LAND AND WATER MANAGEMENT IN RAINFED FARMING SYSTEMS[1]

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[1] Paper presented at the IRAT-ICRISAT Workshop on Water Management and Crop Production, Montpellier, France, 3-6 May 1982.

[2] Agricultural Engineer, Principal Soil and Water Engineer, Principal Soil and Water Scientist, and Program Leader, Farming Systems Research Program respectively. International Crops Research Institute for the Semi-Arid Tropics, Patancheru P.O., A.P. 502 324, India

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SUMMARY

Land and water are the key elements of the resource-base of rainfed farming systems and strategies for effective management of these resources are intimately linked. This paper reviews ICRISAT's research approach for developing improved land and water management practices and their integration with other aspects of farming system. The small watershed-based farming systems approach which holds a good promise for management of Vertisols is discussed. The present status of research on Alfisol management, tank irrigation and runoff modeling at ICRISAT has been reviewed.

1. INTRODUCTION

The organization, activities and goals of Farming Systems Research Program at ICRISAT are based on the premise the a substantial improvement in the productivity of rainfed farming in the Semi-Arid Tropics (SAT) is feasible through a better management of resources -- natural as well as socioeconomic. The farming systems research begins and ends on the farm. It emphasizes problem oriented studies and is multi-disciplinary involving scientists, farmers, government and private industry (Swindale 1981). Land and water are the key elements of the

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resource-base of farming systems and their management strategies are intimately linked. At ICRISAT, several land and water management practices have been studied over the past few years. In these studies the interactive role of factors like climate, energy, crops, fertility, farm implements and socioeconomics vis-a-vis land and water management practices has been consciously recognized. The aim of this paper is to present the approaches and summarize some of the main research results relating to the following aspects:

- o Land management practices for Vertisols and Alfisols, and watershed management.
- o Water harvesting and recycling for supplemental irrigation.
- o Runoff modeling.

2. SOIL AND CLIMATE AT ICRISAT CENTER

Vertisols (black soils) and Alfisols (red soils) which are two of the most abundant soils in the SAT are found at the ICRISAT Center. Although they may occur in close association, their management requirements and runoff characteristics are very different. The most striking example is the fact that farmers crop Alfisols during the rainy season and most of the Vertisols only during the postrainy-season. During the rainy season, runoff is observed to occur earlier on Alfisols than on Vertisols. Their constrasting nature is attributed primarily to differences in types and amount of clay, moisture holding capacity, workability and other associated characteristics.

Vertisols are dark calcareous soils with depths greater than 90 cm. Due to the high content of the montmorillonitic type of clay shrinkage during drying is pronounced as is swelling during wetting. When fully recharged, Vertisols contain from 200-300 mm of available moisture sufficient enough to grow a postrainy-season crop (Virmani 1980). Because of the clay type and the relatively high clay content (50 to 60%), these soils are usually imperfectly drained and have a moderate low hydraulic conductivity. Alfisols are relatively better drained with a moderate hydraulic conductivity. They have variable soil texture ranging from loamy sand to sandy loam at the surface and gravelly clay in the subsurface. They contain 5-15% clay with the clay content, dominantly kaolinite, generally higher in the subsurface layer.

Because of the differences in their clay mineralogy, Vertisols tend to shrink and form cracks when dry while Alfisols tend to form surface crust in drying after heavy rains. Their infiltration is greatly influenced by this difference in behaviour as shown in Table (Krantz et al. 1978).

Thus, inspite of the low infiltration rates of Vertisols, the water intake rate early in the monsoon is high due to the deep cracks and high water holding capacity. The cracks continue to exist as such until sufficient wetting occurs and then the infiltration decreases sharply. In contrast, the initially high infiltration rate of Alfisols drops down quickly and is often greatly reduced during the early rainy season by surface sealing caused by the impact of rain drops on the bare soil.

From an agricultural standpoint the Hyderabad area and much of the SAT can be divided into 3 seasons (Krantz et al. 1978):

- Humid or rainy season of 100-110 day duration. This season, in which rainfall exceeds evapotranspiration, is characterized by a number of high intensity sotrms and occasional prolonged rainless periods. The rainfall ranges from 600-1000 mm/yr with about 85 percent occurring during the rainy season. With improved soil, water and crop management, this period has a high potential for crop production.
- Cool, dry postrainy season of 140-150 days. In this period there is little or no rain, and crop production is dependent mainly upon stored soil moisture and, where feasible, on stored water from tanks or shallow wells. Crop production during this season is better adapted to the deep Vertisols because of their high moisture-retention capacity. However, where water has been stored, crops can be grown on Alfisols and shallow Vertisols by use of supplemental irrigation.
- Hot, dry season of 100-120 day duration. In rainfed agriculture this season is not well suited for crop production because of the high water requirement. This period is however, well suited for land development for improved resources utilization, for land preparation, and for crop sanitation involving weed -- and insect -- source reduction. Although the total rainfall during this period is very low, it is characterized by occurrence of one to three high-intensity storms which facilitates land development and preparation.

3. RESEARCH APPROACH

The land and water management research at ICRISAT is largely based on the analysis of problems on 'real world' farms and certain conventional ameliorative approaches like rainy season fallowing and contour bunding (Kampen and associates 1974).

Most of the component research is executed in small field plots under carefully controlled and manageable conditions. Although these experiments may not give complete answers to questions of actual implementation on a farm scale or to be economic issues involved, they are considered valuable for finding 'leades' for further studies. In order to provide a fuller expression to factors like runoff, erosion and drainage, field size plots of over 0.3 ha size have been used for evaluating some alternative land treatments like broadbed nd furrow and graded flat. Natural watersheds of over 2 ha size have been used for simulating and studying practices like contour and field bunding, safe runoff and disposal and runoff recycling.

On-station operational research is considered as a necessary phase both to test the operational feasibility of practices and implements as a prior step to on-farm research and also to obtain accurate data on time dependent variabilities. This phase of research has been executed on natural watersheds to enable integration of land and water management practices with other technology compoments and to have systems. According to Kampen (1979), watershed is the natural framework for resource development in rainfed agriculture.

The on-farm research is conducted to test and adapt improved technology with participation of farmers, make adoption studies and provide data with demonstration value. Village watersheds of 10-30 ha size are being used for this phase of research.

4. SMALL WATERSHED APPROACH FOR VERTISOLS MANAGEMENT

The low productivity and soil erosion problems of traditional farming systems of Vertisols which are generally fallowed during the rainy season merited priority research attention. It was hypothesized that most of the Vertisols fallowed during the rainy season in Hyderabad region can be double cropped through an appropriate soil-, water-, and crop-management technology. In a computerized water-balance model involving 70 years of rainfall data, soil moisture retention capacity and crop requirements at Hyderabad, the median length of growing season in Vertisols was calculated as 26 weeks (Virmani 1980). In the traditional system of rainy season fallow-postrainy season cropping, the growing season is only 14 weeks. It was found that the practice of contour bunding on these soils leads to yield reduction due to waterlogging near the bunds (ICRISAT Annual Report 1975-76). Similar results were obtained at Bellary Center of the All India Coordinated Research Project on Dryland Agriculture (Chittaranjan and Patnaik 1977).

Evidently, a prospective technology for Vertisol management should include the following features (Virmani et al. 1981).

- Land and water management practices that reduce runoff and erosion, and that give improved surface drainage and better aeration and workability of the soil.
- Cropping system and crop management practices that establish a crop at the very beginning of the rainy season, that make efficient use of moisture throughout both the rainy and postrainy seasons, and that give high sustained level of yields.
- Implements for cultivation, seeding and fertilizing that enable the required land and crop management practices to be effectively carried out. The implements should be suited to animal and human

sources of power.

a) Evaluation of Integrated Technology

Through the experimental studies at ICRISAT, a small watershed integrated approach for Vertisol management was evolved which includes the above mentioned features. 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 grassed waterways and use of graded broadbeds and furrow;
- 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
- some attention to plant protection.

On-station operation research extending over 5 years (1976-77 to 1980-81) has shown that this improved watershed management approach including maize intercropped with pigeonpea can increase profits by about 600% compared with a traditional system based on arainy season fallow followed by postrainy season sorghum or chickpea. This represents a rate of raturn on the added operating expenditures of 250% (Ryan and Sarin 1981). In addition to improvement in productivity, this approach has substantial resource conservation benefits as shown in Table 2. It is evident that runoff is reduced by about 50% and soil loss by over 80%.

It was found that absolute variability in profit is increased, although percentage variability is decreased. The needs for human labaor increase by 250% or more and the pattern of labor use is changed. More labor is needed in the early months of the cropping year, even in April and May, when traditional farm labor use is minimal. Labor peaks occur at normal times but are much greater. If threshing and harvesting must be done by hand, the labor peaks are extreme, particularly in October and November when the first -- that is, the additional crop must be harvested and the second crop planted. There is also a greater need for the use of bullocks. Availability of bullock power represents a serious constraint for the smallest farmers, few of whom own bullocks (Ryan and Sarin 1981).

Institutional help is required to: help the smallest farmers obtain access to bullock power; provide for some community drains; and obtain credit for enterpreneurs to purchase the wheeled tool carrier. New marketing strategies may be necessary to cope with increased local supplies of crops. Storage facilities on the farm or in the village may be needed to prevent spoilage and to ensure that whatever is supplied to the market is in reasonable balance with demand (Swindale 1981).

All Vertisol regions of world will not be suitable for this type of technology. The ICRISAT agroclimatologists have delineated geographical locations of Vertisol regions in India where this technology is likely to hold promise.

For on-farm verification last year we chose a 15 ha watershed in a village called Tadanpally, 40 km north of ICRISAT. Although during 1981 the rainfall was 70% above normal, the watershed management approach was performed well. Two reasonably good crops were raised in the watershed area during 1981-82 where only one grew before. The economics of this improved system has been found to be extremely effective with a rate of return on added expenditures of 244% (Ryan et al. 1982); the adoption and diffusion will be monitored over the coming years.

Similar on-farm verification studies are being initiated this year at Raisen district in the state of Madhya Pradesh and at Gulbarga district in Karnataka (both in India).

b) Evaluation of Land-Treatment Component

In the on-station operational research and on-farm studies described earlier, the multicomponent improved technology has been compared with traditional technology. A separate experiment was felt necessary to study the effect of land treatment component alone. This study (1976-77 to 1980-81) was conducted in field size plots with about 1.5% land slope to compare the 150 cm wide graded broadbed and furrow (BBF) with the graded flat cultivation keeping both the land treatments under improved level of inputs. Both the land treatments were laid on a grade of 0.4 to 0.8%. The BBF land treatments consists of two distinct zones: about 100 cm wide bed zone which is used for cropping, and about 50 cm wide furrow zone which is used for traffic. A sequential cropping of maize followed by chickpea was grown. It was noted that the BBF treatment has substantially lower penetration resistance in its cropping zone as compared to a corresponding zone in flat (Fig. 1). It was also found that during the wet spells airfilled porosity (measured using the difference method; Vomocil 1965) was substantially higher in 0-15 cm layer of cropping zone of BBF as compared to that in flat (Fig. 2). The runoff and soil loss were found to be slightly lower in the BBF as compared to the flat (Table 3). The average produce value was higher by about Rs 600/ha on BBF plots as compared to the flat. The BBF was observed to be particularly advantageous in years of high rainfall. The measurements by Ali Khani (1980) showed that draft is substantially lower in BBF system as compared to the flat. The lower penetration resistance on beds facilitated land preparation during the dry season and the placement of fertilizer and seeds in dry soil at about the desired 8-10 cm depth.

A detailed observation of time requirement for primary tillage, planting, and intercultivation operations showed that the semi-permanent BBF treatment results in considerable saving of time over graded flat as shown in Table 4 (Bansal and Srivastava 1981). Differences in time requirements may be due to several reasons:

o In the BBF treatment only the bed zone is actually tilled during the land preparation phase.

- Operations are speeded up because furrows guide animals and the wheeled tool carrier.
- There is less compaction in the bed zone.
- In the graded-flat treatment 2-3 harrowing operations were executed using the traditional blade harrow.

c) Layout of BBF

The layout of the BBF is flexible and has to be specifically designed for a given location keeping in view the waterhsed characteristics. A detailed topographic survey of the proposed watershed is first made and main and auxillary waterways are planned along topographic depression lines. The beds and furrows are laid at a grade of 0.4-0.8% and a maximum length of run of 100 m is used. The direction of beds is adjusted in a way to minimize top soil movement. The broadbed and furrow layout can be optimized in a natural watershed keeping the waterway length to the minimum essential, but it can also be laid out within a farmer's existing field boundaries where opportunity for adequate drainage is available. This is achieved by planning within the field boundaries and linking the field drains to main waterways of the watersheds. Three alternative land and water management approaches for a Vertisol watershed are illustrated in Figure 3. Approach (a) depicts contour bunding practice which often leads to water stagnation near bunds and reduction in crop yields. Approach (b) shows broadbed and furrow layout within the field boundaries, and field drains linked to main waterway of the watershed. In Approach (c) the broadbed and furrow layout has been planned after removing farmers' field boundaries. In the on-farm verification studies discussed earlier, the field boundaries have been respected and Approach (b) has been used for laying out broadbed and furrows.

5. LAND MANAGEMENT FOR ALIFSOLS

The Alfisols are often characterized by relatively shallow depth, low water retention capacity and unstable soil structure leading to surface sealing during high intensity rain storms. The studies at ICRISAT have shown that considerable runoff occurs in these soils during the early phase of monsoon even when the profile is not yet adequately recharged.

Contour and graded bunding are the locally recommended soil and water management practices for these soils. The major shortcomings with these practices are concentrated water flow along unprotected depression lines and uncontrolled soil and water movement along the main slope in the inter-terrace area. Cooperative studies have been conducted at ICRISAT and several research stations of the All india Coordinated Research Project on Dryland Agriculture to improve inter-terrace land management. It was hypothesized that if water flow is controlled through closely spaced furrows, this could improve in situ soil and water conservation. The surface configurations namely narrow ridge and furrow (75 cm), broadbed and furrow 150 cm), and a wave or sinusoidal shape (150 cm) were used as examples of this approach.

These surface configurations have not shown any appreciable and consistent improvement in crop growth environment over graded flat cultivation.

Based on the existing research evidence and experience, the practices of land smoothing, guide bunds and graded flat cultivation have been predicted to be suitable for Alfisol management in the Hyderabad region (Binswanger et al. 1980).

6. WATER HARVESTING AND SUPPLEMENTAL IRRIGATION

a) Runoff Storage

In designing the storage tanks for runoff collection at ICRISAT Center high storage efficiency was aimed at. The main factors considered were: area occupied by the tank in relation to the catchment area, seepage and evaporation losses, depth of the tank, and cost of construction. Some circular designs were tried to reduce the wetted surface in relation to the volume of water stored. Tanks of depths exceeding 2 m were preferred with a view to reduce the area occupied by the tank and to minimize evaporation losses. A distinctive feature of these tanks is the absence of an outlet structure. After the tank is filled up to designed level runoff is automatically diverted to the main waterway as shown in Figure 4. This design saves the cost of an outlet structure besides decreasing the volume of sediment-laden runoff moving through the tanks.

An analysis done on the performance of the different collection tanks in meeting the demand for supplemental irrigation, particularly during extended rainless periods for both the monsoon and postmonsoon seasons, revealed the following (Pathak 1980, Miranda et al. 1982):

- Deep dug type tanks in Vertisols showed that in most years they can provide a minimum of 30 mm of supplemental irrigation water for the whole donor catchment area for postrainy season crops. Their relatively low seepage rate of less than 5 mm/day is ascribed to be mainly due to the low saturated hydraulic conductivity.
- The performance of tanks located in Vertic Inceptisols was unsatisfactory. This is due to the high seepage rates of greater than 25 mm/day which is suspected to be caused by the presence of permeable layers in the tank bed and also to the low runoff potential of these soils because of their high infiltration rates.
- Where the seepage rate was less than 15 mm/day in tanks located in Alfisols, it was found that collected water was available for one or two supplemental irrigations for whole of the donor catchment during the rainless periods of the rainy season. However, when seepage rate becomes excessive which can be even greater than 55 mm/day water can be collected but cannot be stored to meet supplemental irrigation needs during the dry spells.

b) Scope for Supplemental Irrigation

Harvested water from the watersheds that is stored in tanks is treated as a scarce commodity. It is used sparingly only for 'life saving' irrigation at the most critical stages of crop growth or for extending the cropping season (Kanwar 1980). In principle, Alfisols which are droughty in nature because they have less water holding capacity but produce more runoff early in the rainy season would benefit more from the application of water during the dry spells occurring during the rainy season. In Vertisols which have higher water retention capacity and generate runoff more towards the latter part of the rainy season when the soil is already fully recharged or nearly saturated, collected runoff water can be put to better use in establishing a sequential postrainy season crop or in irrigating the same crop at the most critical stage, such as at flowering. These simple principles are being translated into decision rules with time at ICRISAT.

On operational research plots yields of sorghum and maize on Alfisols were approximately doubled when 50 mm of irrigation was applied during a 30 day drought in late August and early September, 1974. During the following year postrainy season sorghum in Vertisols responded to one supplemental irrigation at the grain filling stage with an increase in yield from 2570 to 3570 kg/ha. In 1979-80 a 60 mm supplemental irrigation to postrainy season sorghum at flowering stage resulted in yield increase from 2950 to 4490 kg/ha. In the 1980-81 postrainy season crop of chickpea, also in Vertisols, the yield was increased from 817 to 1441 kg/ha with one irrigation at flowring stage. It is evident that relatively small amounts of timely water application results in substantial yield increase.

The justaposition of long-term weather records and information relating to water response of various crops will be helpful in deciding scope and developing decision rules for supplemental irrigation.

c) Supplemental Irrigation Through Furrows of BBF System

It has been observed that the application of limited water through furrows becomes difficult where substantial cracking has occurred. We conducted a study during the postrainy season on Vertisols to evaluate the efficiency of shallow cultivation in furrows to facilitate limited water application to chickpea. The treatments were:

T - No supplemental irrigation (control).

T - Uncultivated urrows; oen supplemental irrigation through furrows at chickpea flowering stage.

T - Pre-irrigation shallow cultivation (with hand hoes) in the furrows; one supplemental irrigation through furrows at the chickpea flowering stage.

We found that the rate of advance was substantially higher in cultivated urrows than in uncultivated furrows (Fig. 5). The study indicated that pre-irrigation cultivation in cracked furrows enhances irrigation efficiency and results in considerable saving of water without causing any significant difference in chickpea grain yields (Table 5).

d) Low Cost Tank Sealing Technique

Since the success or failure of water harvesting was found to be related with the capacity to keep this water in the tank; tank sealing studies were initiated to solve the problem of high seepage rates. Early studies in small pits at ICRISAT showed asphalt to be promising in controlling seepage (ICRISAT Annual

Report 1975-76). Asphalt was applied at the rate of 4 lit/m . The seepage reduction in Alfisols varied from 97% to 47% when compared with the control (seepage rates for control varied from 24.7 to 50 mm/day). The large variation in seepage reduction is indicative of how uncertain the effectiveness of asphalt was. In Vertisols there was no significant reduction in seepage rates.

A seepage reduction of about 70% was obtained with a treatment of Na_2Co_3 + straw in Vertisols (ICRISAT Annual Report 1975-76). However, use of straw presented a problem after sometime because, with its decomposition, a porous structure of the lining resulted. In another study, Sharma and Kampen (1977) observed that a lining of silt (15 cm thick) + Na_2Co_3 (0.4 kg/sqm) was successful in cutting down seepage losses by 55%. They reported that the cracking of lining remained the main problem in Vertisols in addition to the necessity f reapplication of salts after 3-5 years.

Maheshwari (1981) tried the use of soil dispersants, soil cement lining and improvement of soil gradiation as the three basic methods to reduce seepage rates in Alfisols and Vertisols. He observed that soil cement (10:1) and a mixture of red and black soils (1:2) were the two most effective linings for tanks on Alfisols (Fig. 5). The seepage rate was as low as 8.2 lit/m /day in soil-cement lined tanks which meant a reduction in seepage of 97.2%. However, cracking was found to occur when the tank was emptied and the lining exposed to the sun increasing the seepage rates when the tank was refilled. We are now attempting to minimize the effect of cracking through provision of expansion joints and filling these joints with asphalt.

7. RUNOFF MODELING

Using measured rainfall and runoff data of several watersheds and standard runoff plots along with associated characteristics, Ryan and Pereira (1978) derived daily rainfall-runoff relationships by multiple regression techniques for Sholapur and Hyderabad regions of India. These empirical relationships have been found to predict runoff satisfactorily on some independent data sets.

A parametric simulation model 'RUNMOD' was developed using the hydrologic data collected at small agricultural watersheds at ICRISAT Center (Krishna 1981). The model needs as inputs: daily rainfall amount, the sotrm duration or rainfall intensity and pan evaporation. The model characterizes infiltration by only two parameters that are determined through calibration by using a nivariate optimization procedure. Once the parameters are determined for a particular land management treatment, they may be applied directly to a similar situation elsewhere for predicting runoff. The flow chart of the model is shown in Figure 7. The various terms used in the flow chart are:

TF - Time function in days, required for soil cracks to close.

MUI - Initial soil moisture in upper zone, mm.

MUX - Total soil moisture in upper zone at field capacity, mm.

MLI - Initial soil moisture in lower zone, mm.

MLX - Total soil moisture in lower zone at field capacity, mm.

RIH - Infiltration parameter -- 'High' rate of infiltration, mm/hr.

RIL - Infiltration parameter -- 'Low' rate of infiltration, mm/hr.

P - Daily precipitation, mm.

SD - Storm duration, hrs.

MRO - Measured runoff, mm.

AE - Evapotranspiration, mm.

MU - Total soil moisture in upper zone at any given time, mm.

ML - Total soil moisture in lower zone at any given time, mm.

F - Infiltration index, mm.

IFN - Amount infiltrated, mm.

DP - Deep percolation, mm.

The model predicts seasonal runoff volume of Vertisol watersheds fairly accurately (ICRISAT Annual Report 1982). This model will now be tried and adapted for Alfisol watersheds. The 'curve number' method of the United States Soil Conservation Service has also shown promising results. These models will be helpful in predicting runoff of ungauged watersheds in different regions for formulating decision rules and for design purposes.

LOOKING AHEAD

Apparently the feedback from the on-farm studies relative to small watershed approach for Vertisol management in India will have a strong bearing on our future research. The encouraging results obtained from the Tadanpally village watershed have given us considerable optimism regarding the applicability and usefulness of our present approach. It seems appropriate to initiate some base line research in Africa to enable us to delineate areas where a technology based on a similar approach will have potential. Research on Alfisols will be focused on testing alternative management approaches primarily at ICRISAT Research Center.

The rainfall-runoff models mentioned in this paper will be tested for different soil and agroclimatic situations. With the help of rainfall-runoff models and hydrologic data, the probability of getting given quantities of water during growing season, and tank failure at varying levels of seepage losses will be studied. The on-going work on tank lining will be continued. Techniques for improving the efficiency of supplemental irrigation will be investigated.

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Table 1. Initial and equilibrium infiltration rates of Vertisols and Alfisols at the ICRISAT Center (based on field measurements using double concentric basins)

Time from start (hrs)	Infiltration rates Vertisols (mm/hr)	Alfisols (mm/hr)
0 - 0.5	76	73
0.5 - 1.0	14	18
1.0 - 2.0	4	15
After 144	0.21 ± 0.1	7.7 ± 3.7

Table 2. Runoff and soil loss under two differently treated Vertisol watersheds at ICRISAT Center

Year	Rainfall (mm) (seasonal)	Broadbed and furrow lay-out 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

Table 3. *Runoff and soil loss under broadbed and furrow (BBF) and graded flat cultivation in field size plots in Vertisols with double cropping and improved level of crop management*

Year	Rainfall, mm (seasonal)	Broadbed and furrow		Graded flat	
		Runoff, mm	Soil loss tonnes/ha	Runoff, mm	Soil loss tonnes/ha
1976-77	688	109.9	1.70	141.1	2.40
1977-78	586	0.6	0.04	0.8	0.04
1978-79					
(a) Seasonal	1125	250.6	1.38	240.8	2.10
(b) Excluding very heavy storms of 14-15 Aug.	907	97.0	0.86	132.1	1.81
1979-80	690	53.9	0.74	63.4	0.84
1980-81	730	61.7	0.48	77.1	0.49
Mean					
(a) Seasonal	764	95.3	0.89	104.6	1.17
(b) Excluding very heavy storms of 14-15 Aug. 1978	720	64.6	0.76	82.9	1.12

Table 4. Time required for various operations in BBF and graded flat cultivations in field size plots in Vertisols

Broadbed and furrow cultivation (BBF)			Flat cultivation		
Operation	Man-hour (per ha)	Bullock pair-hour (per ha)	Operation	Man-hour (per ha)	Bullock pair-hour (per ha)
Summer and rainy seasons			Summer and rainy seasons		
Moldboard plowing	5	2.5	Cultivation	12.6	6.3
Ridging	5	2.5	Cultivation	12.6	6.3
Cultivation	7.4	4.4	Harrowing*	7.0	7.0
Bed shaping	6.7	3.3	Harrowing	11.3	11.3
Planting and fertilizer application	9.0	3.0	Planting and fertilizer application	12.5	4.2
1st inter-row cultivation	12.0	4.0	1st inter-row cultivation	12.3	5.0
2nd inter-row cultivation	8.6	4.3	2nd inter-row cultivation	10.8	5.4
Postrainy season			Postrainy season		
Cultivation	6.3	3.1	Cultivation	8.4	4.2
Planting	18.0	6.0	Planting	15.0	5.0
Inter-row cultivation	7.6	3.8	Inter-row cultivation	10.6	5.3
Total	85.6	36.9		113.1	60.0

*Harrowing was done by using a traditional blade harrow. All other operations were done with the wheeled tool carrier and attachments.

Table 5. Effect of cultivation in furrows on water application and grain yield of chickpea

Treatment	Mean depth of water application (d), mm	Irrigation distribution efficiency[a] (%)	Mean grain yield (Kg/ha)
T_1 - No supplemental irrigation (control)	0	-	690
T_2 - Uncultivated furrows; one supplemental irrigation at flowering	63	60	920
T_3 - Cultivated furrow; one supplemental irrigation at flowering	46	71	912
SE			± 19
CV (%)			5.55

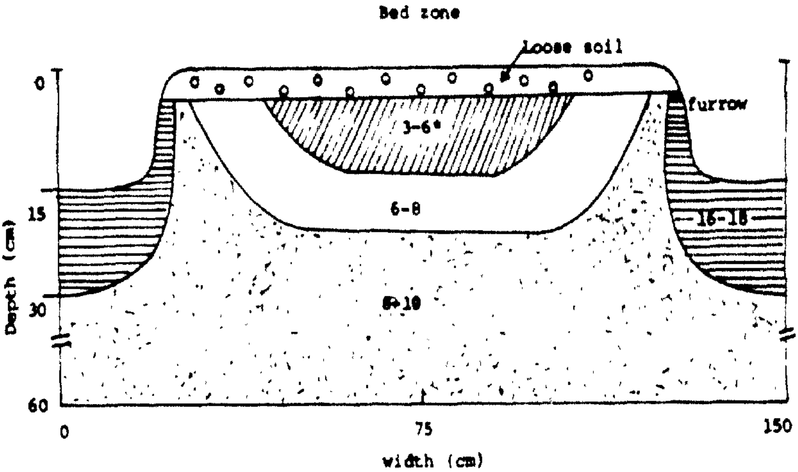
[a] The irrigation distribution efficiency values were computed using the equation:

$$\text{Distribution efficiency} = \left(1 - \frac{\sigma}{\bar{d}}\right) \times 100$$

Where

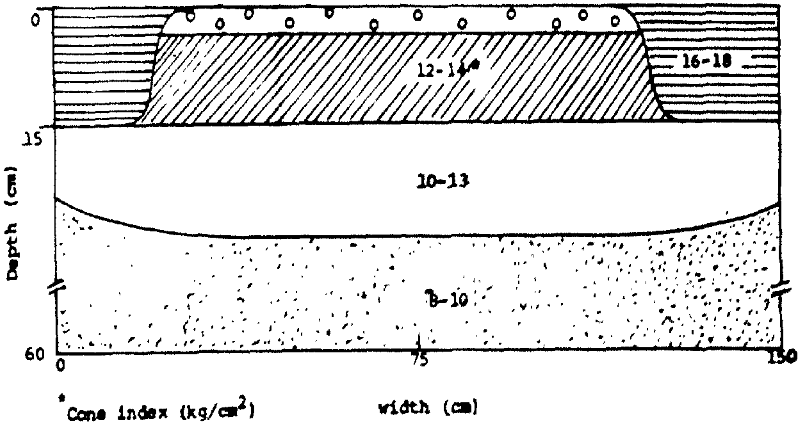
σ = Standard deviation of water application depth along the furrow length

$\bar{d}$ = Mean water application depth



Soil moisture (w/w basis)

Depth	Moisture content %
0-15 cm	24 ± 1.9
15-30 cm	31 ± 2.4
30-60 cm	33 ± 2.9



*Cone index (kg/cm²)

Figure 1 : Penetration resistance zones under BBF and flat systems of cultivation on Vertisols at ICRISAT Center, 1980/81

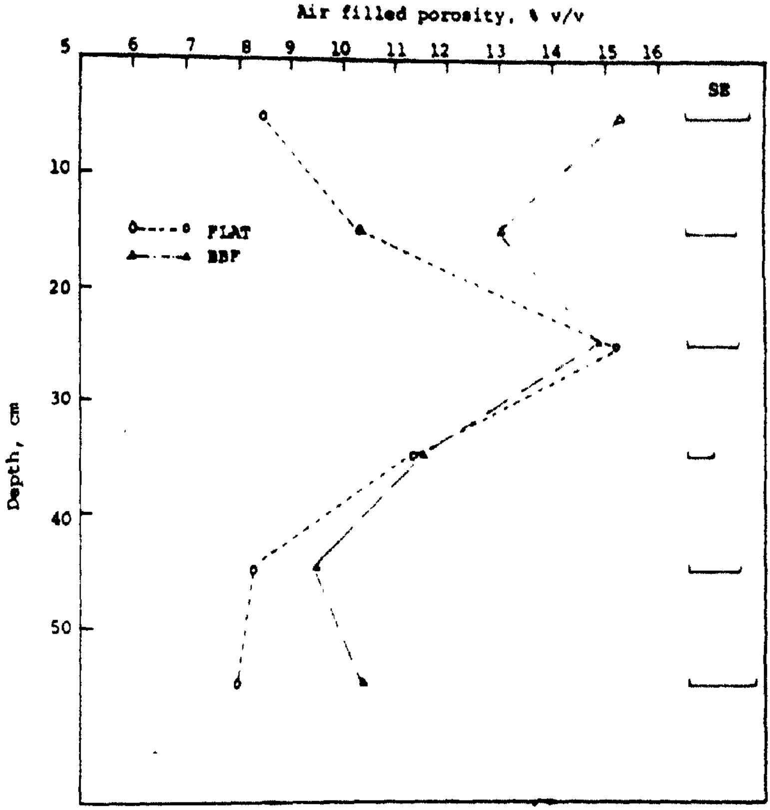
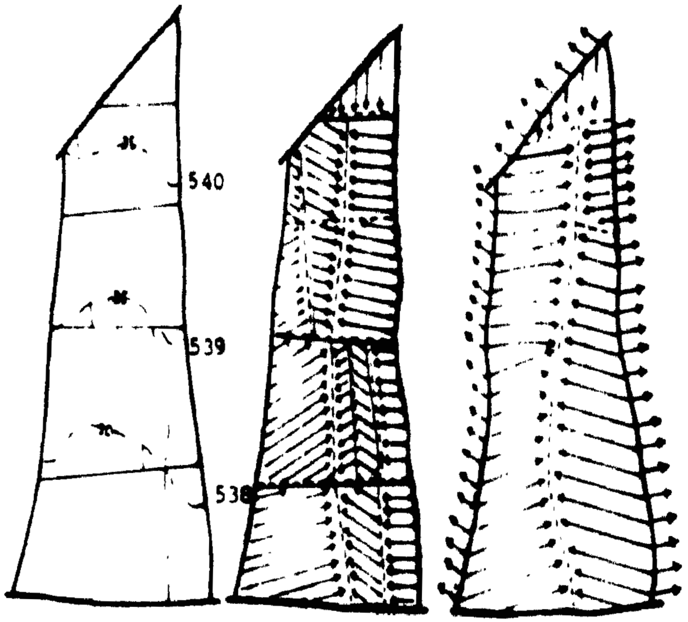


FIG. 2 : Air filled porosity during high moisture period



a. Contour bunds

b. Broadbed-and-furrow layout within field boundaries.

Broadbed-and-furrow layout after removing field boundaries.

——→ Bed and furrow direction
— - - Field bunds
- - - Grassed waterways
- - Contour bunds
][Waste weir

Figure 3: Three alternative land and water management approaches for a Vertisol watershed.

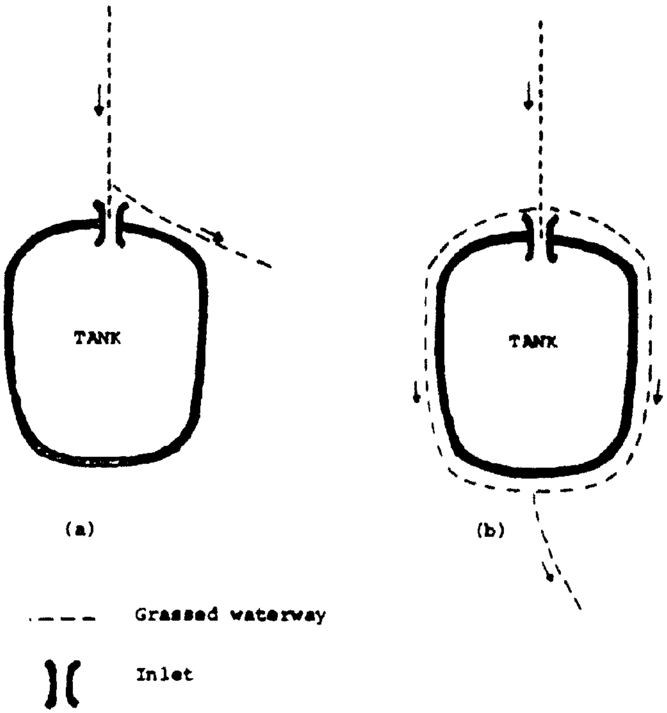


Figure 4 : Alternative arrangements for diverting runoff after filling up of the tank

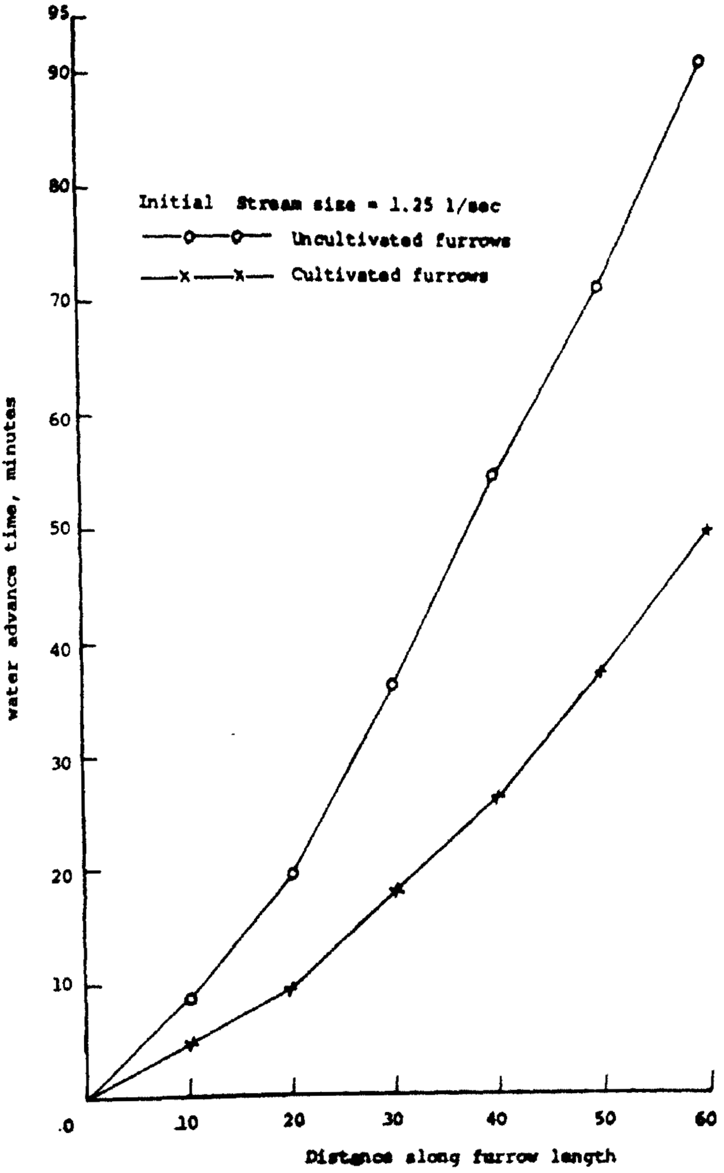
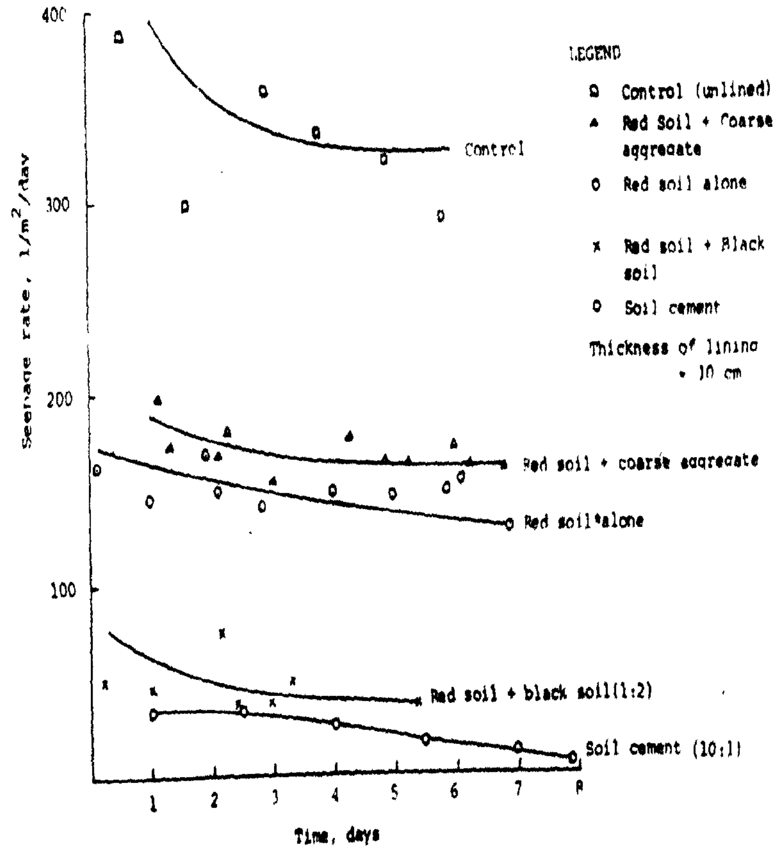


Figure 5 : Effects of cultivation in furrows on water advance



* Material passing 1mm sieve

FIGURE 6 : PERFORMANCE OF DIFFERENT LINING TREATMENTS IN ALFISOLS

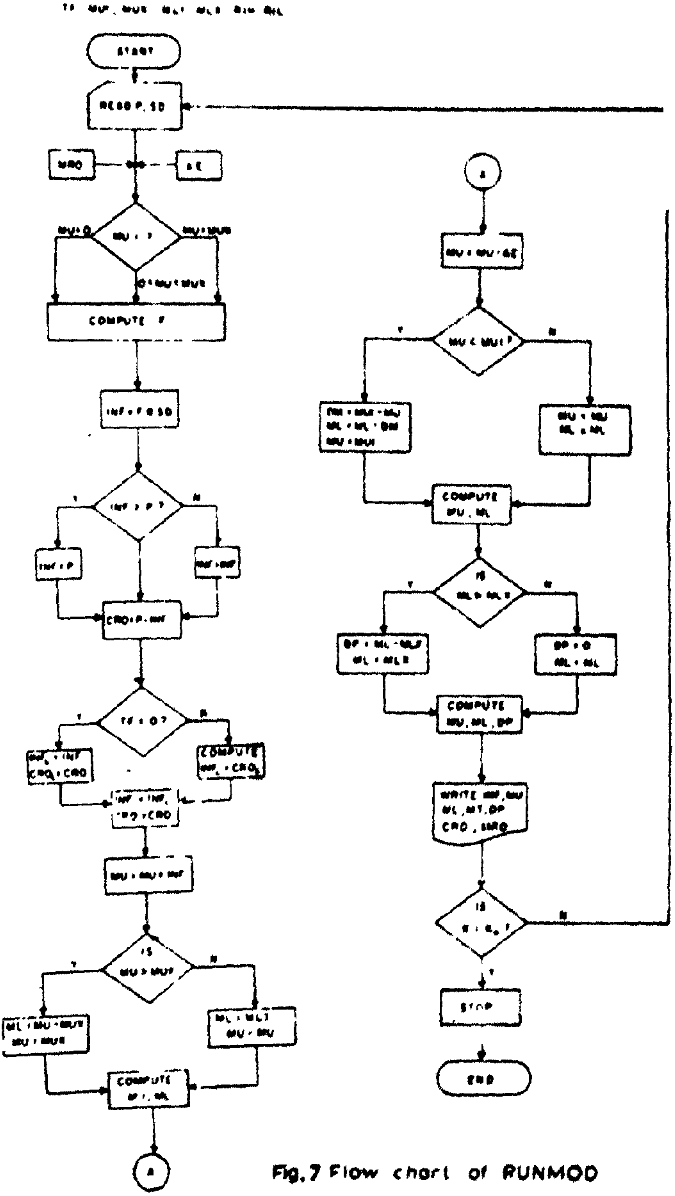


Fig. 7 Flow chart of RUNMOD