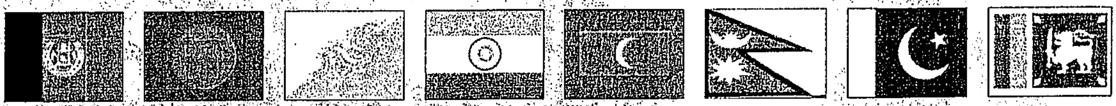

Techniques of Water Conservation & Rainwater Harvesting for Drought Management

(SAARC Training Program)

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New Tools and Best Bet Options for Efficient Management of Soil and Water Resources in Drylands of Asia

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The dry areas of the developing world occupy about 3 billion hectares and are home to 2.5 billion people: 41% of the earth's land area and more than one-third of its population. About 16% of this population lives in chronic poverty. Drylands have limited natural resources. They already face serious environmental constraints, which are likely to worsen as a result of climate change. Agricultural production systems in dry areas are over-stretched. Dryland systems are characterized by persistent water scarcity, rapid population growth, frequent droughts, high climatic variability, land degradation and desertification, and widespread poverty. To ensure the future livelihoods of dryland farming communities, it is critical to manage risk more effectively and enhance productivity through efficient management of soil and water resources and sustainable intensification of production systems. In most developing countries, the problem of soil and water resource degradation have been in existence in the past also, however, the pace of degradation has greatly increased in recent times due to burgeoning population and the enhanced means of exploitation of natural resources. There is urgent need to implement the best bet options available for the soil and water conservation. This paper discusses some of the field- and community-based soil and water conservation options that were found promising for improving productivity and reducing runoff and soil loss. The strategies for improving the adoption of soil and water conservation practices by farmers is also discussed. The adequate availability of the hydrological data, which are critical for the proper planning and design of soil and water interventions are lacking in most regions. This paper discusses few new tools, which could be used to collect or generate such information required for effective planning and design of soil and water conservation interventions.

New Tools for Monitoring and modeling Hydrological Parameters

The data on runoff volume, peak runoff rate, soil loss and other related parameters are needed for the proper planning and designing of soil and water conservation interventions. New tools for monitoring and modeling hydrological parameters are discussed below.

Soil loss measurement from agricultural fields/watersheds

The monitoring of soil loss and sediment flow from the agricultural fields/watersheds is a complex and difficult task. There are very few standard equipments available in the market, which can be used for measuring the soil loss from the small agricultural watersheds. Some of the serious problems with commonly used methods and some new developments (Pathak, 1991 and Pathak and Sudi, 2004), which have been made at ICRISAT Center for monitoring soil loss and sediment flow from the small agricultural watersheds are discussed below.

Manual sampling

In most developing countries, manual sampling is still the most commonly used method for monitoring sediment flow from the small agricultural watersheds. However, there are some serious problems with this method. The extreme variation in sediment concentration during the runoff events makes this method totally inappropriate for monitoring sediment from small agricultural watersheds **(Fig. 1).**

Due to these extreme variations in sediment concentration the expected error in estimating the soil loss could be extremely high and are often found in the range of ±30 to 420% that of actual soil loss. Also operationally it is very difficult to collect the runoff samples at the right time particularly during high rainfall events. This makes the data collected by manual method highly unreliable and often useless. Therefore the manual method of runoff sampling is not recommended for monitoring soil loss from the small agricultural watersheds.

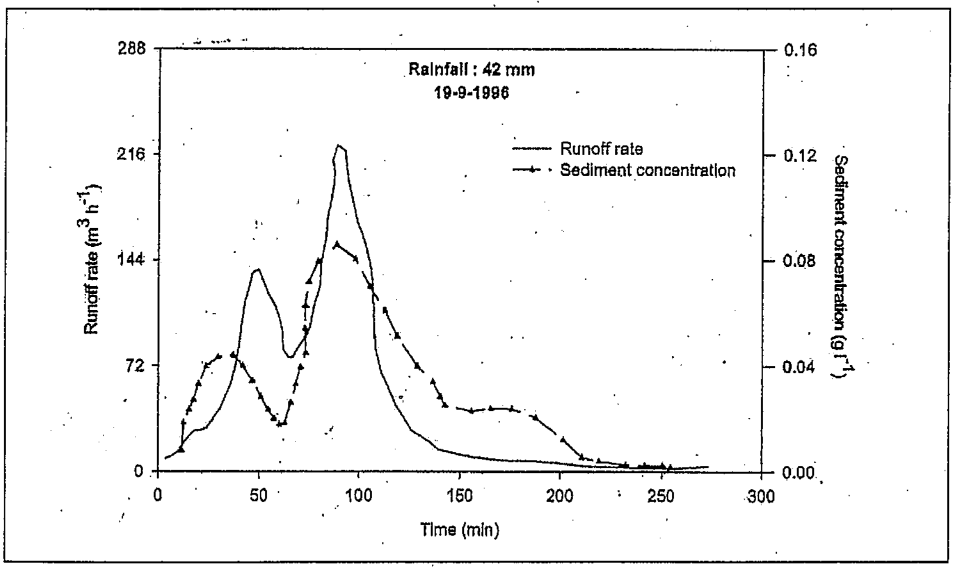


Fig. 1 : Sediment concentration variation with time during one runoff event at BW7 watershed, ICRISAT Center, Pantancheru, A.P., India (Pathak et al., 2004)

Microprocessor-based automatic sediment sampler

The microprocessor-based automatic sediment sampler can be used to measure soil loss as well as temporal changes in sediment movements during the runoff hydrographs from the agricultural Plots watersheds. At ICRISAT a micro-processor based automatic sediment sampler **(Fig. 2)** has been developed for small agricultural watersheds (Pathak and Sudi, 2004).

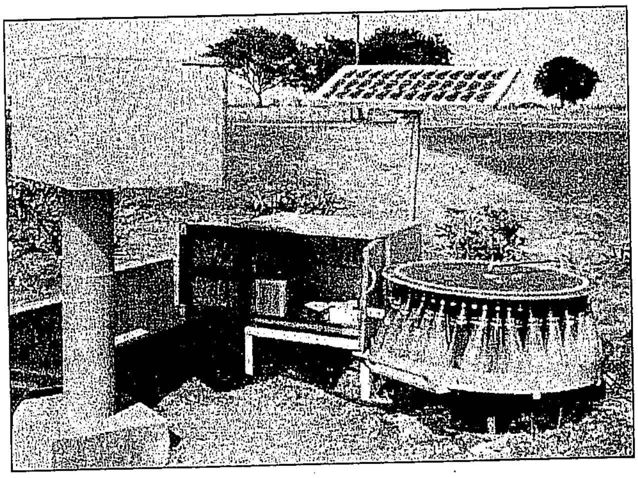


Fig. 2 : Micro-processor based automatic sediment sampler

This sediment sampler consists of circular sample collection unit fitted with DC shunt motor and bottles, microprocessor-based control unit **(Fig. 3),** 12v 55 Amph battery, bilge submergible pump, water level sensors, and solar panel (optional for recharging 12v battery).

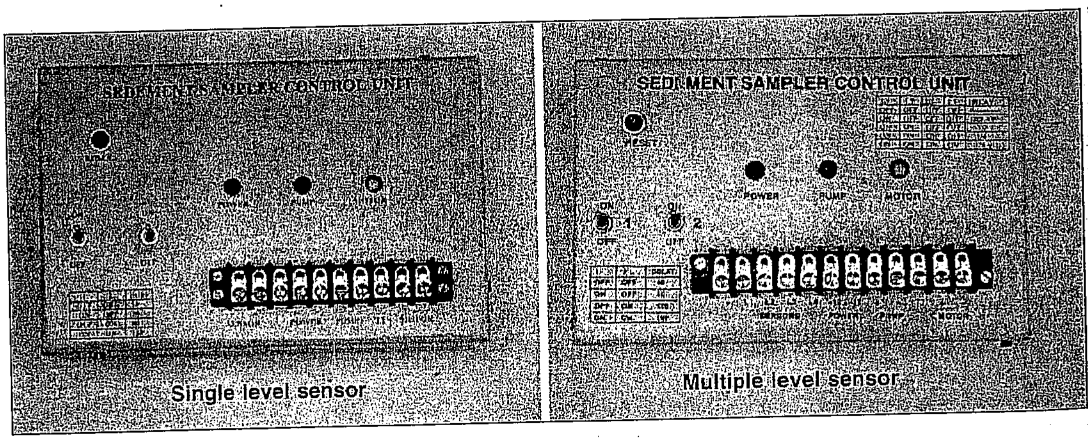


Fig. 3 : Single and multiple level sensors of control unit

Salient features of the Sediment Sampler are as follows:

- Fully automatic runoff samples collection
- Samples can be collected at required time interval (15, 30, 60 and 120 minutes or any desired time intervals) as well as at required flow depths
- Can be used for soil loss estimation as well as temporal distribution of sediments during runoff hydrographs
- The 8748 microprocessor-based controller is used which can be reprogrammed easily
- Suitable even for the remotely located gauging station as well as small to medium size watersheds (1-5000 ha)
- Accurate and reliable data acquisition
- Simple and easy to operate
- Efficient and cost-effective

Runoff measurement from small agricultural watersheds

Accurate determination of runoff volume, peak runoff rate, and other related information from small and medium areas invariably requires the continuous recording of the water level. Stage-level recorders are commonly used for this purpose. Many types of stage-level recorders are commercially available. They can be broadly classified into two types: mechanical type and digital type stage-level recorders.

Mechanical stage-level recorder

In developing countries mechanical type runoff recorders are most commonly used for monitoring runoff **(Fig. 4).** There are several operational problems with the mechanical type runoff recorders. The most common problems are related to clock functioning, gear set functioning, pen and its marking on charts. The processing of data from chart is very time consuming and the recorder needs continuous monitoring.

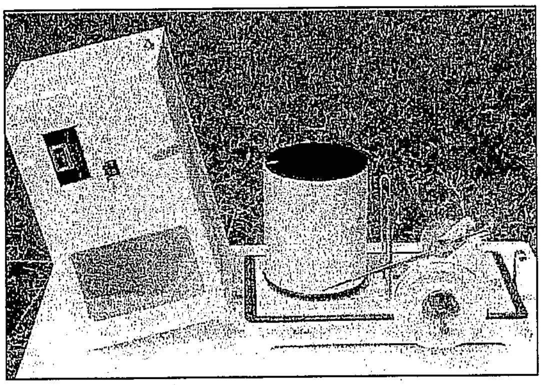


Fig. 4 : A drum-type mechanical runoff recorder

Digital automatic stage-level recorder (Thalimedes)

Thalimedes is a float operated shaft encoder with digital data logger which can be used to continuously monitor the runoff from the watershed/field **(Fig. 5).** It is easy to handle and its cost-effective ratio makes it an appropriate device for modernization of existing mechanical chart-operated stage-level recorder monitoring stations (Pathak, 1999).

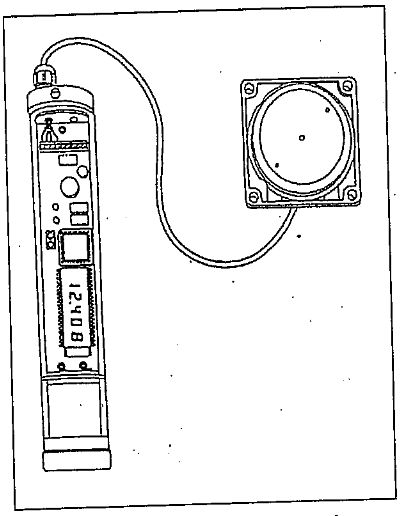


Fig. 5 : Digital runoff recorder

Integrated digital runoff recorder and sediment sampler device

An Integrated digital runoff recorder and sediment sampler device have been developed by ICRISAT Scientists in collaboration with Farm and Engineering Services at ICRISAT **(Figs. 6 and 7)**. The main feature of this new equipment is that all the operations (viz. runoff recording, sediment sampler operation and solar panel controller etc.) are controlled by one single micro-processor unit. The unit can store the data up to 130,000 records in 1 MB flash memory, which has a ring memory system. The complete unit works on a 12 v battery with solar panel to recharge it. Even during the emergency power operation or main battery failure, runoff recording is done with its backup battery. This integrated unit makes the calculation of runoff and soil loss very easy and accurate. It is also very cost - effective.

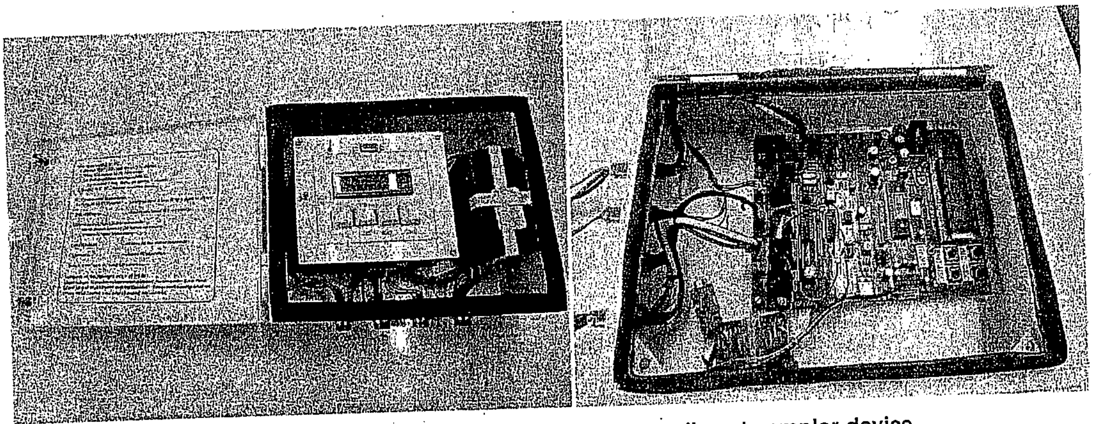


Fig. 6 : Integrated digital runoff recorder and sediment sampler device

Salient features of integrated runoff and soil loss unit

- It is low-cost, easy to handle and accurate data collection equipment
- It is micro-processor based data logger with shaft encoder

- Digital LCD of measured level, date, time and battery status
- Even during the emergency power operation or main battery failure, runoff recording is done with its backup battery
- Stores data up to 130000 measured values with ring memory system
- Programmable setting of sampling and logging intervals from 1 min to 24 h (flexibility not possible with mechanical recorders)
- Less moving parts; no problem due to gear/clock and chart mechanism
- Compact, rugged and light weight equipment
- Suitable for remotely located gauging stations and require minimum maintenance

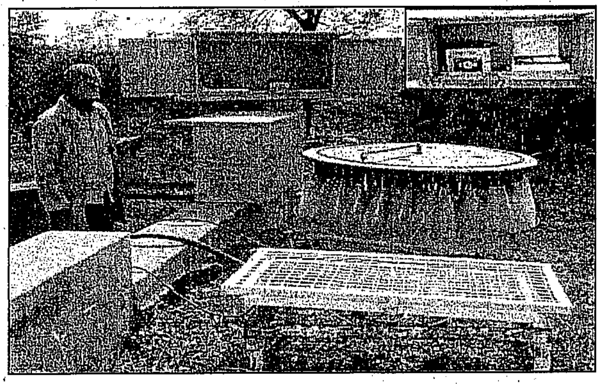


Fig. 7 : Integrated digital runoff recorder and sediment sampler device (New microprocessor is shown in inset)

Hydrological Models for Proper Planning and Assessing the Impact of Soil and Water Interventions

The long-term hydrological data at the watershed scale are generally not available in most regions of India. The hydrological models can be effectively used to generate such data, which can be used for the planning and design of various watershed interventions. These models can also be used to assess the long-term impact of watershed program on soil and water resources. Some of the hydrological models developed at ICRISAT are discussed below.

Simple Runoff and Water Balance Models

Information on surface runoff is needed in the planning and design of soil and water management system. For example, it is needed in the design of soil conservation structures, runoff harvesting and groundwater recharging structures, drains and other interventions. Runoff models can be used to generate this vital information. Some of the simple hydrological models, which have been developed at ICRISAT for small agricultural watersheds, are described here.

RUNMOD Runoff Model: A parametric simulation model was developed to predict runoff from small agricultural watersheds (Krishna, 1979). The input data for it are the daily rainfall amount, storm duration or rainfall intensity, pan evaporation, and soil moisture. By means of a univariate optimization procedure, measured runoff data are used to determine the proportion of rainfall that infiltrates and the part that runs off. Once these parameters are determined for a particular soil and land management treatment, they can be applied directly to other watersheds of similar cover, topography, and moisture storage and transmission properties for predicting runoff and other water balance components.

SCS Curve Runoff Model: A runoff model based on a modified SCS curve number technique and on soil moisture accounting procedure was developed for small watersheds in the semi-arid tropics (Pathak et al., 1989). In this model, certain soil characteristics which have strong influence on runoff such as cracking and land smoothing are included. The model uses one day time intervals and needs simple inputs, which are normally available such as: daily rainfall, pan evaporation, canopy cover coefficient, soil depth, initial soil moisture, moisture at wilting point and field capacity. The main outputs are daily runoff volume and soil moisture. The model has four input parameters which are estimated through calibration using measured runoff and soil moisture content data. Once the parameters are determined for a particular soil and land management system, they can be used to predict runoff and soil moisture form other ungauged watersheds with similar soils and management systems.

Tests with data from three small watersheds at ICRISAT Center in India show that the model is capable of simulating daily, monthly, and annual runoff quite accurately. It is also able to simulate satisfactorily the daily moisture. The biggest advantage of this model appears to be its simplicity and accuracy. Also since this model is linked to SCS curve numbers, its use and applicability is quite wide.

Runoff Water Harvesting Models

A Runoff cum water harvesting model was developed (Pathak et al., 1989, Ajay Kumar, 1991) to simulate the daily runoff, soil moisture and water availability in the tank. This model has two main components, the first component predicts the daily runoff and soil moisture and second component calculates the daily water balance in the tank... This model has been extensively used in different regions of India for calculating various parameters for water harvesting. For example, this model was used to assess the runoff potential from three watersheds in Andhra Pradesh viz. Nandavaram, Sripuram and Kacharam. Probability analysis applied to the results obtained from runoff model. Probabilities of getting 20, 40, 60 and 100 mm of simulated runoff were done based on the 26 years of climatic data **(Fig. 8).**

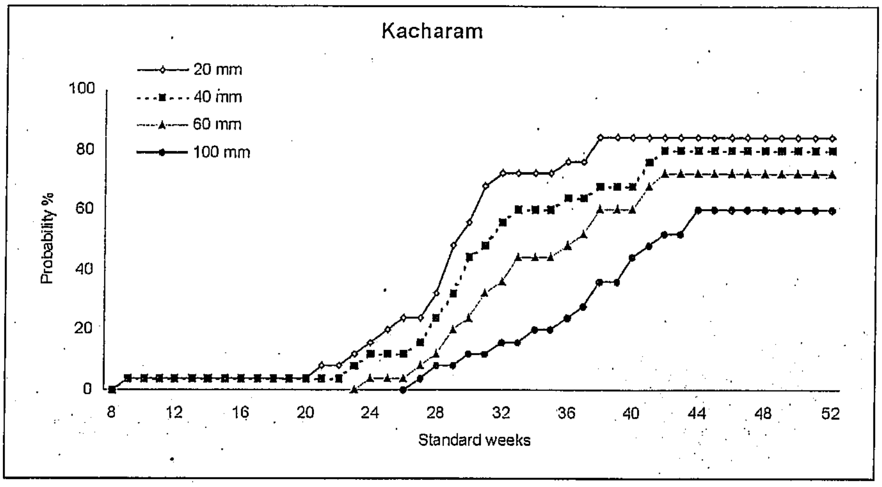


Fig. 8 : Probabilities of obtaining 20, 40, 60 and 100 mm cumulative runoff in Kacharam watershed (based on 26 years of simulated data)

Considerable information on various aspects of runoff water harvesting could be obtained by using the runoff and water harvesting models. These models can assess the prospects of runoff water harvesting. It can also be used to estimate the optimum tank size, which is very important for the success of the water harvesting system.

The runoff and water harvesting model can be used for following objectives:

- To assess the prospects of runoff water harvesting and groundwater recharging and its utilization for agriculture
- To assess the probabilities of getting different amounts of irrigation water in the tank
- To assess the conditional probabilities of getting different amounts of irrigation water in the tank
- To find out optimum tank size and other design parameters
- To develop strategies for scheduling supplemental irrigation

Digital Terrain Model (DTM)

The automation of terrain analysis and use of digital elevation models (DEM) have made possible to easily quantify the topographic attributes of the landscape and to use topography as one of the major driving variables for many hydrological models. These topographic models, commonly called as digital terrain models (DTMs). The DTMs include the topographic effect on the soil water balance and coupled with a functional soil water balance to spatially simulate the soil water balance. ICRISAT in collaboration with Michigan State University, USA, developed a SALUS-TERRAE, a digital terrain model (Bruno Basso et al., 2000), which can be used at the landscape level. Few of the outputs from the model are shown in **Fig. 9.** These digital terrain models are extremely useful for the watershed programs. However, their major bottleneck is on the accurate availability of topographic data.

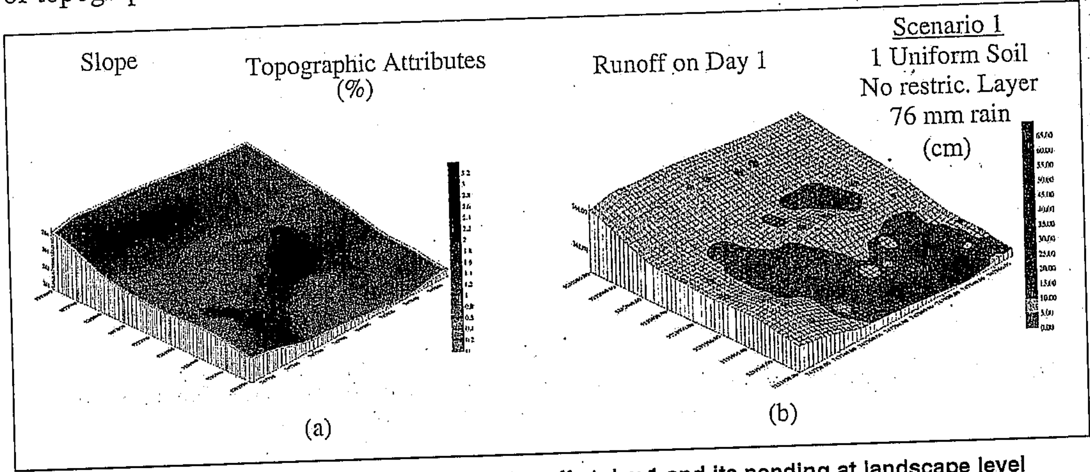


Fig.9 : (a) Slope levels in a landscape (b) Runoff at day 1 and its ponding at landscape level

Best Bet Options of Soil and Water Conservation

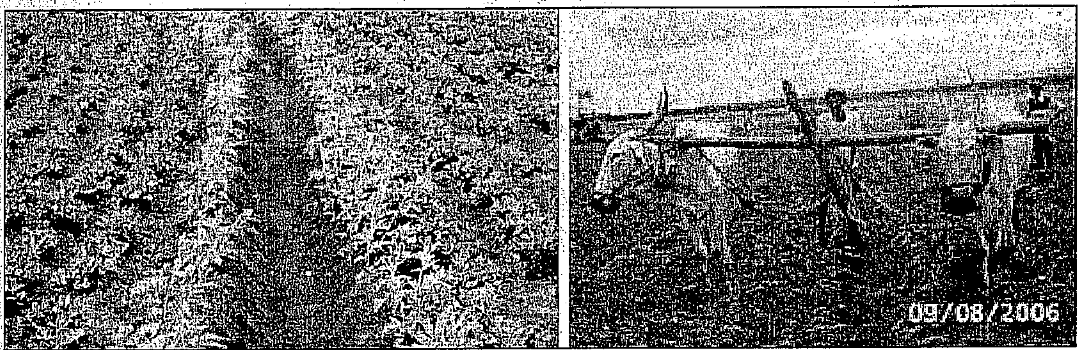
Soil and water conservation measures are important for effective conservation of soil and water. The main aim of these practices is to reduce or prevent either water erosion or wind erosion, while achieving the desired moisture for sustainable production. The suitability of any soil and water management practices depends greatly upon soil, topography, climate, cropping system and farmers resources. Some of the promising *in-situ* and *ex-situ* soil and water conservation practices are discussed below:

Field Based Soil Land Water Conservation

Contour Cultivation and Conservation Furrows

In several rainfed regions, the up and down cultivation is still a common practice. This results in poor rainfall infiltration and accelerated soil erosion. Contour cultivation or cultivation across the slope is a simple method of cultivation, which can effectively increase rainfall infiltration and reduce runoff and soil loss on gently sloping lands. The contour cultivation involves performing cultural practices such as plowing, planting and cultivating on the contours. It creates a series of miniature barriers to runoff water when it flows along the slope.

In most situations the effectiveness of the contour cultivation can be greatly enhanced by adding conservation furrows into the system. In this system in addition to contour cultivation, a series of furrows are opened on contour or across the slope at 3.0-7.5 m apart (**Fig. 10**). The spacing between the furrows and its size can be chosen based on the rainfall, soils, crops and topography (Pathak et al., 2009). The furrows can be made either during planting time or during interculture operations using traditional plough. Generally, two passes in the same furrow may be needed to obtain the required furrow size. These furrows harvest the local runoff water and improve soil moisture in the adjoining crop rows, particularly during the period of moisture stress. One of the major advantages of this system is that it provides stability to contour cultivation particularly during moderate and big runoff events. Using the farmer participatory approach, Pathak et al. (2009) reported on the performance of the practices followed by farmers (flat cultivation) as compared with contour cultivation along with conservation furrows based on the results of 121 trails conducted in the farmers' fields in four districts of Karnataka during 2006-08 (**Table 1**). Contour cultivation along with the conservation furrows was found promising both in terms of increasing crop yields and better adaptation by farmers. This land and water management system increased the crop yields of maize, soybean and groundnut by 16-21% over the farmers practice.



Groundnut crop with conservation furrow — Formation of conservation furrows using local implements

Fig. 10 : Conservation furrow system at Hedigonda watershed, Haveri, Karnataka, India.

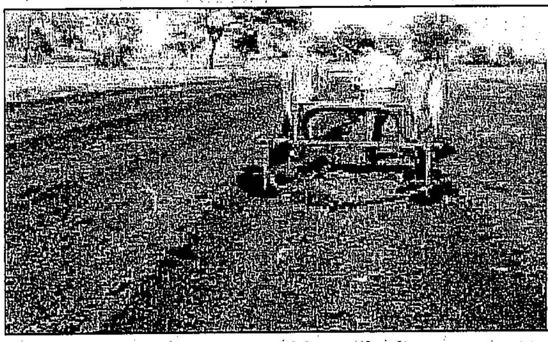
Table 1 : Crop yields (t ha^{-1}) in different land water management systems during 2006-08 at Sujala watersheds in different districts of Karnataka, India.

District	Crop	Yield with farmers' practice	Yield with Contour cultivation with conservation furrows	Increase in yield (%)
Haveri	Maize	3.35	3.89	16
Dharwad	Soybean	1.47	1.80	23
Kolar	Groundnut	1.23	1.43	16
Tumkur	Groundnut	1.25	1.50	21
	Finger millet	1.28	159	24

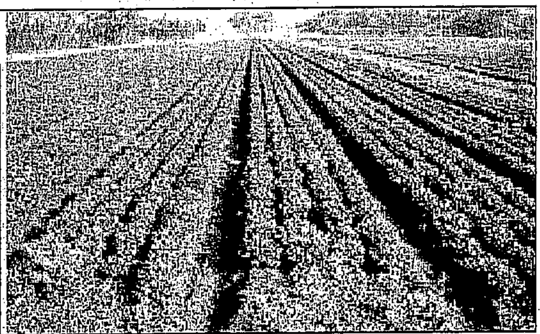
Source: Sujala-ICRISAT watershed project, Terminal Report (2008)

Broad-bed and Furrow and Related Systems

On soils such as Vertisols, the problem of waterlogging and water scarcity occurring during the same cropping season is quite common. For such situation, there is a need for an *in-situ* soil and water conservation and proper drainage technology that can protect the soil from erosion through out the season and provide control at the place where the rain falls. A raised land configuration "Broadbed and furrow" (BBF) system has been found to satisfactorily attain these goals **(Fig. 11)**.



BBF formation with tropicultor



Groundnut crop on BBF

Fig. 11 : The broadbed and furrow system at the ICRISAT Center Patancheru, Andhra Pradesh, India.

After perfecting the BBF system at the ICRISAT Center Patancheru, India this technology was taken up for a large scale adoption by farmers in Madhya Pradesh. Total 140 farmers in 17 villages conducted action research-cum-demonstrations on enhancing water use efficiency (WUE) through increased crop yields during 2007-2009. Significantly higher crop yields were recorded in the improved management system compared to farmer's practice **(Table 2)**. The average soybean productivity increased by 24% due to improved technology.

Table 2 : Mean Soybean yield in BBF and traditional management system in Madhya Pradesh during 2007-09.

District	Soybean grain yield (t ha^{-1})		Increase over farmer's practice (%)
	BBF System	Farmer's practice	
Guna	1.7	1.46	16
Raisen	2.28	1.56	45
Vidisha	2.23	1.72	30
Indore	2.90	2.51	15
Sehore	2.50	2.09	19
Mean	2.32	1.87	24

Source:Report on water use efficiency project, (2009) Some of the major benefits of the semi - permanent BBF system are:

- The raised bed portion acts as an *in-situ* 'bund' to conserve more moisture and ensures soil stability; the shallow furrows provides good surface drainage to promote aeration in the seedbed and root zone; prevents water logging of crops on the bed.
- The BBF design is quite flexible for accommodating crops and cropping systems with widely differing row spacing requirements.
- Precision operations such as seed and fertilizer placement and mechanical weeding are facilitated by the defined traffic zone (furrows), which saves energy, time, cost of operation and inputs.
- Can be maintained in the longer- term (25-30 years)
- Reduces runoff and soil loss and improves soil properties over the years.
- Facilitates double cropping and increases crop yields.

Tied Ridges and Scoops

Tied ridges or furrow diking is a proven soil and water conservation method under both mechanized and labor-intensive systems, and is used in many rainfed areas of the world. Tied ridging results in the formation of small earthen dikes or dam across the furrow of a ridge furrow system. It captures and holds runoff water in place until it infiltrates into the soil. Tied ridges are most effective when constructed on the contour. Under mechanized systems, the furrow dykes are usually destroyed by tillage operations and need to be reconstructed each season. They also obstruct cultivation and other field operations.

Scoops have been extensively used in the Asian, Australian and African SAT as an *in-situ* soil and water conservation system. Scoops on agricultural land involve the formation of small basin depression at closely spaced interval to retain runoff water and eroded sediments from rainstorm **(Fig.12).** The scoops can be made manually or by machine. The commonly used machine for making scoops is tractor drawn chain diker equipment, which is extensively used in different countries.

Fig. 12 : Scoops with sorghum crop on an Alfisol, ICRISAT Center, Patancheru, India.
Source: Pathak and Laryea (1995)

Techniques of Water Con...

Bunding

Bunding is one of the most commonly used methods for the conservation of soil and water on agricultural lands. A bund is a mechanical measure where an embankment or ridge of earth is constructed across a slope to control runoff and minimize soil erosion. Some of the most commonly used bunding systems are given below:

- Contour bunding
- Modified contour bunds
- Graded bunding
- Field bunding
- Compartmental bunding
- Vegetative bunds

Vegetative barriers or vegetative hedges or live bunds of conservation have drawn greater attention in recent years because of their long life, low cost and low maintenance needs. In several situations, the vegetative barriers are more effective and economical than the mechanical measures viz. contour and graded bunds. Vegetative barriers can be established either on contour or on moderate slope of 0.4 to 0.8%. In this system, the vegetative hedges acts as a barrier to runoff flow, which slows down the runoff velocity, resulting in the deposition of eroded sediments and increased rainwater infiltration. It is advisable to establish the vegetative hedges on small bund. This increases its effectiveness particularly during the first few years when the vegetative hedges are not so well established.

In Northeast Thailand, Vetiver hedge and semi-circular vetiver rings around the plants have been successfully used for efficient soil and water conservation **(Fig. 13).** Horticultural plants have been extensively used as vegetative barriers for controlling soil erosion and conserving rainfalls **(Fig.14).**

Tillage

Tillage on such poor soils helps to increase pore space and also keeps the soil loose so as to maintain higher level of infiltration. Laryea et al. (1991) found that cultivation of the surface greatly enhanced water intake of soil particularly in the beginning of rainy season. In the absence of cultivation, the highly crusting Alfisols produce as much or even more runoff than the low permeable Vertisols under similar rainfall situations. Larson (1962) stated that pulling a tillage implement through soil results in the total porosity and thickness of the tilled area being greatly increased temporarily. Surface roughness and micro depressions thus created play greater role in higher retention of water. On many SAT soils, intensive primary tillage has been found necessary for creating favourable root proliferation and enhancing rainfall infiltration. The positive effects of deep tillage on rainwater conservation, better root development and increased crop yields were observed for 2 to 5 years after deep tillage, depending on the soil texture and rainfalls. On Alfisols

Fig 13 : Vetiver hedge as field bund and Semicircular *vetiver* rings around plants for effective soil and water conservation measure at Tad Fa watershed

Fig. 14 : Cultivation of annual crops with horticultural plants and banana with fruit trees as crop diversification, Tad Fa watershed, Thailand

the off-season tillage serves several useful purposes and should be done whenever feasible. The off-season tillage has been found to minimize the loss by evaporation of stored water by "mulching" effect and thus allowing the acceleration of planting operations and extension of the growing season (Pathak et al. 1987).

In recent times the Zero tillage/minimum tillage/conservation tillage has gained considrable attention. In many regions it has been found to reduce production costs, greatly reduce energy needs, ensure better soil water retention, reduce runoff, water and wind erosion, ensures little or no damage from machinery and save labour (Young, 1982). However, the success of mechanized conservation tillage depends largely on herbicides (which may be expensive and hazardous in nature for use by the resource-poor farmers of the SAT). Crop residues being left on the soil surface to protect it against the impact of torrential rains, and no-till planting equipment to allow precision sowing through trash. Unfortunately, most of the farmers in the SAT use crop residues to feed their animals and to construct fences and buildings. In most parts of semi-arid India, animals are allowed to roam freely on the field after crops have been harvested. Consequently, most of the residue left over is consumed by these animals (Laryea et al., 1991).

Community Based Water Harvesting and Soil Conservation Structures

The community based soil and water conservation can play key role in improving surface and groundwater availability and controlling soil erosion. Studies have shown that the cost of water harvesting and groundwater recharging structures varies considerably with type of structures and selection of appropriate location. Some of the most promising community based soil and water conservation measures are discussed below:

Masonry Check Dam

Masonry check dams are permanent structures effectively used for controlling gully erosion, water harvesting and groundwater recharging **(Fig. 15)**. These structures are popular in watershed programs. The cost of construction is generally quite high. The cross-section of dam and other specifications are finalized considering the following criteria: there should be no possibility of the dam being over-topped by flood-water, the seepage line should be well within the toe at the downstream face, the upstream and downstream faces should be stable under the worst conditions, the foundation shear stress should be within safe limit, proper spillway should be constructed to handle the excess runoff and the dam and foundation should be safe against piping and undermining. Some of the benefits of this type structures are:

- Long lasting structures with little regular maintenance.
- Effective in controlling gully and harvesting water under high runoff flow condition.

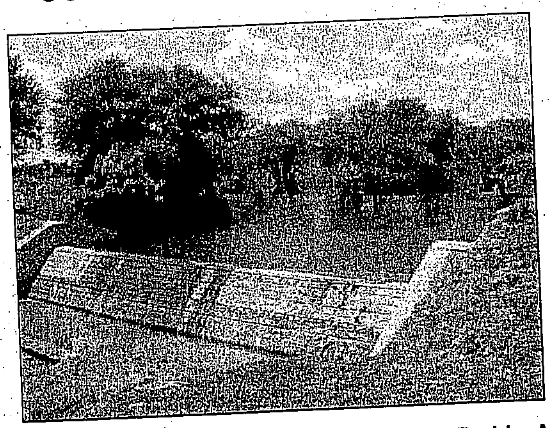


Fig. 15 : A masonry check dam at Kothapally watershed, Ranga Reddy, Andhra Pradesh, India.

Low-Cost Earthen Check Dam

Earthen check dams are very popular in the watershed programs for controlling gully erosion and for harvesting runoff water **(Fig. 16)**. These are constructed using locally available materials. The cost of construction is generally quite low. Some of the major benefits of earthen check dam are:

- These structures serve as water storage and recharging groundwater
- These structures can be constructed using locally available materials
- Simple in design and can be easily constructed by local community
- These structures are of low-cost as well as cost-effective in recharging per unit volume of water.

Fig.16 : Earthen check dam at Lalatora watershed, Vidisha, Madhya Pradesh, India.

Farm Ponds

Farm ponds are very age old practice of harvesting runoff water. These are bodies of water, made either constructed by excavating a pit or by constructing an embankment across a watercourse or the combination of both **(Fig.17).**

Farm pond size is decided on the basis of expected runoff and the total requirement of water for irrigation, livestock and domestic use. Once the capacity of the pond is determined, the next step is to determine the dimensions of the pond. To achieve the overall higher efficiency, the following guidelines should be adopted in the design and construction of farm ponds:

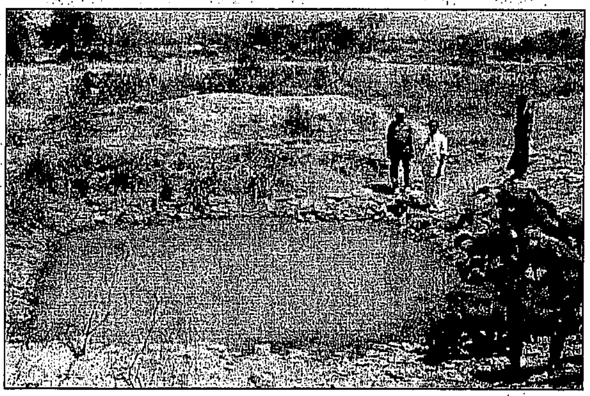


Fig. 17 : A dugout farm pond at Guntimadugu watershed, Kadapa, Andhra Pradesh, India.

High-Storage Efficiency (ratio of volume of water storage to excavation): This can be achieved by locating the pond in a gully, depression, or on land having steep slopes.

Reduce the Seepage Losses: This can be achieved by selecting the pond site having subsoils with low saturated hydraulic conductivity.

Minimize the Evaporation Losses: As far as possible, the ponds should be made deeper but with acceptable storage efficiency to reduce water surface exposure and to use smaller land area under the pond.

Gully Checks with Loose Boulder Wall

Loose boulder gully checks are quite popular for controlling gully erosion and for increasing groundwater recharge (**Fig.18**). These are very low cost structures and quite simple in construction. These gully checks are built with loose boulder only, and may be reinforced by wire mesh, steel posts, if required for stability. Some of the key benefits of these structures are:

- Low-cost and simple in construction with the locally available materials
- These are effective in controlling gully and improving groundwater

Fig. 18 : Series of loose boulder wall gully checks at Bundi watershed, Rajasthan, India.

Improving Adoption of Soil and Water Conservation Practices

In seeking workable conservation prescriptions, research institutions, governments and aid agencies should cooperate closely and fully with local farmers, extension personnel, and community leaders. Such an approach permits information exchanges about what already works well, what might work well, and what would be required to make proposed new soil and water conservation techniques feasible and acceptable. Some of the key points, which can facilitate the greater adoption of soil and water conservation techniques, are:

Short-Term and Visible Benefits To Farmers: Profitability is assessed in the context of financial return to investment, savings in time and labor, modifications needed in the management of farm activities to integrate innovations, increased risk of failure associated with adoption, and many other factors. Unless the economic return associated with adoption is high enough to compensate adopters for all of these costs, farmers will not adopt any recommended technologies. They evaluate all soil and water conservation technologies and techniques in the context of short-run and long-run return to investment. Conservation practices that produce short-run benefits will be more readily adopted than conservation technologies and techniques that produce only long-term benefits.

Participatory Research cum Demonstration: Participatory research cum demonstrations is useful to show potential adopters that soil and water conservation technologies and techniques are appropriate for farming systems. Field demonstrations are also useful to show potential adopters the type of technical skills they must possess to effectively implement recommended soil and water conservation programs on their farm. Before adoption of technology by farmers is expected to take place, the technology must be adequately demonstrated in terms of its benefits as well as its limitations. Farmers must have enough time to assess the improved technology and compare this with what they have become familiar and have been practicing for a long time.

Greater Emphasis to Rainwater Management and Increasing Crop Yields: Increased emphasis should be given to rainwater management. This will enhance the adoption of soil and water conservation practices by farmers. This will provide both short (from moisture conservation) and long-term (from the soil conservation) benefits to the farmers.

Selecting the Appropriate Technologies with Full Technical and Other Assistance: Identify the right soil and water conservation technology as per their socio-economic conditions and which give farmers both short and long-term benefits. Also provide all the assistance and other help including capacity building in effectively implementing the technology.

Encourage More Farmers-to-Farmers Transfer: This facilitates the adoption of new soil and water conservation technologies.

Government Policy to Promote Adoption: Government policy has a very important role to play in the adoption of new practices. For example, in China, terracing has been promoted by the governments as the main soil and water conservation practice for which subsidies are provided.

Technology Which Reduces Risk: Small farmers tend to avoid adopting technologies and techniques that increase the level of risk.

Integrated Watershed Approach: Implementation of soil and water practices in integrated watershed mode for greater impact and increased adoption.

Capacity Building: Important for effective implementation of new technology in the fields.

Increased Farmers' Perception of Environmental Problems and Their Effects: Perception of soil erosion does not mean that farmers are motivated to reduce it. Farmers, without assistance, cannot be expected to know that the erosion of fine, nutrient rich particles of soil reduces soil fertility. Farmers' awareness of environmental problems has been one of the most important factors to affect adoption and continued use of soil and water conservation technologies and techniques at the farm level.

Conclusion

Most rainfed regions are facing multi-faceted problems of land degradation, water shortage, acute poverty and escalating population pressure. Clearly there is an imbalance between natural resources, population and basic human needs in most rainfed regions. Fast deterioration of natural resources is one of the key issues, threatening sustainable development of rainfed agriculture. For improving agricultural production and livelihoods, soil and water resources have to be managed efficiently in sustainable manner.

Improved and appropriate soil and water management practices are most important in the rainfed areas. For both *in-situ* and *ex-situ* soil and land water conservation practices such as conservation furrows, tied ridges, scoops, broadbed and furrow system, bunding, vegetative barriers, tillage systems, check dams and others, considerable body of research knowledge and experiences exist. The real challenge is to identify appropriate technologies, implementation and execution strategies for different rainfed regions. The adoption of soil and water conservation practices is still a major problem in most rainfed regions. Clearly these technologies require new strategies greater and sustained support from the implementing agencies than generally required for other improved agricultural technologies viz. varieties, fertilizers and others.

In most developing countries the availability of adequate hydrological data at the watersheds scale are lacking. This results in higher development costs, less impact and often failure of the structures and other soil and water management interventions. Some of the new equipments/tools, which can be used for monitoring runoff and soil loss viz. digital runoff recorder. Microprocessor-based pumping type sediment sampler and integrated runoff and soil loss monitoring unit are discussed. Some of the key salient features of these equipments in terms of accuracy, reliability and cost-effectiveness are also covered. It was found that the most commonly used method of manual sampling is not suitable for estimating soil loss. This method is found to be highly unreliable and inaccurate. Among the various sediment samplers the microprocessor-based automatic sediment sampler is found to be highly reliable and accurate for monitoring soil loss from small agricultural areas. Recently ICRISAT has developed an integrated unit for monitoring runoff and soil loss from the small agricultural watersheds.

Hydrological models are useful for planning, design and assessing the long-term impact of soil and water interventions and generating long-term hydrological data for the new areas. Some of the hydrological models developed at ICRISAT, which can be used for small agricultural watersheds are discussed. These include a parametric runoff model "RUNMOD", modified SCS curve number runoff and water balance model, and a runoff water harvesting model. Results have shown that considerable information on the various aspects of runoff water harvesting, groundwater recharging and field-based soil and water management interventions can be obtained by using these models. The information generated from these models can greatly assist in the proper planning, development and management of land and water resources.

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