Water Harvesting for Collecting and Conserving Water Supplies

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Abstract

Water-harvesting/runoff-farming techniques are technically feasible methods of supplying water for animals, households, and growing plants. Some water-harvesting systems have been outstanding successes, others total failures. Despite use of proper materials and design, many systems have failed because social and economic factors were not adequately integrated into the systems. There will be a higher probability of system failure when funds are available for construction at no obligation to the user unless there is a clear understanding of who is responsible for maintenance. A successful water-harvesting system must be: (a) technically sound, properly designed, and maintained; (b) socially acceptable to the water user and his method of operation; and (c) economically feasible in both initial cost and maintenance at the user level.

Introduction

Water harvesting is the term used to describe the process of collecting and storing water from an area that has been modified or treated to increase precipitation runoff. A water-harvesting system is a complete facility for collecting and storing runoff. The system consists of a catchment or water-collecting area, a water storage facility, and various auxiliary components such as sediment or trash traps, fencing, and evaporation control. Runoff farming is a water-harvesting system specifically designed to provide water for growing plants. Water harvesting can be an expensive method of water supply; but it can provide water in most areas where other methods are not feasible.

Water harvesting is an ancient method of water supply dating back to over 5000 years (Hardan 1975). During the past 30 years, increased awareness of the importance of water conservation has generated a renewed interest in water harvesting. There is a considerable amount of technical literature which describes or presents information concerning the various techniques of water harvesting and runoff farming. Unfortunately, much of this information is scattered in scientific or technical journals and proceedings of various meetings, and is written in a manner that is difficult to interpret for direct field application by farmers and technicians (Frasier 1975, Cooley et al. 1975, Hollick 1982). This paper summarizes some of the methods and materials used to collect and store precipitation runoff for growing crops and for providing drinking water for man and animals. Some effective concepts and methods are outlined here.

System Design

Irrespective of the intended use for the collected water, the basic criteria for designing a water-harvesting/runoff-farming system are the same. There is no system that is universally "best", since each site has its own unique characteristics. The designer, installer, and the ultimate user should become as familiar as possible with the available techniques and adapt one that is best suited to the local environmental, social, and economic condi-

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Alfisols in the semi-arid tropics. Proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 December 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

tions. There are many separate elements that must be considered: precipitation patterns, water-requirement patterns, land topography, alternative water sources, availability of materials, equipment, labor, and acceptability of water-harvesting concepts by the water user. Many of these factors are interrelated, and must be considered simultaneously.

Precipitation

The quantity and timing of precipitation is one of the most difficult parameters to lay down accurately. Monthly averages, obtained from long-term precipitation records, are the most common data base. To minimize the effect of short-term random fluctuations, it is desirable to use records dating back a minimum of 10 years. If there are extreme variations in precipitation quantities, data from the two wettest years should be deleted. When sufficient years of precipitation data are available, expected rainfall amounts can be determined by probability analysis techniques. Usually it is not economically feasible to design a water-harvesting system to meet the least expected precipitation. The user must decide the amount of risk that can be accepted should there be insufficient precipitation during some periods.

Water Requirements

Table 1 lists the total consumptive water use for a few common crops. Table 2 gives estimates of daily domestic household use and daily drinking water requirements for various animals. For runoff-farming applications, the crop-growing season is the time of water need, and the water supply system must be able to supply the weekly or other short-term consumptive use demands (Erie et al. 1982). Seepage and evaporative losses of water from storage must be included as part of the water requirement.

Alternative Water Sources

The various alternative methods of water supply should be considered prior to installation of a water-harvesting system. There have been instances where the local people were aware of other potential water sources, such as undeveloped springs or shallow groundwater; but technicians not familiar with the area made the decision to use water harvesting as the method of water supply without thoroughly investigating other potential sources. Utilizing temporary or intermittent water sources with the total water supply system can, in some places, justify the installation of smaller water-harvesting systems.

Table 1. Total water consumptive use for selected crops.

Crop	Period of growth	Total seasonal use (mm)
Cash or oil crops		
Castor bean	Apr-Nov	1130
Cotton	Apr-Nov	1050
Flax	Nov-Jun	795
Safflower	Jan-Jul	1150
Soybean	Jun-Oct	560
Sugar beet	Oct-Jul	1090
Lawn or hay crops		
Alfalfa	Feb-Nov	2030
Bermuda grass	Apr-Oct	1100
Blue panic grass	Apr-Nov	1330
Small grain crops		
Barley	Nov-May	635
Sorghum	Jul-Oct	645
Wheat	Nov-May	655
Fruit		
Grapefruit	Jan-Dec	1215
Grape (early-maturing)	Mar-Jun	380
Grape (late-maturing)	Mar-Jul	500
Orange (navel)	Jan-Dec	990
Vegetables		
Broccoli	Sep-Feb	500
Cabbage (early)	Sep-Jan	435
Cabbage (late)	Sep-Mar	620
Cantaloup (early)	Apr-Jul	520
Cantaloup (late)	Aug-Nov	430
Carrot	Sep-Mar	420
Cauliflower	Sep-Jan	470
Lettuce	Sep-Dec	215
Onion (dry)	Nov-May	590
Onion (green)	Sep-Jan	445
Potato	Feb-Jun	620
Maize (sweet)	Mar-Jun	500
Green manure crops		
Guar	Jul-Oct	590
Pea (papago)	Jan-May	495
Sesbania	Jul-Sep	330

Source: Erie et al. 1982.

Table 2. Estimates of daily water requirement for domestic use and drinking water for various animals.

Use	Daily water requirement (L d^{-1})
Domestic	
Per person cooking, drinking, and washing	40
Additional for flush toilets and shower	75-150
Animal drinking	
Beef cattle	
Mature animals	30-45
Cows with calves	40-85
Calves	20-30
Dairy cattle	
Mature animals	40-55
Cows with calves	45-70
Sheep	
Mature animals	4-8
Ewes with lambs	6-10
Horses	40-45
Wildlife	
Mule deer	4-8
Antelope	1-2
Elk	20-30
Swine	15
Chicken (per 100 head)	15
Turkeys (per 100 head)	25

Source: Frasier and Hyers 1983.

Availability of Materials and Labor

The cost of alternative water sources, and the importance of the water supply, determine the cost of a system. One must balance the cost of materials with the cost of labor. Usually, water-harvesting systems for supplying drinking water are constructed from materials that are more costly than can be economically justified for runoff-farming applications.

In many installations there will be several combinations of catchment and storage size that will provide the required quantities of water. The system with the lowest total cost is often the desired unit, but maintenance costs must also be included in the selection process. To insure that there are no critical periods when there will be insufficient water, the final size of the catchment and storage tank should be determined by computing an incremental water budget of collected water versus water needs (Frasier and Myers 1983).

Acceptance and Needs as Viewed by the User

The acceptance of water-harvesting concepts by the water user is an important factor in the performance of a water-harvesting system. Some materials and/or system designs require more maintenance than others. If the user does not believe that the system is the best for his purpose or situation and fails to provide the required maintenance, the system will fail. In areas where the concepts of water-harvesting/runoff-farming are not fully accepted because of various social or economic factors, the first system installed must be constructed from materials that have minimum maintenance requirements and maximum effectiveness. Materials and techniques that cost less may be used on subsequent units once the user has been shown that the ideas are valid.

Catchment Area Treatments

There are many ways that a catchment area can be modified to increase the quantity of precipitation runoff. These can be separated into three general categories: (1) topography modifications, (2) soil modifications, and (3) impermeable coverings or membranes. Table 3 presents a list of some of the common catchment treatments.

Topography modifications

The earliest catchment treatments are believed to have involved some form of topography modifications, and were simply areas cleared of brush and rocks, with small collection or diversion ditches to direct the runoff water to the storage. An example of this technique is the placement of water collection channels at the lower edge of rock outcroppings. With a minimum of materials or skilled labor, relatively large quantities of water can be obtained at low costs. Some of the most extensive uses of topography modification for catchment treatments are the "roaded" catchments in western Australia. These

Table 3. Potential water-harvesting catchment treatments.

Treatment	Runoff efficiency (%)	Estimated life (years)	Materials initial cost[1] (U.S. $ m^{-2})
Topography modifications			
Land smoothing and clearing	20-35	5-10	0.05- 0.20
Soil modifications			
Sodium salts	50-80	5-10	0.20- 0.50
Water repellents, paraffin wax	60-95	5-8	0.50- 1.00
Bitumen	50-80	2-5	1.00- 2.00
Impermeable coverings			
Gravel-covered sheeting	75-95	10-20	1.00- 1.75
Asphalt-fabric membrane	85-95	10-20	1.75- 2.50
Concrete, sheet metal, and artifical rubber	60-95	10-20	5.00-20.00

1. Adjusted to 1983 material costs.
Source: Frasier 1981.

are large areas of bare land shaped and compacted into parallel ridges and furrows (Laing 1981, Frith 1975).

Catchments utilizing topography-modification techniques are usually characterized by low initial costs, but they may have relatively low runoff efficiencies. These treatments are effective if properly matched to suitable soil types and topographic features. Slope angles and overland flow distances must be properly designed to avoid serious damage to the catchment surface through water erosion (Hollick 1982).

Soil modifications

Soil modification treatments involve chemicals applied to the soil surface by spraying or mixing to reduce or stop water infiltration. These treatments can potentially provide large quantities of water at low cost. Unfortunately, most soil modification treatments have been unsuccessful because of the necessity to match specific soil and climatic characteristics. Bitumen or asphalt have been widely tested as a soil modification treatment. This treatment is best suited for use on fine sandy soils and has a projected effective life of 2-5 years (Myers et al. 1967).

Salt treatment (sodium-dispersed clay) is potentially the cheapest soil modification technique. This treatment consists of mixing a water-soluble sodium-based salt ($NaCl$) at a rate of about 11 t ha^{-1} into the top 2 cm of soil. After mixing the salt with the soil, the area is wetted and compacted to a firm, smooth surface. For this treatment to be effective, the soil should be made up with 20% or more of kaolinite- or illite-type clay. The sodium salt disperses the clay, plugs the soil pores, and reduces the hydraulic conductivity (Dutt 1981).

Water-repellent treatments can potentially be a low-cost soil modification technique. A chemical that is applied to the catchment surface causes the soil to become hydrophobic (water-repellent) by changing the surface tension characteristics between the water and soil particles. Many chemicals can create a water-repellent surface, but only a few compounds have been shown to be effective for water-harvesting applications (Myers and Frasier 1969). One of the simplest water-repellent chemicals to apply is a water-based sodium silanolate. The treatment does not provide any soil stabilization and is not suited for soils containing over 15% clay. It does have high potential for increasing runoff from rock outcroppings where soil erosion is not a problem. It has an effective life of 3-5 years.

Another water-repellent treatment is formed by spraying molten, refined wax on the prepared soil surface. The wax is deposited as a thin layer on the surface, and as the sun warms the soil, the wax remelts and moves into the soil, coating the soil particles with a thin coat of wax and rendering them water-repellent (Fink et al. 1973). This treatment is best suited to soils containing less than 20% clay and catchment sites where the surface soil temperature exceeds the melting point of the wax during some part of the year (Frasier 1980). The paraffin wax does not provide significant soil stabilization, and the treatment can be damaged by water erosion.

Impermeable coverings or membranes

Any impermeable or waterproof sheeting or membrane can be used as catchment covering. Many conventional construction materials such as concrete, sheet metal, and artificial rubber sheetings have been used (Cooley et al. 1975). These materials are relatively expensive, but when properly installed and maintained are durable, and may be the best treatment for some locations. Large expanses of concrete will crack. All cracks and expansion joints must be periodically filled with some type of sealer. Roofs of sheet metal have long been used to collect rainwater. Costs can be reduced by placing the sheet metal on the ground (Lauritzen 1967). In the 1950s, many catchments were covered with sheets of artificial rubber. Improper placement and susceptibility to damage by wind and animals destroyed most of these units.

Several types of plastic and other thin sheetings have been investigated as potential soil coverings for water-harvesting catchments. Unfortunately, most of these thin film coverings were found to be susceptible to mechanical damage and sunlight deterioration. Wind damage potential can be reduced by placing a shallow layer of clean gravel on the sheeting after it has been positioned on the catchment surface. The sheeting is the waterproof membrane, and the gravel protects the sheeting from mechanical damage. This treatment requires periodic maintenance to ensure that the sheeting remains covered with the gravel. Wind-blown dust trapped in the gravel layer provides a seedbed for plants and has been a minor problem. This treatment is relatively inexpensive if clean gravel is readily available (Cluff 1975).

One treatment being widely used to supply drinking water for wildlife and livestock in the United States is a membrane of asphalt-saturated fabric. The fabric is either a random-weave fiberglass matting or a synthetic polyester filter fabric matting. The matting is unrolled on the prepared catchment surface and saturated with the asphalt emulsion. Three to 10 days later, a second coating of asphalt is brushed on the membrane. These membranes are relatively resistant to damage by wind, animals, and weathering processes (Myers and Frasier 1974).

Water Storage

Water-storage techniques for holding the water collected from a catchment area can be separated into two general groups: (1) the soil profile or monolith, and (2) tanks or ponds. The type of storage selected will depend on many factors, such as the ultimate use of the water, availability of construction materials, availability and skills of labor, and site topography.

Soil monolith storages

In many runoff-farming applications, the soil profile within the crop-growing area is the water storage container. The primary factors that must be considered in designing soil monolith storages are: (1) the depth of the soil profile, (2) water-holding capacity of the soil, and (3) the infiltration rate of the soil surface.

Tank and pond storage

Any container capable of holding water is a potential water-storage facility. External water storage is a necessary component for drinking water supply systems, and may also be a part of a runoff-farming system where the water is applied to the cropped area by some form of irrigation system. In many water-harvesting systems, the storage facility is the most expensive single item, and may represent up to 50% of the total cost.

Unlined earthen pits, or ponds, are usually not satisfactory methods of storing water for water-harvesting systems unless seepage losses are naturally low, the soil is sealed with chemicals, or the losses are controlled by liners of plastic or artificial rubber. Exposed liners are susceptible to damage from sun, wind, animals, and plants. Chemical soil sealants have limited applications, and should be used only as recommended and guaranteed by the manufacturer.

There are many types, shapes, and sizes of wooden, metal and reinforced plastic storage containers. Costs and availability are primary factors for determining the potential suitability of these containers. One common type of storage is a tank constructed with steel walls, with a concrete bottom or other type of impermeable liner or bottom. Containers constructed from concrete and plaster are relatively inexpensive, but their construction requires a significant amount of hand labor (Frasier and Myers 1983).

Since water harvesting is generally an expensive method of supplying water, controlling evaporation losses is an important factor, and should be an integral part of all water-storage facilities. Although relatively expensive, roofs over the storage are commonly used. Floating covers of low-density synthetic foam rubber are effective means of controlling evaporation from vertical-walled, open-topped containers (Dedrick et al. 1973). Evaporation control on sloping-side pits or ponds is difficult because the water-surface area varies with the depth.

Runoff-farming Systems

There are two basic runoff-farming systems. One is the direct water application system by which the runoff water is stored in the soil profile of the crop-growing area. The other is the supplemental water system by which runoff water is stored off-site and applied to the crop as needed. Some runoff-farming installations are a combination of the two types.

Direct water systems

In a direct water system the collected runoff water is diverted or directed onto the cropped area during precipitation. With this system, both runoff water and precipitation infiltrate into the soil. Except during low-intensity storms, the combined quantity of runoff and precipitation will exceed the infiltration rate of the soil. Dikes or ridges must be placed around the runon (cropped) area to retain the water and allow it to infiltrate into the soil. The runoff water for these systems may be obtained from channels using water-spreading techniques.

One common direct water runoff-farming system used for growing shrubs or trees comprises small catchments prepared directly upslope of the growing area. Typical catchment areas vary from irregular shapes with minimal site preparation and soil treatment to graded, compacted areas that are sealed to maximize the runoff efficiency. Runoff to runon area ratios vary from 1:1 to 20:1, depending on the expected quantity of water needed.

Systems utilizing water-spreading techniques, by which the water is diverted from channels or upland areas, may encompass relatively large areas (Fig. 1). They have been used for growing grain crops and forage grasses. Some of these systems may have

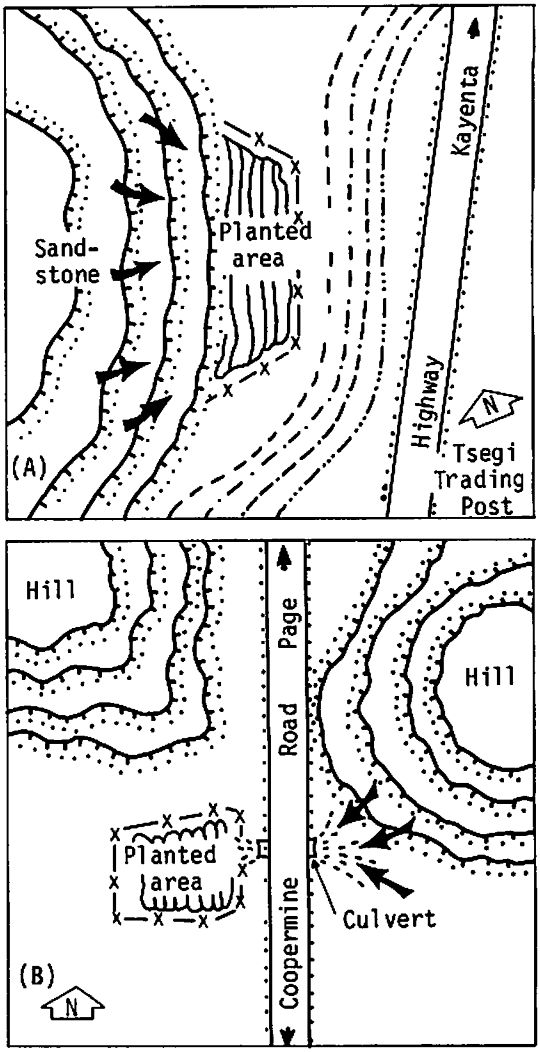


Figure 1. Water-spreading runoff-farming systems. A: John Boyd floodwater farming area near Copermine, Arizona, USA. B: Tsegi Canyon floodwater farming area near Kagenta, Arizona. (Source: Billy 1981.)

extensive ditching systems within the cropped area to permit better control of the water. Most of these systems in use today have evolved, over many years, by trial and error.

Supplemental water systems

A supplemental water system is one by which runoff water is collected and stored in a tank or pond away from the growing area, permitting its later application to the crop through some form of irrigation system. These systems have the advantage of being able to supply water to the crop when needed, but the disadvantage of extra costs and problems of providing the required water storage and irrigation facilities. If the catchment and storage facilities are located above or upslope of the cropped area, flood irrigation systems are an effective means of water application.

In the past decade, drip or trickle irrigation systems have come into use. These systems facilitate uniform water application, but are expensive to install. If the catchment and storage facilities are upslope, gravity provides the required water pressure. Otherwise, the water pressure is obtained by pumping.

Excess water that does not infiltrate into the soil profile drains into a storage tank or pond for later use. A typical system is composed of land graded into large ridges and furrows (roaded catchments) which have a gradient leading to the storage pond. Crops, such as grapes or fruit trees, are planted in the bottom of the furrows. An irrigation pump-back system is used to water the plants between runoff flows.

Case Histories

Village water

Shungopovi, Hopi Indian Reservation. The village of Shungopovi is located in Second Mesa, on the Hopi Indian Reservation in northeastern Arizona, USA. The village, built on top of sandstone rock mesas, had no source of water except that carried up from the valley, initially on foot, and later on the backs of burros. In the early 1930s a small water-harvesting system was installed to partially relieve the water shortage in the village. An area of approximately 0.3 ha was cleared of vegetation and the loose soil removed to expose the sandstone bedrock. A deep cistern was dug into the rock and covered with a concrete roof. This system was a functional part of the village water supply for about 30 years (Chiarella and Beck 1975).

Techo Cueneca, Mexico. The Techo Cueneca water-harvesting system provides part of the domestic water supply for 30 families (approximately 180 people) for the village of Lagunita y Ranchos Nuevos, in north-central Mexico. This system consists of an inverted galvanized metal roof (269 m^2) supported on a steel framework above a steel tank of 80 m^3. Labor for constructing the unit represented 36% of the total cost, and was provided by the village. The system provides drinking water to the entire village for an average of 4.5 months each year. The villagers are allotted 20 L d^{-1} per family. Water produced from the system is about one-third the cost incurred by hauling (1981 data; Carmona and Velasco 1981).

Pan Tak, Papago Indian Reservation. This is a multifamily water supply system. The Pan Tak village has three families (approximately 15 people) located approximately 100 km west of Tucson, Arizona. The water supply was a shallow well, a steel, closed-top storage tank of 39 m^3, and a gravity distribution system. The well, when pumped slowly, provided an adequate supply for existing domestic requirements.

In 1966, a large petroleum company, interested in water-harvesting, constructed a water-harvesting system adjacent to the village. This system consisted of a 1-ha catchment coated with sprayed asphalt, and a 300-m^3 steel rimmed, concrete-bottommed tank (uncovered). The design allowed the water to seep from the tank to the groundwater where it could be pumped as needed to maintain the level of the well. The catchment area was reasonably effective in producing runoff for a few years, but there are no data or reports as to the success of recharging the groundwater and its recovery by the well. There was no scheduled maintenance program, and the system was abandoned.

In 1981 a grant was obtained by the Papago Indian Tribe to rejuvenate the system to increase the village's water supply. The lower half of the catchment area was cleared of vegetation, smoothed, and a membrane treatment of gravel-covered polyethylene installed. The large storage tank was cleaned and fitted with a pump, chlorinator, and filter unit and connected to the domestic supply tank. Two years later, this system was not being used because of the lack of local interest.

Runoff farming

Page Ranch, University of Arizona. The Page Ranch runoff-farming facility is located at the University of Arizona Page-Trowbridge Experimental Range north of Tucson, Arizona. This facility is used as an experimental and demonstration facility, and has several types of runoff-farming systems. The largest unit is a combination system for growing grapes. The catchment area was shaped into large ridges and furrows, and the sides of the ridges treated with sodium chloride mixed into the top 2.5 cm of soil. Grapes are planted at the bottom of the furrows. Excess water from the furrows drained into a pond sealed with sodium salts. The water collected in the pond is pumped back onto the grape-growing area and applied through a trickle irrigation system (Dutt and McCreary 1975).

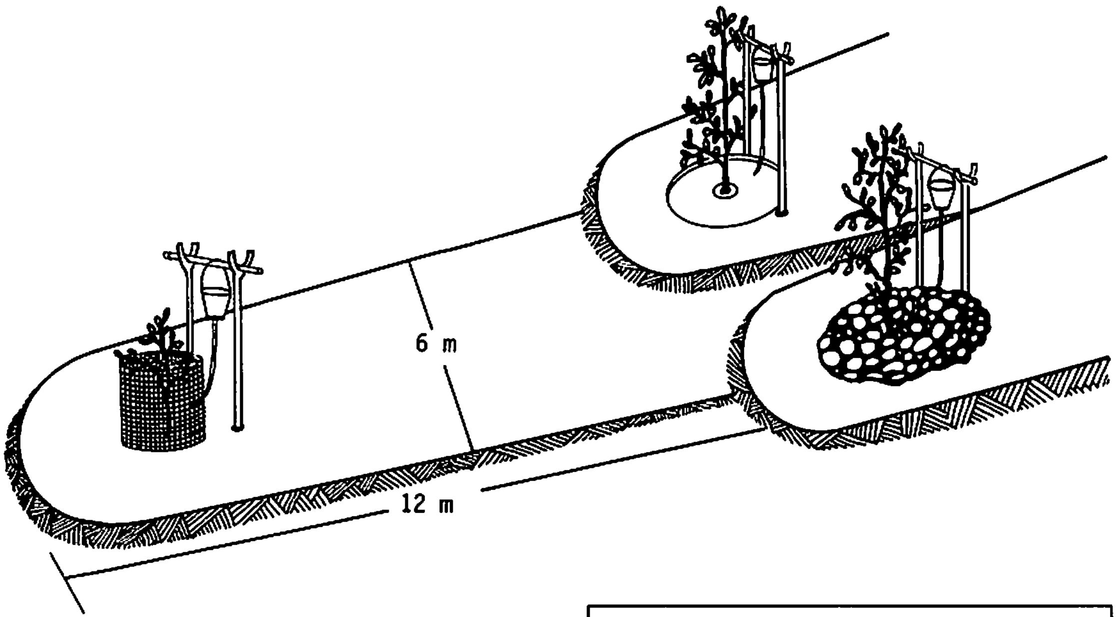
Black Mesa, University of Arizona. The Black Mesa water-harvesting system, a demonstration facility located in northeastern Arizona on displaced overburden from a strip coal mine, is one of the largest combination systems in the United States. It consists of (1) three water storage ponds with a total capacity of slightly over 3000 m^3, (2) two leveled agricultural terraces of 1 ha each, (3) a "roaded" catchment for a 0.5-ha orchard, and (4) a fiberglass-asphalt gravel catchment of 3.2 ha, and a 2.9-ha salt-treated catchment. A pump system is used to transfer the collected water between ponds and to lift the water to irrigate the crop areas initially by flood irrigation, then later by means of a sprinkler system.

Annual crops grown and evaluated were beet, onion, turnip, potato, chard, lettuce, cabbage, tomato, squash, bean, pumpkin, melon, mango, and maize. All crops, except tomato, did well, with some producing at levels above the national average. The economic value of the maize produced was the lowest of all crops. This was not unexpected because maize is a traditional food in the area, and was planted for social reasons. Fruit trees had never been grown in the area before. All trees were growing well after 3 years, but it was too soon to determine the potential production of the varieties planted. Income from the water-harvesting project was about $1700 net per cultivated ha in 1981. Agricultural yields are expected to increase when the orchards reach maturity (Thames and Cluff 1982).

Mexico. One of the many runoff-farming systems being evaluated in Mexico is located in the state of Nuevo Leon. This system is composed of a set of 248 direct-runoff units for growing pistachio trees. Each tree has a separate contributing runoff area of 70 m^2 (Fig. 2). Runoff area treatments under evaluation are: (1) compacted soil, (2) soda ash (Na_2CO_3), (3) road oil, (4) gravel-covered polyethylene, (5) gravel-covered asphalt, and (6) control (smoothed soil). Soil moisture is monitored under each tree at depths of 15, 35, and 55 cm. Also included were various soil coverings immediately around the tree to limit water loss by evaporation (Velasco and Carmona 1980). Because of the growth rates of the trees, this is a relatively long-term study. One preliminary observation was that on some of the salt-treated units, the treated soil eroded from the catchment surface, and was deposited around the trees. This significantly reduced the infiltration rate.

U.S. Water Conservation Laboratory. The U.S. Water Conservation Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Phoenix, Arizona, has several water-harvesting, runoff-farming research sites. One runoff farming site in south-central Arizona was used to determine if the marginal plant growth and seed yields of native stands of jojoba (*Simmondsia chinensis*) could be improved with additional water using water-harvesting techniques. Small (20-m^2) direct-runoff systems were constructed around individual bushes in native stands. Three runoff area treatments were evaluated: (1) control (undisturbed), (2) compacted and later treated with clay and sodium salts, and (3) paraffin wax water repellents. Water use of each plant was determined by neutron soil moisture measurements. Because of severe frost encountered at three separate times during the 7-year study (1974-80), it was concluded that commercial farming of jojoba, under the climatic conditions at the test site, would not be practical (Fink and Ehrler 1981).

Southwest Rangeland Watershed Research Center. Limited studies have been conducted near Tombstone, Arizona, by the Southwest Rangeland Watershed Research Center, Agricultural Research Service, U.S. Department of Agriculture, on the effects of additional water provided by a direct-application runoff-farming system on the forage production of blue panic grass (*Panicum antidotale*). Runoff to crop-growing area ratios of 0:1, 1:1, 2:1, and 3:1 were evaluated. Runoff area treatments were (1) bare soil, (2) seeded with grass, and (3) waterproofed with paraffin wax. During a 3-year study, forage yields, using waxed runoff areas of 2:1, were 16 times the control (0:1). Adjusting yields to account for the land removed from potential production with the catchment area showed an average yield 5 times greater from the treated runoff area, as compared with an uninterrupted planting of grass (Schreiber and Frasier 1978). The increased forage production obtained from the waterproofed runoff area is probably not economically feasible for most areas where forage is the only product.



Socioeconomic Considerations

Water-harvesting/runoff-farming techniques are practical methods of water supply for most parts of the world. It is a relatively expensive method of water supply. During the past few decades there have been several water-harvesting/runoff-farming systems constructed and evaluated worldwide. While many of these systems have been outstanding successes, some were failures. Some systems failed despite extensive efforts because of material and/or design deficiencies. Some others failed because of personnel changes, communication failures, or because the water was not needed. Word-of-mouth publicity of one failure will often spread more widely than all of the publicity from 10 successful units.

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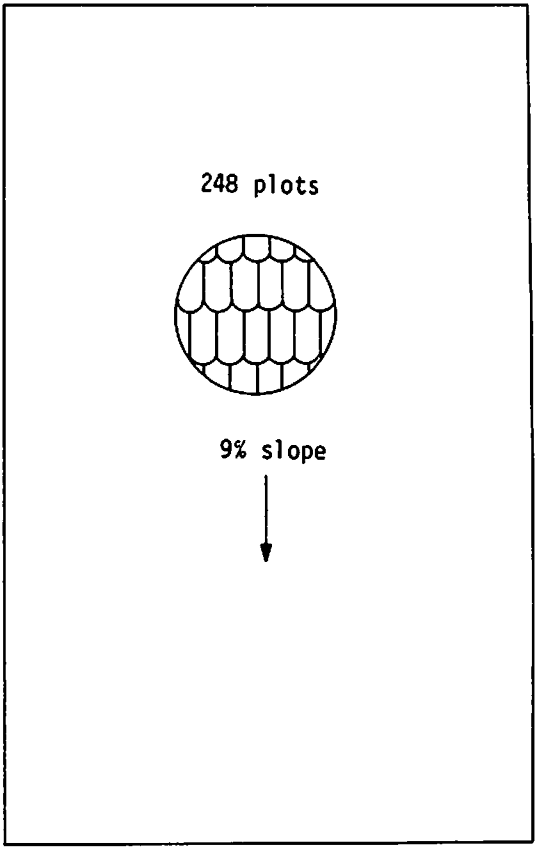

Figure 2. An experimental runoff-farming system for growing pistachio nuts. (Source: Velasco and Carmona 1980.)

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