6403	5598	5868	5943	5739	5360
Average BW1 and BW3A	4916	4509	5688	5625	5497	5355	5367	5163
BW7A (across boundaries)	3722	3706	5315	5193	3615	4303	4217	4401
Average BW1, BW3A, BW7A	4518	4241	5564	5481	4870	5004	4984	4909

B. Profits

Maize pigeonpea intercrop	1976-77	1977-78	Average
BW2 (within boundaries)	3125	3968	3547
BW1 (across boundaries)	2706	3599	3153
BW3A (across boundaries)	2879	4988	3934
Average BW1 and BW3A	2793	4294	3543
BW7A (across boundaries)	1724	3911	2818
Average BW1, BW3A, BW7A	2436	4166	3302

a. Such comparisons are primarily illustrative since no replicated experiments can be done on this issue. Analysis in different programs have made comparisons based on different watersheds. These differences arise because, with the exception of BW1 and BW2, watersheds differ in other dimensions in addition to the difference in field boundaries. We simply report all comparisons currently available.

b. Prices used for the analysis are average market prices from Hyderabad and the same for all watersheds but they differ across years.

Appendix Table 7. Average utilization of tanks in selected districts.

District	No. of tanks studied	Av. settled command area acres	Av. actual area irrigated by tanks	% utilization (4)/(3) X 100
(1)	(2)	(3)	(4)	(5)
Medak	10	340	346	102
Mahbubnagar	10	232	150	65
Anantapur	3	827	1069	129
Kurnool	2	693	317	46
Sholapur	3	952	309	32

Source: Survey Data (KVSR) Tank Irrigation Project

Appendix Table 8. Cost of tank construction by size groups in selected districts (Rs/acre of settled command area).

	Medak	Mahabubnagar	Anantapur	Kurnool	Akola	Sholapur
Small (< 250 acres)	5036	5115				
Medium (250-500 acres)	3836	3717	3627	4031	3102	3053
Big (Above 500 acres)	2843	2859	3392	2511	2247	2032
All	3904	3987	3434	2861	2358	2205

Source: Tank irrigation project. For details see VoSR Part II

Appendix Table 9. Impact of implements and broadbeds and furrows (Rs/ha).

Increase due to	Gross returns			Gross profits[a]		
	Pigeonpea sorghum intercrop	Castor	Pigeonpea pearl millet intercrop	Pigeonpea sorghum intercrop	Castor	Pigeonpea pearl millet intercrop
Mahboobnagar (Alfisols)						
Implements[b]	907 (61)	611 (84)	591 (99)	691	508	178
Broadbeds and furrows[c]	262 (11)	-22 (-2)	-106 (-9)	196	-8	-162
Akola (medium-deep Vertisols)						
		Maize	Kharif sorghum		Maize	Kharif sorghum
Implements	135 (9)	387 (29)	300 (17)	85	273	111
Broadbeds and furrows	252 (15)	-460 (-27)	36 (2)	265	-454	81
Sholapur (deep Vertisols)						
		Mung followed by sorghum	Rabi sorghum		Mung followed by sorghum	Rabi sorghum
Implements	956 (27)	969 (36)	311 (16)	1484	656	72
Broadbeds and furrows	127 (3)	78 (2)	140 (6)	290	272	44

a. Gross profits are defined as gross returns less costs for material inputs, machinery and bullock labor.
b. Changing from traditional to improved implements on flat.
c. Changing from flat to Broadbeds and furrows (BBF) with improved implements.

Number in parentheses are percentage changes with gross returns of lower technology level as basis for percentage change.

A-0038