Runoff farming

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Abstract

"Runoff farming" is identical with "Water Harvesting but for Irrigation Purposes". When the harvested runoff water from un-cropped areas is directed to a cropped area, this technique is called runoff farming. Soil profile acts as a water storage container, but storage in ponds or cisterns is also feasible. Factors affecting the capacity of soil storage are: depth of the soil profile, depth of plant roots, texture, structure, infiltration rate and the water holding capacity of the soil. The catchment-to-field ratio can range from 1:1 and from 1:many square kilometers. The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield.

Two runoff farming water harvesting groups are generally recognized, 1. rainwater harvesting and 2. floodwater harvesting. Rainwater harvesting can be further divided into 1. microcatchment, and 2. macrocatchment runoff farming types. Floodwater harvesting can also be divided into two 1. within streambed and 2. through diversion runoff farming types. Microcatchment runoff farming is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area. Macrocatchment runoff farming (catchment area being 1,000 m^2 - 200 ha) system is referred to by some authors as "runoff farming water harvesting from long slopes", as " medium-sized catchment water harvesting" or as "harvesting from external catchment systems". Runoff farming with floodwater harvesting comprises a systems with catchments being many square kilometers in size, from which runoff water flows through a major wadi (bed of an ephemeral stream or river), the water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement. Runoff farming requires relatively large labor inputs and land. Development of runoff farming is increasing specially in semi-arid and arid areas after 1950, partly due to the successful reconstruction of ancient water harvesting farms in the Negev. Low-cost efficient use of runoff farming in arid zones for food and fuel production could help to restore self sufficiency in food production for local populations in many dry regions. Countries where this method has been used include Egypt, Tunisia, Libya, and southern Algeria. Some other countries outside Africa include Isreal, Jordan, North Yemen, India, Pakistan and the Soviet Union.

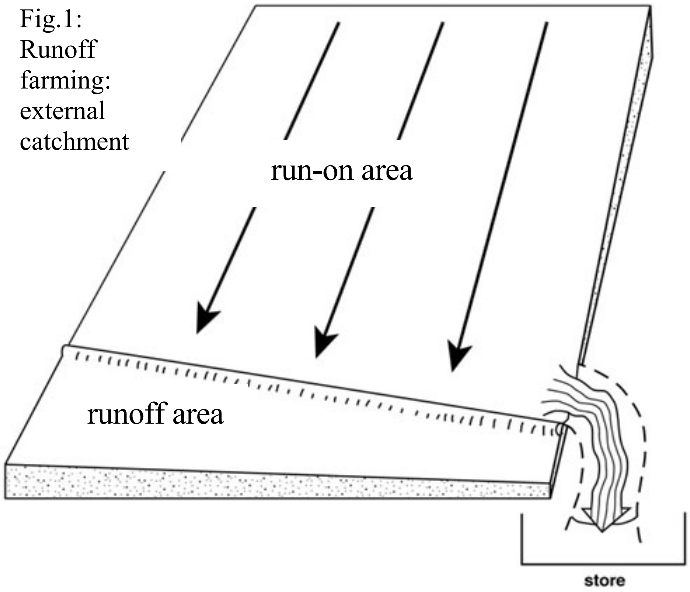
There should be a global cooperation between scientists and practitioners involved in water harvesting and runoff farming. By learning from failures and successes, a high degree of sustainability might be reached, similar to the one which apparently existed in the past thousand of years. Runoff farming has proved to be a valuable tool especially in dry marginal areas to increase crop yields and reduce cropping risk, to improve pasture growth, to boost re-afforestation, to allow a higher degree of food production, to fight soil erosion, to make best use of available water resources, to suppress soil salinity and, in a few cases and to recharge the local groundwater.

Keywords

Runoff farming; rainfed farming; water harvesting; recession farming; runoff cropping; water conservation.

Introduction

Fig.1: Runoff farming: external catchment



In arid areas (i.e., areas with an annual rainfall below 200 mm), it is best to encourage and collect the runoff from a barren catchment area, and lead it to a cropping area in the valley bottom (FAO 1987, Hudson 1988, Finkel 1986), the method is called runoff farming (see Fig. 1). "Runoff farming" is identical with "Water Harvesting for Irrigation Purposes". In many dry regions of the world, runoff farming was already an important means of securing sufficient water for agricultural crops or pasture areas two to three millennia ago. In many of those areas, such as in Yemen, runoff irrigation is still practiced today; in other parts of the arid and semi-arid world those systems have been given up, the structures are destroyed and the skills forgotten (Prinz 1994). The runoff can either be diverted directly and spread on the fields or collected in some way to be used at a later time (Rosegrant et al., 2001). The size of the catchment can be (in the case of microcatchment) rather small, in the case of macrocatchment and floodwater it is relatively large and measures must be taken to route the runoff to the collection area and to prevent significant infiltration losses.

Runoff farming require relatively large labor inputs and land requirements (Thompson et al., 2001). The runoff area (catchment) should show a sufficiently high run-off coefficient (impermeability would be optimal) and the "run-on" area, where the accumulated water is stored and/or utilized, should have (for water storage in the soil matrix) a high infiltration rate a high storage capacity, which depends on soil texture, organic matter content and general soil structure, a sufficient soil depth (> 1m) (Lalljee and Facknath 1999, Prinz 1994). The ratio of catchment-to-field can range from 1:1 and from 1:many square kilometers in size according to Micro- or Macro-Catchment or Floodwater runoff farming system.

Surface runoff is diverted by means of simple earthen or rock bunds into fields that have been surrounded by ridges and possibly terraced (Prinz et al., 1994).

Some authors (e.g. Oweis; Hachum and Kijne 1999) restrict runoff farming to situations where the harvested runoff water is diverted directly into the cropped area during the rainfall event, excluding any storage in ponds, cisterns etc. Other authors exclude floodwater harvesting when talking on "runoff farming". The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield (Prinz 2002). The most suitable areas for runoff farming are those with an average annual rainfall of 300 - 600 mm and with rainfalls during few but relatively intensive rainstorms (Esser 1999). Runoff farming in a small watershed can also be encouraged by shaping the catchment and by removing the surface stones. The method was practiced many centuries ago in the Negev Desert (Evenari and Koller 1956). Level terraces were constructed in the valley bottom. These water-spreading terraces are known as "limanim", from a Greek term for port. The water filled the first terrace, and was then drained off at the side through a stone weir or over a low gabion into the field below (http://www.agnet.org/library/article/eb 448.html).

Classification of runoff farming water harvesting techniques

Different authors have classified water harvesting methods in various ways (see Reij, Mulder and Begemann (1988) for an extensive review of different classification methods) and a standardized classification system has yet to be developed. Pacey and Cullis (1986) classify rainwater harvesting techniques into three broad categories external catchment systems, microcatchments, and rooftop runoff collection.

According to Nasr (1999), there are two basic types of runoff-farming systems: **first**, the

* direct water application system, where the runoff water is stored in the soil of the crop growing area during the precipitation, and **second,** the
* supplemental water system, where the collected water is stored offsite in some reservoirs and later used to irrigate a certain crop area.

As also according to Critchley and Siegert (1991), generally, two runoff farming water harvesting groups are generally recognized, rainwater harvesting and floodwater harvesting. Rainwater harvesting can be further divided into microcatchment, and macrocatchment runoff farming types. Floodwater harvesting can also be divided into within streambed and through diversion runoff farming types.

See Tab.1 for the classification of **runoff farming water harvesting (RFWH) types** and table 2 for **runoff farming water harvesting (RFWH) techniques**.

See Fig. 2 for runoff farming water harvesting A: Microcatchment 'Negarin' Type, B: Macrocatchment 'Hillside Conduit' system, C: Floodwater Harvesting: Floodwater diversion system, Sources: A: Rocheleau et al., 1988; B and C: Prinz 1996

Rainwater harvesting runoff farming

a) Microcatchment runoff farming water harvesting (MIRFWH) systems:

Microcatchment runoff farming water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area/basin. This infiltration area/basin may be planted with annual crops, or with a single tree or bush (Boers and Ben-Asher 1982) see Fig. 2 (part A).

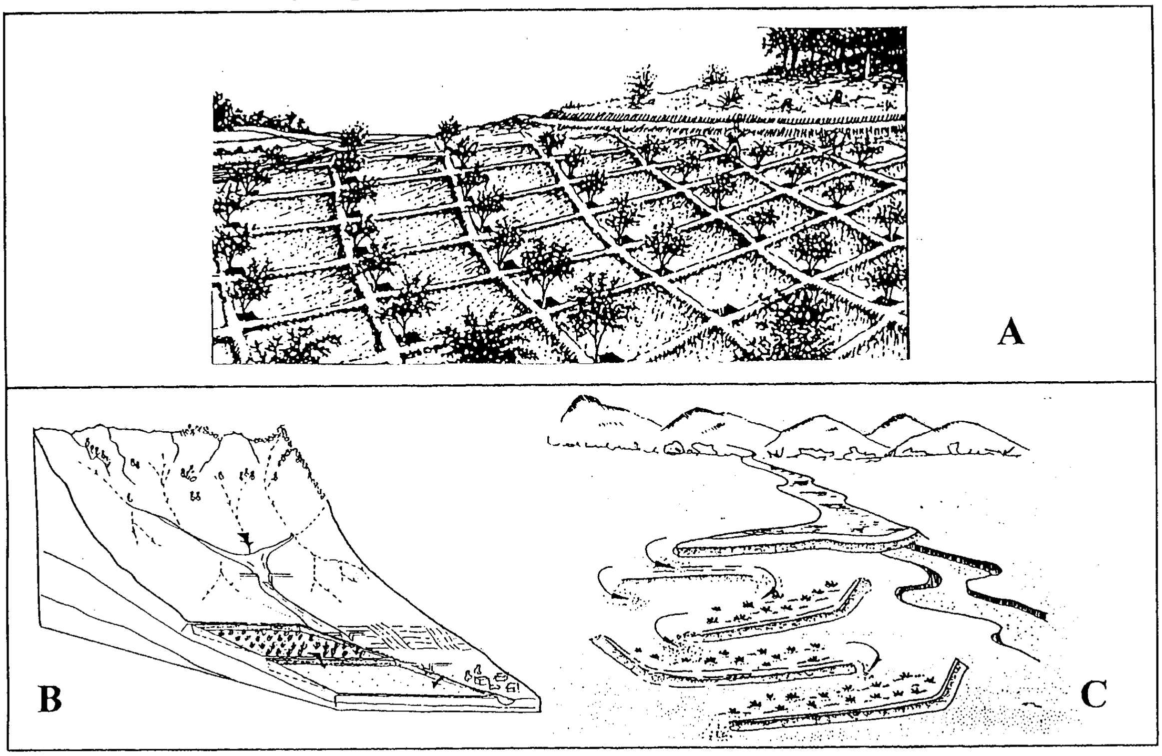


Fig. 2 for runoff farming water harvesting A: Microcatchment 'Negarin' Type, B: Macrocatchment 'Hillside Conduit' system, C: Floodwater Harvesting: Floodwater diversion system,
Sources: A: Rocheleau et al., (1988); B and C: Prinz (1996)

The advantages of MIRFWH systems are (Prinz 1996):

* Simple to design and cheap to install, therefore easily replicable and adaptable.
* Higher runoff efficiency than medium or large scale water harvesting systems; no conveyance losses.
* Includes also erosion control.
* Can also be constructed on almost any slope, including almost level plains.

One type of microcatchment technique is **'Inter-row water harvesting'** (Prinz 1996)**.**
Inter-row water harvesting is applied either on flat land or on gentle slopes of up to 5 % having soil at least 1 m deep. The annual rainfall should not be less than 200 mm/year.

On flat terrain (0 - 1 % inclination) bunds are constructed, compacted and, under higher-input conditions, treated with chemicals to increase runoff. The aridity of the location determines the **catchment to the cropping ratio (CCR)**, which varies from 1:1 to 5:1 (Fig. 3). Examples are given from India (Vijayalakshmi et al., 1982) and the USA (Frasier 1994) (Prinz 1996).

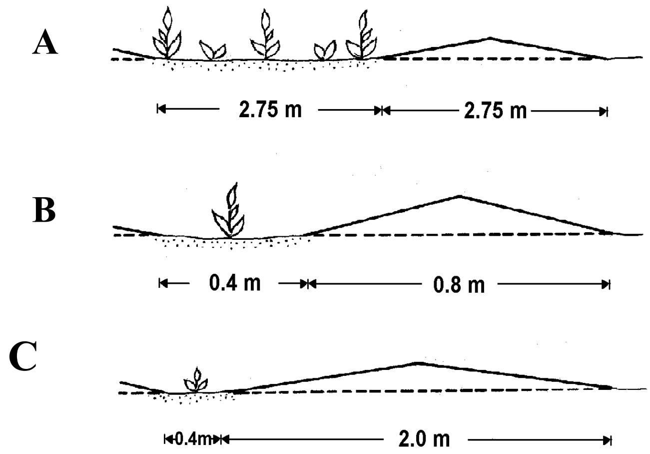
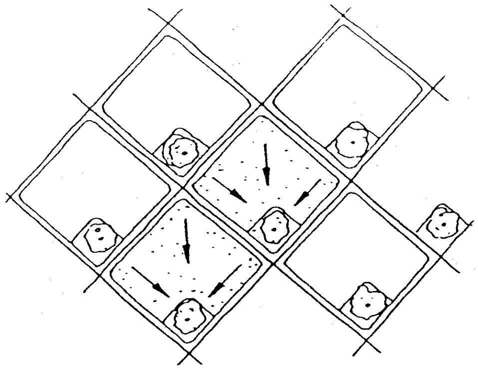
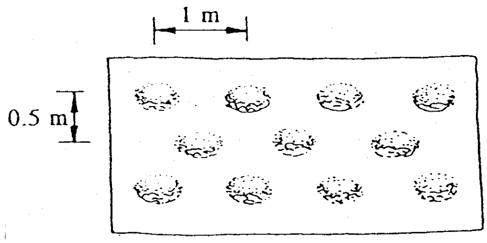
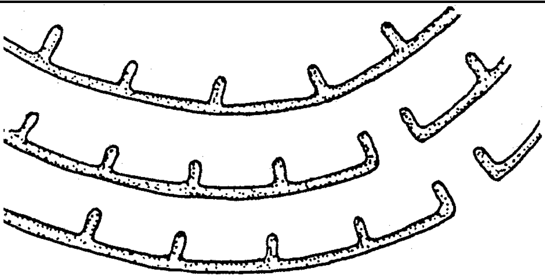
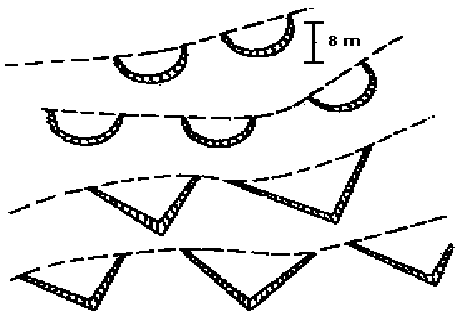


Fig. 3: Various forms of flat-land inter-row microcatchment runoff farming water harvesting froms, the aridity of the location is increasing from A to C (Prinz 1986).

On sloping land (1 - 20% inclination) these systems are called "contour ridges" (USA) or "Matuta" (East Africa). The ridges of about 0.40 m height are built from 2 to 20 m apart, depending on slope, soil surface treatment, general CCR and type of crop to be grown. The catchment area should be weeded and compacted; the crops are either grown in the furrow, along the upper side of the bund or on top of the bund. On sloping land, this system is recommended only for areas with a known regular rainfall pattern; very high rainfall intensities may cause breakages of the bunds. Crops cultivated in row water harvesting systems are maize, beans, millet, rice or (in the USA) grapes and olives (Pacey and Cullis 1986, Finkel and Finkel 1986, Tobby 1994). The preparation of the land for inter-row water harvesting can be fully mechanized. Other types of microcatchment runoff farming systems are depicted and in short described in Fig. 4a and Fig. 4b (Prinz 1996). Fig. 5 shows also the most prominent types of this system .

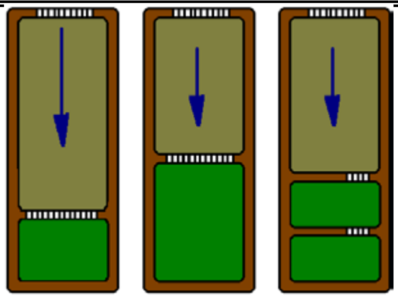
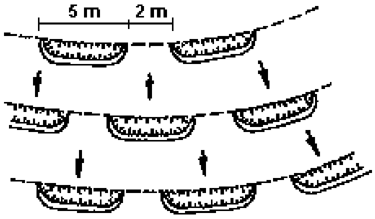
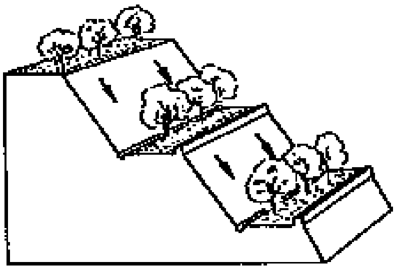
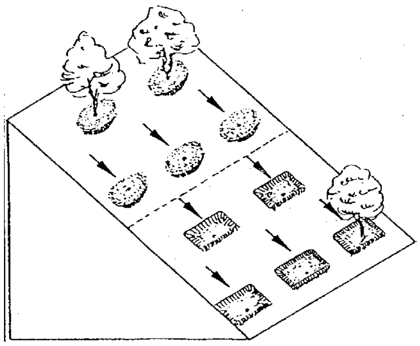
Fig. 4a: Various types of microcatchment (MC) runoff farming water harvesting systems (Prinz 1996)

Type	Illustration	Parameters	Remarks & References
Negarin		CA= 3 - 250 CR= 1 - 10 CCR= 3 : 1 - 25:1 PREC= 150 - 600 mm/a SL = 1 - 20%	Ben-Asher 1988
Pitting		CA= 0.25 CR= 0.08 CCR= 3:1 PREC= 350 - 600 mm/a SL= 0 - 5%	"Zay system" (West Africa), "Kitui Pitting", "Katumani Pitting" (Kenya) Buritz et al. 1986 Gichangi et al. 1989
Contour ridges		CA= 100 CR= 20 CCR= 5:1 PREC= 300 - 600 mm/a SL= 5 - 25%	Critchley 1987
Semi-circular hoops (demi-lunes); Triangular bunds		CA= 24-226 CR= 6-57 CCR= 4:1 PREC= 300 - 600 mm/a SL= 2 - 20%	MoALD 1984

CA = Catchment size (m^2)
CR = Cropping area (m^2)
CCR = Catchment cropping ratio
SL = Slope

PREC = Precipitation
SLCA = Slope of catchment area
SLCR = Slope of cropping area

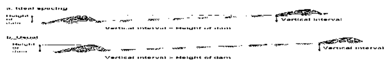
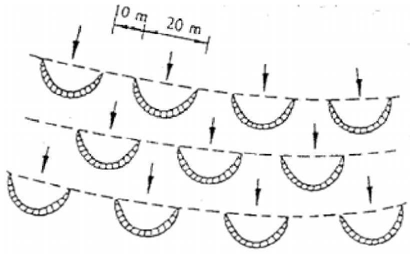
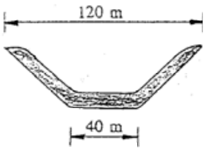
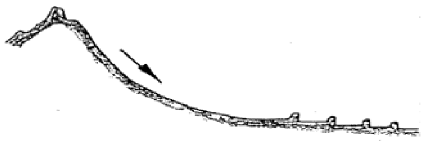
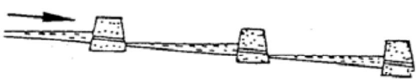
Fig. 4b: Various types of microcatchment (MC) runoff farming water harvesting systems (Prinz 1996)

Type	Illustration	Parameters	Remarks & References
Meskat-type		CA= 500 CR= 250 CCR= 2:1 PREC= 200 - 600 mm/a SL= 2 - 15%	El Amami 1983
Vallerani-type (fully mechanized)		CA= ~ 15 CR= ~ 2.4 CCR= 6:1 PREC=100 - 600 mm/a SL= 20 - 50%	400 MC/ha = 960m² CR/ha Preparation by "wavy dolphin plough";
Contour bench terrac-es		CA= ~2-16 CR= 2-8 CCR= 1:1-8:1 PREC= 100 - 600 mm/a SL= 20 - 50%	"Conservation bench terraces"
Eye brow terraces; Hillslope micro-catchments		CA= 5 - 50 CR= 1 - 5 CCR= 3:1 - 20:1 PREC= 100 - 600 mm/a SL= 1 - 50%	100,000 trees programme in the Negev/Israel Ben-Asher 1988

CA = Catchment size (m^2)
CR = Cropping area (m^2)
CCR = Catchment cropping ratio
SL = Slope

PREC = Precipitation
SLCA = Slope of catchment area
SLCR = Slope of cropping area

Fig. 4c: Types of macrocatchment runoff farming water harvesting systems (Prinz 1996)

Type	Illustration	Parameters	Remarks and References
Stone dams		(extreme variations) PREC= 300 - 600 mm/a	Diguettes or Digues filtrantes: Permeable contour check dams
Large semi-circular hoops		CA= 750 - 10,000 CR= 50 - 350 CCR= 15:1 - 40:1 PREC= 200 - 400mm/a SL= 1 - 10%	Staggered position: used for crops or pasture improvement Reij et al., 1988
Trapezoidal bunds		CA= 5 - 3 x 10^5 CR= 3,500 CCR= 15:1 - 100:1 PREC= 200 - 400 mm/a SL= 1 - 10%	Staggered position; mainly for crops Reij et al., 1988
Hillside conduit systems		CA= 10 - 10^7 CR= 1 - 10^5 CCR= 10:1 - 100:1 PREC= 100 - 600 mm/a SLCA= > 10% SLCR= 0 - 10%	Examples: Avdat and Shifta Experimental Farms, Negev, Israel; For trees and annual crops Klemm 1990
Liman terraces		CA= $2x10^4$ - $2x10^5$ CR= 1,000 - 5,000 CCR= 20:1 - 100:1 PREC= 100 - 300 mm/a SL= 1 - 10%	In Israel mainly planted to Eucalyptus tree species; sometimes built in succession. Bruins et al., 1986
Cultivated reservoirs		CA= 1,000 - 10,000 CR= 100 - 2,000 CCR= 10:1 - 100:1 PREC= 150 - 600 mm/a SLCA = > 10% SLCR = 0 - 10%	Khadin, Rajastan (India); Ahar, Bihar (India); Tera, SE Sudan Kolarkar et al., 1983, Pacey and Cullis, 1986, Agarwal and Narain 1997

CA = Catchment size (m^2)
CR = Cropping area (m^2)
CCR = Catchment cropping ratio
SL = Slope
PREC = Precipitation
SLCA = Slope of catchment area
SLCR = Slope of cropping area

The **disadvantages of MIRFWH systems** are (Prinz 1996):

* The catchment uses potentially arable land (exception: steep slopes)
* The catchment area has to be maintained, i.e. kept free of vegetation which requires a relatively high labor input.
* If overtopping takes place during exceptionally heavy rainstorms, the systems may be irrevocably damaged.
* Low crop density, low yield in comparison with other irrigation methods (e.g. 40 trees per hectare for the Negarin type WH, see Fig. 4a).

See Tab.1 for classification of runoff farming water harvesting (RFWH) types and Tab. 2 for runoff farming water harvesting (RFWH) techniques.

b) **Macrocatchment runoff farming water harvesting (MARFWH) system**

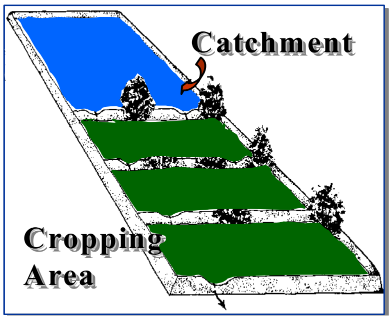
Macrocatchment runoff farming (catchment area being 1,000 m^2 - 200 ha) system is referred to by some authors as "runoff farming water harvesting from long slopes", as " medium-sized catchments water harvesting" or as "harvesting from external catchment systems" (Pacey and Cullis 1988, Reij et al., 1988). It is characterized by (Prinz 1996) as:

* A CCR of 10:1 to 100:1; the catchment being located outside the arable areas.
* The predominance of turbulent runoff and channel flow of the catchment water in comparison with sheet or rill flow of microcatchments.
* The partial area contribution phenomenon which is not relevant for microcatchments.
* The catchment area may have an inclination of 5 to 50 %; the cropping area is either terraced or located in flat terrain.

Fig. 5 shows the Micro- and Macro-catchment rainwater harvesting techniques. See also Fig. 4c for macrocatchment runoff farming water harvesting systems.

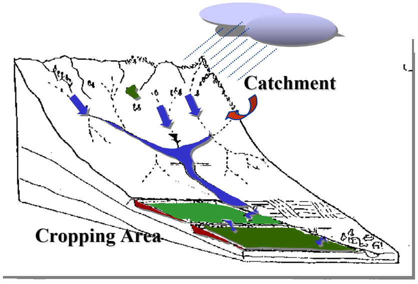
See Tab.1 for classification of runoff farming water harvesting (RFWH) types and table 2 for runoff farming water harvesting (RFWH) techniques. See Fig. 5 for examples of runoff water harvesting techniques with general features. Microcatchment: Meskat system from Tunisia (Source: El Amami, 1983) and Macrocatchment technique: Hillside Conduit technique (Source:. Prinz 1998), Source of text: Prinz 1998, Prinz 2002.

Rainwater Harvesting: Microcatchment Techniques



- Size: 2 m² - 1000 m² area; Catchment / Cropping Areas: Adjacent;
- Flow: Sheet or rill flow;
- Ratio between catchment area and cropping area (CCR) 1 : 1 to 25: 1;

Rainwater Harvesting: Macrocatchment Techniques



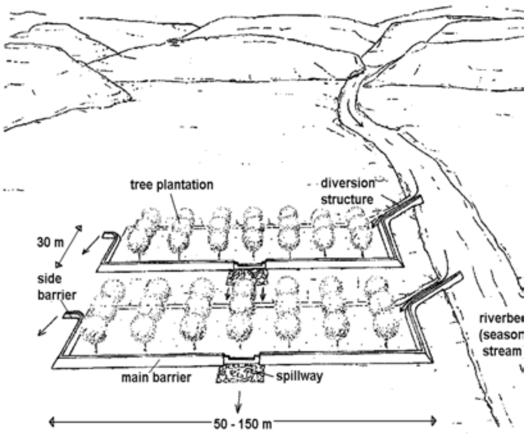
- Size: 0.1 ha to 200 ha
- Flow: Turbulent runoff , channel flow
- CCR: 10:1 - 100:1
- Precipitation: 100 to 1000 mm / annum
- Inclination of catchment: 5 - 60 %
- Cropping Area: Terraced or in flat terrain

Fig. 5: Examples of Rainwater Harvesting techniques with general features. Microcatchment: Meskat system from Tunisia (Source: El Amami, 1983); Macrocatchment technique: Hillside Conduit technique (Source:. Prinz 1998); Source of text: Prinz 1998, Prinz 2002

Floodwater harvesting runoff farming

Runoff farming with floodwater harvesting comprises systems with catchments being many square kilometers in size, from which runoff water flows through a major wadi (bed of an ephemeral stream or river), necessitating more complex structures of dams and distribution networks (Prinz 1996). It is also called 'Large catchment water harvesting' or 'spate irrigation' comprises two forms (Prinz 2002). Floodwater harvesting runoff farming can be classified into two types:

Floodwater Harvesting



- Size: > 200 ha
- Flow: Channel flow; complex structures needed
- CCR: 100:1 - 10,000 :1 (and more)
- Precipitation: 100 to 600 mm / annum
- Cropping Area: Terraced or in flat terrain

1. **Floodwater harvesting within the stream bed,** water flow is dammed and, as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
2. F**loodwater diversion**, wadi water is forced to leave its natural course and conveyed to nearby cropping areas (see Fig. 6).

These systems - the catchments being many square kilometers in size - require more complex structures of dams and distribution networks and a higher technical input than the other two water harvesting methods.

See Tab.1 for the classification of runoff farming water harvesting (RFWH) types and table 2 for runoff farming water harvesting (RFWH) techniques

Fig. 6: Example of Floodwater Harvesting / Floodwater Diversion and general features of Floodwater Harvesting, Source of figure: GTZ 1993; Source of text: Prinz 1998, Prinz 2002

It is difficult to give exact figures on the present total area worldwide under the various forms of overland flow water harvesting. India's leading position in this respect is undebatable. Pakistan will be the second with more than 1.5 million hectares under Rainwater or Floodwater Harvesting. Fig. 7 shows the irrigated area under flood water harvesting in North Africa and the Middle East, according to FAO (1997), totalling about 2 million hectares.

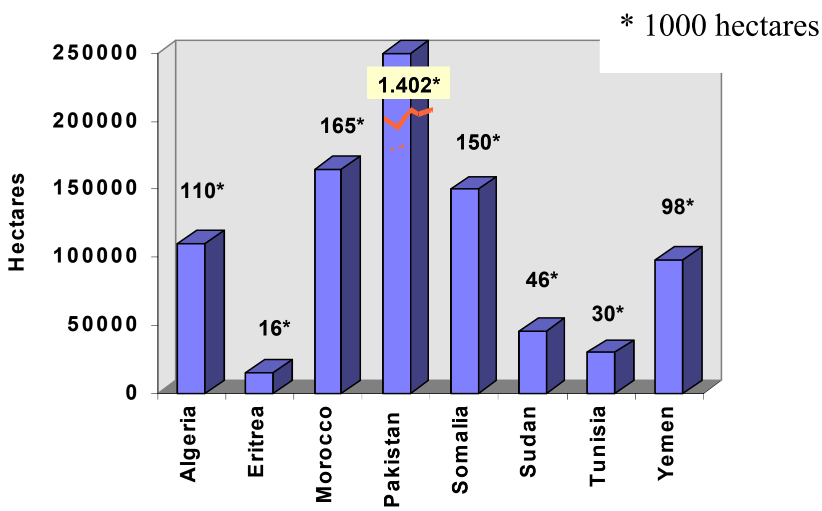


Fig. 7:Area under flood water harvesting ('spate irrigation') in selected countries of North Africa and the Middle East (Source: FAO 1997)

Tab. 1: Classification of runoff farming water harvesting (RFWH) types (Prinz 1996)

RFWH TYPE	**Kind of flow**	**Kind of surface**	**Size of catch ment**	**Catchme nt: cropping area ratio**	**Water storage type**	**Water use**
1. MICRO-CATCH MENT WH	Sheet and rill flow	Treated and untreated ground surfaces	2-1000 m^2	1:1 - 25:1	Soil profile (reservoirs, cisterns)	Tree planta-tion
2. MACRO CATCH MENT WH	Turbule nt runoff/ channel flow	Treated or untreated ground surfaces	1000 m^2 - 200 ha	10:1 - 100:1	Soil profile (reservoirs, cisterns)	Crop and trees
3. FLOOD-WATER WH	Flood water flow	Untreate d ground surfaces	200 ha - 50 km^2	100:1 - 10,000:1	Soil profile	Any kind of crop

Tab. 2: Runoff farming water harvesting (RFWH) techniques (Prinz 1996)

WH Group	**RAINWATER HARVESTING (RWH)**		**FLOODWATER HARVESTING (FWH)**	
WH Type	**1. Micro-Catchment**	**2. Macro-Catchment**	**1. within streambed**	**2. through diversion**
Techniques	Contour Bunds	Hillside Conduit Systems	Jessour Type	Wild Flooding
	Interrow-WH			
	Negarin / Meskat Type	Semi-circular Hoops	Liman Terraces	Water Dispersion
	Pitting Techniques	Cultivated Reservoirs/ Tanks	Percolation Dams	Water Distribution
	Eyebrow Technique	Stone Dams		
	Vallerani Type	Liman Terraces		
	Semi-circular Bunds	Jessour Macro-Catchments		
	Contour Bench Terraces			
Kind of Storage	Soil Profile (Ponds)	Soil Profile, Cisterns, Ponds, Reservoirs	Soil Profile	
			Reservoirs	Ponds
Aquifer Recharge	Very Limited	Limited	Strong	Very strong

A high storage capacity of the soil (i.e. medium textured soils) and a sufficient soil depth (> 1 m) are prerequisites here (Huibers 1985). The water retention capacity has to be high enough to supply the crops with water until the next rainfall event.

The tools used to identify possible runoff irrigation areas are (Prinz 1996):
- field visits;
- areal surveys and evaluation of aerial photographs;
- satellite images and their classification and evaluation (Tauer and Humborg 1992, Prinz 1998).

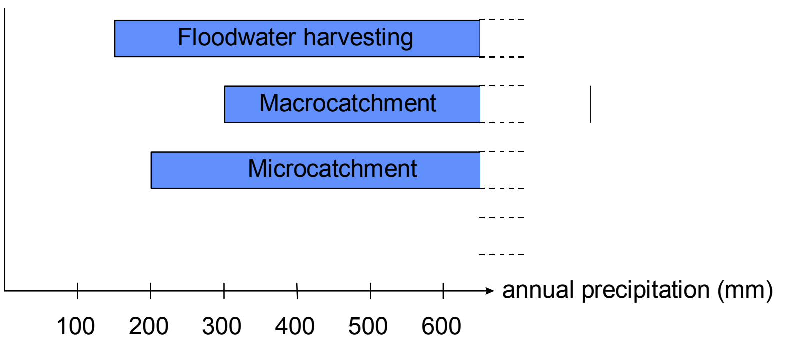


Fig. 8: Annual precipitation ranges for different forms of runoff farming water harvesting (Prinz 1996).

For annual precipitation ranges for different forms of runoff farming water harvesting see Fig. 8 (Prinz 1996).

Advantages of runoff farming water harvesting

Runoff farming has the potential to increase the productivity of arable and grazing land by increasing the yields and by reducing the risk of crop failure. They also facilitate re- or afforestation, fruit tree planting or agroforestry. With regard to tree establishment, water harvesting can contribute to fight desertification. Especially water harvesting for runoff farming are relatively cheap to implement and can therefore be a viable alternative where irrigation water from other sources is not readily available or too costly. Unlike pumping water, water harvesting saves energy and maintenance costs. Using harvested rainwater helps in decreasing the use of other valuable water sources like groundwater. Remote sensing and Geographical Information Systems (GIS) can help in the determination of areas suitable for water harvesting (Prinz 2002).

The advantage of macro-catchment systems is that no loss of potential arable land is caused by the presence of the catchments; instead they consist of slopes un-favourable for agriculture. The existing fields can be retained or expanded and water supply to them can be improved (Prinz; Tauer and Vögtle 1994).

Runoff farming does not necessarily depend on high technology, although it does require expertise, primarily for evaluating site suitability and in designing the system (Bruins; Evenari and Nessler 1986). Runoff farming is more appropriate to agricultural application where rainfall is limited rather than in the seasonally humid environment.

Bruins, Evenari and Nessler (1986) estimate that an additional 3 - 5 % of arid areas could be cultivated using runoff farming methods. Strong progress has been made in breeding for enhanced crop yields in rainfed areas, even in the more marginal rainfed environments. The continued application of conventional breeding and the recent developments in non-conventional breeding offer considerable potential for improving cereal yield growth in rainfed environments (Rosegrant et al., 2002).

Throughout the last decade, development of microcatchment systems for runoff water harvesting for runoff farming was increasingly considered amongst the most suitable strategies for improving the soil productivity in semi-arid and arid areas (http://tony.csd.unp.ac.za/UNPDepartments/inr/Vetiver/VETNL14_4.htm)

Disavantage of runoff farming water harvesting

Although runoff farming methods can increase the water availability, the climatic risks still exists and in years with extremely low rainfall, it can not compensate for the water shortage. Successful water harvesting projects are often based on farmers' experience and trial and error rather than on scientifically well established techniques, and can therefore not be reproduced easily. Agricultural extension services have often limited experience with it.

Further disadvantages are:

* the possible conflicts between upstream and downstream users, and a
* possible harm to fauna and flora adapted to running waters and wetlands (Prinz 2002).
* Whilst used in many semi-arid environments (including the Sahel), runoff farms require relatively large labour inputs.
* Runoff farming require a relatively large natural watershed area, which concentrates its rainfall into a small catchment basin, usually amounting to about 0.40 hectre or less (Bean and Saubel 1972), (**http://www.is.ch2m.com/iidweb/current/documents/QSAPEIR/Section_3.8.pdf**).
* Appropriate investments and policy reforms will be required to enhance the contribution of rainfed agriculture (Rosegrant et al., 2002).

It is widely accepted that micro-catchment schemes and other water harvesting methods have to conform with a set of primary criteria, amongst which the essential are those related to land configuration, slope, soil characteristics and quality and economics of operation and maintenance (**http://tony.csd.unp.ac.za/UNPDepartments/inr/Vetiver/VETNL14_4.htm**).

Design input for runoff farming water harvesting systems

The basic design input for RFWH systems includes:

* Topography of the area.
* Soil type, including texture and water retention capacity, soil depth, infiltration characteristics, and hydraulic conductivity.
* Climate, including daily rainfall for a reasonable number of years (at least 15), evaporation, transpiration, either measured or computed from climatic data such as temperature, solar radiation, humidity, wind, vapor pressure deficit, etc.
* Crop, including rooting depth, growing season, critical stages of growth, and spacing (Oweis, Hachum and Kijne, 1999).

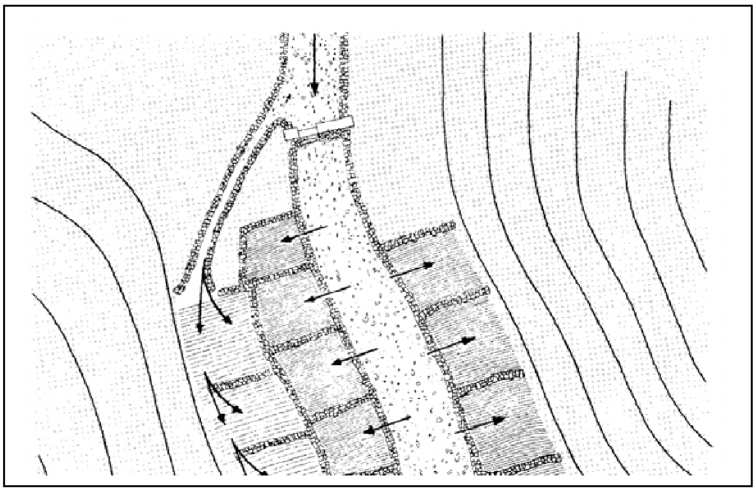


Fig. 9. Floodwater diversion scheme: Design of water-spreading dams in large, deep wadis (Nabataean system). Source: Evenari and Koller 1956, from Cox and Atkins 1979

See Fig. 9 for floodwater diversion design of water-spreading dams in large deep wadis (Nabataean system)

Runoff farming water harvesting systems in different geographical regions

During this century, only very few water harvesting activities in research or implementation were undertaken before 1950. Australian farmers had already started to harvest water for domestic and animal use after World War I. During World War II, some water harvesting activities were carried out on islands with high rainfall (e.g. on the Caribbean island of Antigue). After 1950 water harvesting received renewed interest on the research level as well as in the implementation sector, partly due to the successful reconstruction of ancient water harvesting farms in the Negev by Evenari and collegues (Evenari et al., 1971). Most of the research activities have been carried out in Israel, Australia, the USA and India, but efforts in other countries should also be not neglected (Prinz 1996).

Runoff farming water harvesting played a more important role in the past for the well-being of people in dry areas than it currently does. The reasons are manifold (Prinz 1996):

* Alternative sources of water for irrigation were not available:
  - no pumping from groundwater or other deep water sources
  - very few large dams
  - no long distance conveying of water through lined canals, pipes etc.
* The building of structures for water harvesting, the cleaning and smoothing of runoff surfaces, the maintenance of canals and reservoirs etc. were labor intensive. In the older times, labor was cheaper.

- Agriculture was the backbone of the society and very few other choices to generate income were given. Therefore, relatively more input was invested in agriculture including runoff agriculture.

Unfortunately, the extreme importance of certain runoff farming water harvesting techniques is often not reflected by the number or depth of publications. Some of the techniques are still presently practiced (Prinz 1996).

Low-cost efficient and intelligent use of runoff farming water harvesting in arid zones for food and fuel production systems could help to restore self sufficiency in food production for local populations in many African dry-land regions. Countries where this method has been used historically include Egypt, Tunisia, Libya, and southern Algeria. Some other countries outside Africa where rain-water harvesting runoff agriculture has been practiced successfully include Isreal, Jordan, North Yemen, India, and the Soviet Union (Bruins; Evenari and Nessler 1986).

In North America, rainwater harvesting agriculture was practiced in a variety of techniques by the Anasazi people nearly 1000 years ago. These consisted of dams in seasonal streams (or washes), earth and stone contour terraces and enclosed gardens with stone retaining walls. The main crops produced were maize, kidney beans, tepary beans and squash. Today, the Hopi people of north-eastern Arizona use similar runoff farming systems which probably date back to the 13th century (Bruins; Evenari and Nessler 1986).

Rainwater and floodwater harvesting have been practiced in many dry regions of the world since millennia (Agarwal and Narain 1997, Prinz 1996).

Africa

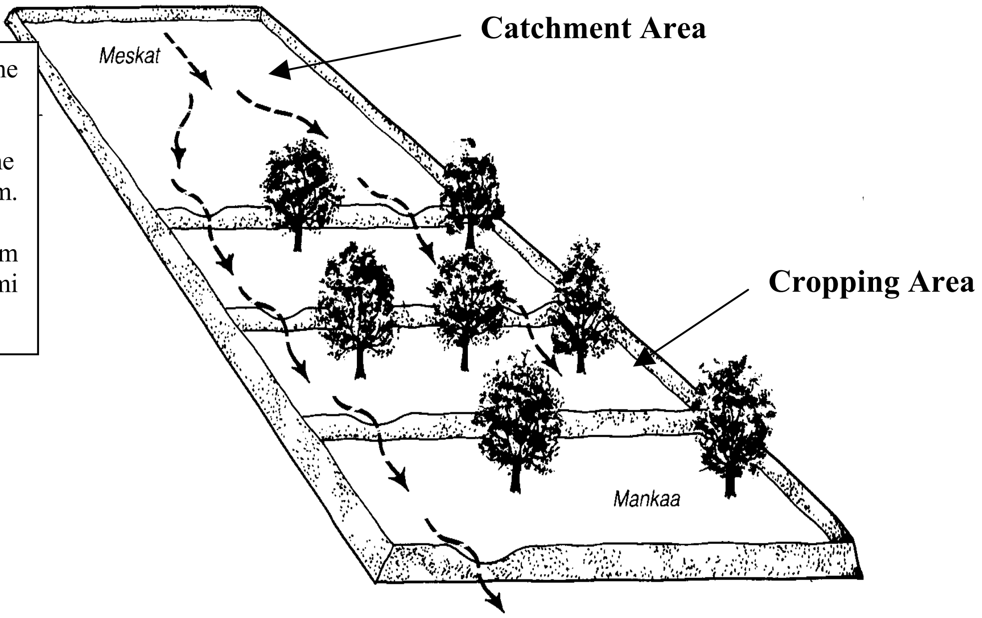
North Africa

In North Africa, water harvesting has a long tradition and is still used extensively in Morocco, Tunisia and to a lesser extent in Algeria. Traditional techniques of water harvesting have been reported from many other regions of Sub- Saharan Africa (Critchley et al., 1992), like the "Caag" and the "Gawan" systems in Somalia; various types of "Hafirs" in Sudan (UNEP 1983) and the ‘Zay’ or ‘Zai’system in Westafrica.

Since at least Roman times runoff farming water harvesting techniques were applied extensively in North Africa. Archeological research by the UNESCO Libyan Valleys team revealed that the wealth of the "granary of the Roman empire" was largely based on runoff irrigation (Gilbertson 1986). The team excavated structures in an area several hundred kilometers from the coast in the Libyan pre-desert, where the mean annual precipitation is well below fifty millimeters. The farming system here lasted well over 400 years and it sustained a large stationary population, often wealthy, which created enough crops to generate even a surplus. It produced barley, wheat, olive oil, grapes, figs, dates, sheep, cattle and pigs. The precipitation is variable, falling in just one or two rain storms, often separated by droughts several years long. (There is no evidence of climatic change since Roman period).
In Morocco's Anti Atlas region, Kutsch (1982) investigated the traditional and partly still practiced runoff farming water harvesting techniques. He found a wealth of experience and a great variety of locally well adapted systems (Prinz 1996). In Algeria, the "lacs collinaires", the rainwater storage ponds are traditional means of runoff farming water harvesting for agriculture. The open ponds are mainly used for watering animals. In Tunesia, the "Meskat" (see Fig. 10) and the "Jessour" (see Fig. 11) systems have a long tradition and are also still practiced. The "Meskat" microcatchment system consists of an impluvium called "meskat", of about 500 m^2 in

size, and a "manka" or cropping area of about 250 m^2 (Fig. 10). Thus, the CCR is 2:1. Both are surrounded by a 20 cm high bund, equipped with spillways to let runoff flow into the "manka" plots (Prinz 1996).

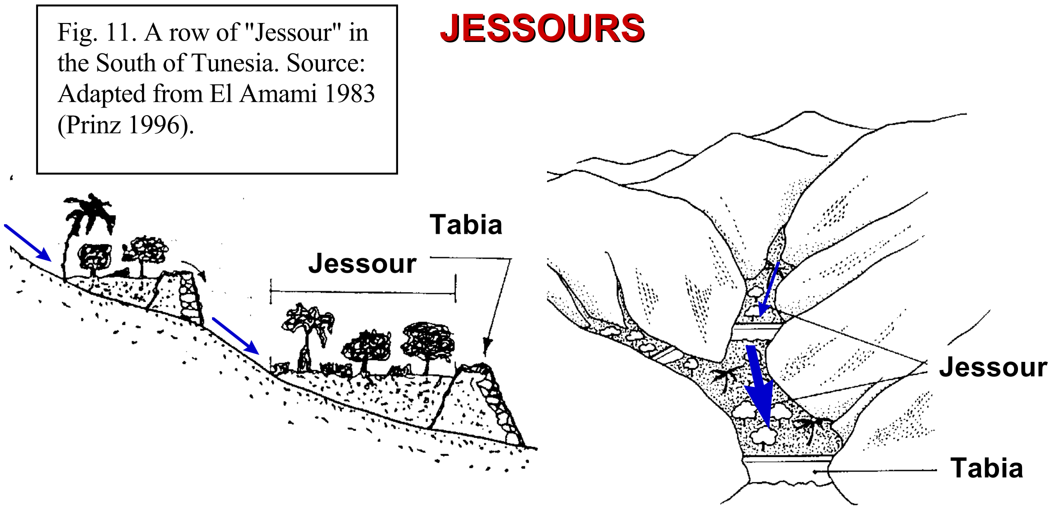
Fig. 10. The Tunesian "Meskat" microcatchment system. Source: Adapted from El Amami 1983



This system can provide the fruit tree plantation with about 2,000 m^3 extra water during the rainy season. Whereas the "Meskats" are mainly found in the Sousse region, the "Jessour" (see Fig. 11) are widespread in the South (Matmata). The "Jessour" (see Fig. 11) system is a terraced wadi system with earth dikes ("tabia") which are often reinforced by dry stone walls ("sirra"). The sediments accumulating behind the dikes are used for cropping (Fig. 11). Most "Jessour" (see Fig. 11) have a lateral or central spillway (Prinz 1996).

The "Mgouds" in Central Tunisia are channel systems used to divert floodwater from the wadi to the fields (Tobbi 1994). In Lybia, archeological and historical studies have revealed the development and expansion of a highly successful dry (runoff based) farming agriculture during Roman times. On the slopes of the western and eastern mountain ranges some of these techniques continue to be practiced (Al-Ghariani 1994).

Fig. 11. A row of "Jessour" in the South of Tunesia. Source: Adapted from El Amami 1983 (Prinz 1996).



In Egypt, the North-West coast and the Northern Sinai areas have a long tradition in runoff farming water harvesting. Remnants from Roman times are frequently found (El-Shafei 1994). Some wadi terracing structures have been in use for over centuries (Fig. 12).

Fig. 12. Wadi Terraces from Roman times still in use in Marsa Matruh area (NW coast, Egypt). Photo: Prinz

In different parts of Libya, experimental sites of contour-ridge terracing covering more than 53,000 ha have recently been established (Al-Ghariani 1994). In 1990, the government of Tunisia started the implementation of the National Strategy of Surface Runoff Mobilization which aims, among other things, at building 21 dams, 203 small earth dams, 1,000 ponds, 2,000 works to recharge groundwater and 2,000 works for irrigation through water spreading by the year 2,000 (Achouri 1994). Up to 1984, "Meskats" covered 300,000 ha where 100,000 olive trees were planted; "Jessours" (see Fig. 11) covered 400,000 ha (Tobbi 1994). Modern spate irrigation techniques have been applied in Central Tunisia since 1980, covering an area of 4,250 ha and harvesting about 20 Mm^3 of water annually (Prinz 1996).
In Wadi El-Arish region of Egypt, stone dykes were used to direct the runoff water flow for irrigation purposes. Also cisterns, which store water meant for animal and human consumption as well as for supplemental irrigation, are common in Egypt. The number of cisterns has increased from less than 3,000 in 1960 to about 15,000 in 1993 with a capacity of about 4 million m^3 (Shatta and Attia 1994).
In the North-Western region of Egypt a GTZ/FAO sponsored project on land use planning including runoff farming water harvesting activities was carried out (El-Shafey). Since 1984, Morocco has started constructing dams ("Barrages Collinaires") to harvest floodwater. The upstream catchment area under these dams ranges from 500 to 10,000 hectares. As of 1988, thirty five of these dams had been constructed. They provide irrigation water for about 160,000 animals and 3,000 ha of cultivated plots (Prinz 1996).

Sub-Saharan Africa

Traditional techniques of runoff farming water harvesting have been reported from many regions of Sub Saharan Africa (Reij et al., 1988, Critchley et al., 1992a, Critchley et al., 1992b, van Dijk and Reij 1993). A few of these systems will be described by Prinz 1996 as follows:

The central range lands of Somalia are home to two small scale runoff farming water harvesting systems which have been important local components of the production system for generations (Prinz 1996). The Caag system is a technique used to impound runoff from small water courses, gullies or even roadside drains (Fig. 13). Sometimes ditches are dug to direct water into the fields. Runoff is impounded by the use of earth bunds. The entire plot may be a hectare or more in size. The alignment of the bunds is achieved by eye and by experience. In this system, runoff is impounded to a maximum depth of 30 cm. If water stands for more than five days or so, the bund may be deliberately breached to prevent water-logging (Reij et al., 1988).

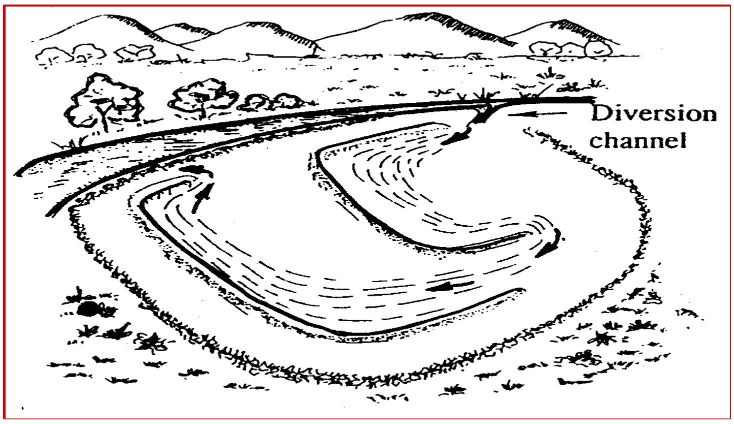


Fig. 13. The "Caag" system in Hiraan region, Central Somalia (150-300 mm annual rainfall). (Source: Critchley et al., 1992b)

The Gawan system is used where the land is almost flat and where is less runoff. Small bunds are made which divide plots into "grids" of basins. Individual basins are in the order of 500 m^2 or above in size (Prinz 1996). In both of these systems, sorghum is the usual crop grown, although cowpeas are also common. If rain permits, two crops are taken each year (Reij et al., 1988). In Sudan, various types of "Haffirs" have been in use since ancient times. Their water is used for domestic and animal consumption as well as for pasture improvement and paddy cultivation (UNEP 1983). The Haussa in Niger's Ader Doutchi Maggia have altered a considerable area with rock bunds, stalks and earth to divert water to their fields (Prinz 1996).
The Mossi in Burkina Faso also constructed rock bunds and stone terraces in the past. Somerhalter (1987) made mention of the existence of various traditional runoff farming water harvesting techniques (although on a small scale) in the Ouaddai area in Chad (Prinz 1996).

The "Zay" or sometimes “Zai” system in Burkina Faso is a form of pitting which consists of digging holes that have a depth of 5 - 15 cm and a diameter of 10 - 30 cm. The usual spacing is between 50 - 100 cm (Wright 1985). This results in a CCR of about 1 - 3:1. Manure and grasses are mixed with some of the soil and put into the zay (Fig. 14). The rest of the soil is used to form a small dike down slope of the pit. The Zay method is applied in combination with bunds to conserve runoff, which is slowed down by the bunds (Prinz 1996).
Many other traditional runoff farming water harvesting systems existed or still exist, but the basic problem is that knowledge and information in this zone is extremely limited and fragmentary (Reij et al., 1988).

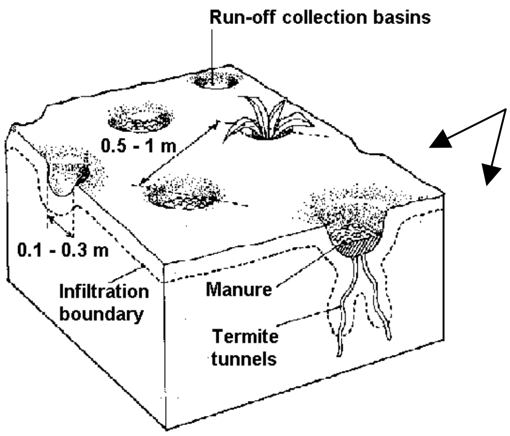


Fig. 14. The zay (zai) microcatchment runoff farming water harvesting system in Burkina Faso. Source: Reijntjes et al 1992

An agroforestry project (PAF) aimed at improving tree planting using microcatchments was initiated by OXFAM in 1979 at the Yatenga Province of Burkina Faso. In 1982, this was modified to contour stone bunds (aligned along the contour) and used for crop production. Later, it was combined with the traditional "zai" or “zay”systems which has improved its acceptability by the local farmers. It was reported that by the end of 1989, some 8,000 hectares in over 400 villages had been modified with stone bunds (Critchley et al., 1992a). Various research projects are being carried out on the Central Plateau of Burkina Faso by many research institutes. Emphasis in the region is mainly put on improving stone bund construction, studying the effects of stone bunds on runoff, erosion and yields, rehabilitation of degraded catchment areas and combination of stone bunds with tied ridges (Buritz and Dudeck 1986). In the Hiraan Region of Somalia the local runoff farming water harvesting techniques known as "Caag" and "Gawan" still continue (Abdi 1986). In Ethiopia, the Sudan and Botswana, small check-dams made of earth are used to catch moderate overland flow passing down slight slopes. They are called "haffirs" and support crops planted upslope (Barrow 1987).

In 1985, the Institute of Hydraulic Structures and Rural Engineering, University of Karlsruhe, Germany, started a project in Mali with the aim of testing the feasibility of runoff irrigation in the Sahel region. The total contributing area was 127 ha and the collecting area was 3.3 ha so that the CCR (ratio between catchment area and cropping area) was 40:1. These systems have now being operated for nine years and the harvests for sorghum are three times those for comparable sites using rainfed agriculture (Klemm 1990, Fig. 15).

In 1989-91 a study was carried out by the same Institute which aimed at the development of a methodology of identifying areas suitable for runoff irrigation. Maximum use was made of data obtained from satellite systems (Landsat-TM and SPOT) on the basis of site inspections in W-Mali and N Burkina Faso. A methodology was developed which integrates meteorological, pedological, topographic and socio-economic data sets in an user-friendly GIS, distinguishing between the suitability of a site for microcatchments or macrocatchments (Tauer and Humborg 1992; Prinz et al., 1994).

Fig. 15. A macrocatchment runoff farming water harvesting system in Mali, Kayes Province. Photo: Klemm

In 1988, special ploughs developed by Italian scientists were used in Niger for the implementation of (Vallerani type) microcatchments on a large scale. Results from these plots showed excellent rates of tree establishment (Antinori and Vallerani 1994).

Sudano-Sahelian savannah of the Ouahigouya region of north-western Burkina Faso

At the time of the first storms of the rainy season, and without tilling the soil, they drill-seed sorghum on the best land and millet (plus some groundnut and cowpea) on sandy or gravelly land, in holes every metre. They re-sow as many as five times if necessary and then hoe once or twice. On the sandy soil in the north, hoe is combined with clearing around the roots, thus improving infiltration around the clumps of millet. The farmers treat exhausted soils with applications of organic material (2 to 5 t/ha of dried, powdered paddock dung and household ash) or a mulch of cereal stalks and branches of pulses unattractive to livestock, such as *Piliostigma reticulatum* and *Bauhimia refuscens*, and then leave the land as grassland. They use the zaï method to restore exhausted land, catching runoff in a small pit that contains some organic manure (see Fig. 16). The tunnelling activity of termites allows this organic matter to trap 100 mm of water after the first storms (Roose 1996)

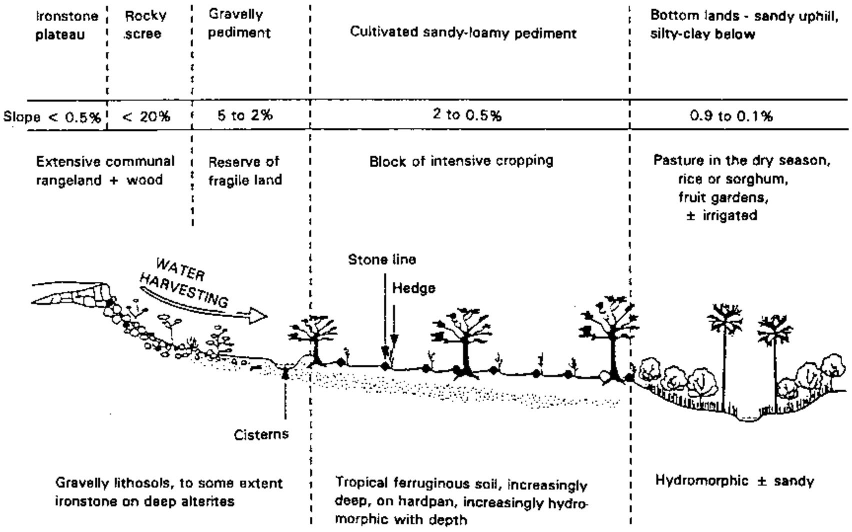


Fig. 16: Improved use of a granitic landscape on the Mossi Plateau: runoff farming
Source: Roose, E.; (1996)

Runoff irrigation was introduced in the Sahel region of West Africa at a time of a growing need for water resources. The Institute of Hydraulic Structures and Rural Engineering, University of Karlsruhe, Germany, has been engaged in this applied research since 1985. The runoff irrigation systems thus introduced have performed well achieving over three times the yield of comparable sites depending solely on rainfed agriculture. Provided the physical frame conditions for macro- and micro-catchment systems such as deep and heavy soils with a high useable field capacity for the cropped areas and high runoff rates for the uncropped areas are available, potential sites for runoff farming water harvesting can be identified. The use of satellite remote sensing and GIS for large areas would no doubt, afford the analysis of data in a systematic manner. The relevant social, economical and political parameters should be super-imposed against the physical frame conditions in order to determine the long-term success of a runoff irrigation system (Prinz; Tauer and Vögtle 1994).

Asia

In India a great variety of rain water harvesting techniques developed over the last 2,000 years. In many areas, the "tank" system is traditionally the backbone of agricultural production; their total number is about 500.000. Ahars are important in Bihar region; unlike tanks, the beds are not dug out. Out of the 46 million hectares under irrigation in India, about 6 million hectares are irrigated from "sources other than government canals, wells and tubewells", mainly various forms of water harvesting (Agarwal and Narain 1997, UNEP 1983, Sengupta 1993, Pacey and Cullis 1986).

A very old flood diversion technique called "warping" is found in China's loess area which harvests water as well as sediment (Prinz 1996). In Afghanistan, composite microcatchments have been in use for a long time. In a survey conducted in the early 1970s, over 70,000 ha of Meskat-type systems used for growing fruit trees were reported (Prinz 1996).

Pakistan

In Baluchistan two runoff farming water harvesting techniques were already applied in ancient times: the "Khuskaba" system and the "Sailaba" system. The first one employs bunds being built across the slope of the land to increase infiltration. The latter one utilizes floods in natural water courses which are captured by earthen bunds (Oosterbaan 1983). Fig. 17 depicts such a water spreading system in Pakistan.

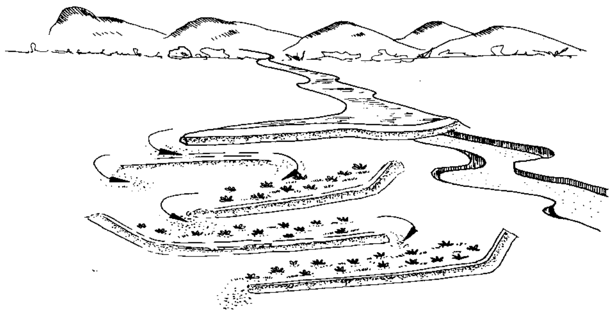


Fig. 17: Water spreading system in Pakistan to divert floodwater for agricultural use. Source: Adapted from French and Hussain 1964

India

In India, the "tank" system is traditionally the backbone of agricultural production in arid and semi-arid areas. The tanks collect rainwater and are constructed either by bunding or by excavating the ground. It is estimated that 4 to 10 hectares of catchment are required to fill one hectare of tank bed. In West Rajastan, with desert-like conditions having only 167 mm annual precipitation, large bunds were constructed as early as the 15th century to accumulate runoff. These "Khadin" create a reservoir which can be emptied at the end of the monsoon season to cultivate wheat and chickpeas with the remaining retained moisture (Kolarkar et al., 1983). A similar system called "Ahar" developed in the state of Bihar (UNEP 1983, Pacey and Cullis 1986). Ahars are often built in series. It was observed that brackish groundwater in the neighbourhood of Ahars became potable after the Ahar was built, due to increased supply of rain water (Prinz 1996).

In central India, a very old cultivation system based on water harvesting and runoff farming in the Narmada valley in Madhya Pradesh locally known as *haveli* still exists. This system is location specific, like other indigenous runoff farming systems of the country. It is practiced in areas with black cotton soil. Fields are embanked (average height of embankment being 1 m) on four sides. Rainwater remains in the field until the beginning of October. A few days before sowing *rabi* (winter) crops, the excess water is drained off. Water is let out very gradually. The cultivators know from long experience which field ought to be drained first. The water from one field enters into another, and then another till it joins the natural drainage or lake. There is a mutual understanding amongst the farmers as to when to release the water (Kolarkar et al., 1980).

The monsoon showers inundate the fields. The rain water is allowed to stand in the fields for a few months until the sowing time for rabi (winter) crops like wheat and gram. The water not only seeps down to saturate the soil but also recharges groundwater. At sowing time the high embankments or bundhans are breached and the water is gradually let out to flow from field to field to ultimately join a natural drainage feature or a lake. This system is ideal for the soil composition of the area. Haveli technique kills also the *kans*, a hardy and stubborn weed (http://www.teriin.org/camps/newslt/issue2.pdf).

In India, winter rains are particularly undependable and are mostly received too late. As per records the dry spell between September and December, 2000, was one of the longest. This long dry spell has left a trail of miseries. Most of the rainfed farmers could not sow rabi crops. Those who ventured and had sown the seed, the crops completely wilted after germination. However, in those villages where harvested rainwater was available, the farmers could harvest the benefits of this water to sow their crops in time as usual and the impact of this long dry spell was not at all felt by these farmers. The only alternative for sustainable crop production in such region, is therefore, “runoff farming”. i.e., harvesting surplus rainwater during monsoon and use it for providing supplemental irrigation as and when needed. This has given a new direction to the management of natural resources for the mutual benefit of the people as well as the hilly eco-system (Mittal and Aggarwal 2001).

At the Centre for Arid Zone Studies in Jodhpur, Rajasthan and at the International Centre for Research in the Semi-Arid Tropics (ICRISAT) in Hyderabad, various research projects on runoff farming water harvesting related programmes have been going on since 1975 (Prinz 1996).
One of the findings at these research stations was that alfisols have greater runoff potential than vertisols and therefore the scope of profitable yield responses is greater on alfisols (Ryan et al., 1980).

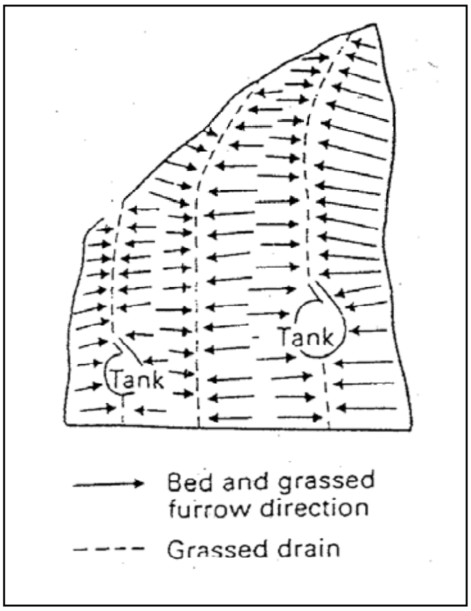


Fig. 18. The broad-bed and furrow runoff collection system of ICRISAT, Hyderabad, India. Source: Barrow 1987

In the eighties, ICRISAT also developed a system of broad beds and grassed drains which collects runoff in storage tanks during the rainy season to be used for supplementary irrigation during the dry season. To apply the water to the plants, bullock-drawn water casts equipped with sprinklers are used. Research results show that crop yields increased between two and fivefold (Barrow 1987, Fig. 18).

ICRISAT also carried out another research work aimed at adapting a traditional tank irrigation technology to modern socio-economic conditions. The concept of this work was to improve tank management with water control and to find an alternative system of runoff and erosion controlling land management for groundwater recharge and sustained well irrigation (Von Oppen 1985). These concepts have been found to have great potential and research is still going on (Prinz 1996).

Middle East

In the Middle East archaeological evidence of water harvesting structures appears in Jordan, Israel, Palestine, Syria, Iraq, the Negev (Evenari et al., 1971) and the Arabian Peninsula (mainly the Yemen); the oldest being believed to have been constructed over 9,000 years ago.

The outstanding importance of the Middle East in the development of ancient runoff farming water harvesting techniques is unquestioned (Prinz 1996). In Jordan, there is indication of early runoff farming water harvesting structures believed to have been constructed over 9,000 years ago. Evidence exists that simple runoff farming water harvesting structures were used in Southern Mesopotamia as early as in 4,500 BC (Bruins et al., 1986).
In Yemen, small dams storing runoff for later use in irrigation or rural supply have been constructed since the beginning of the eighties; the total storage capacity is between 50,000 to 90,000 m^3 (Bamatraf 1994). Internationally, the most widely known runoff-irrigation systems have been found in the semi-arid to arid Negev desert region of Israel (Evenari et al., 1971).

Runoff agriculture in this region can be traced back as far as the 10 th century BC when it was introduced by the Israelites of that period (Adato 1987). The Negev's most productive period in history however, began with the arrival of the Nabateans late in the 3rd century B.C. (Fig. 19). Runoff farming continued throughout Roman rule and reached its peak during the Byzantine era (Prinz 1996).

Fig. 19: Reconstruction of an ancient runoff farming water harvesting system ("Hillsite conduit system") in Wadi Avdat/Negev (100 mm annual precipitation, CCR 175:1, 2 ha cropping area). Photo: Prinz

In North Yemen, a system dating back to at least 1,000 B.C. diverted enough floodwater to irrigate 20,000 hectares (50,000 acres) producing agricultural products that may have fed as many as 300,000 people (Adato 1987, Eger 1988). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement (Bamatraf 1994).

Israel

In arid regions, the ancient runoff agriculture practiced by the Nabatean people (200 B.C. to 630 A.D.) in the Negev Desert is an example of a unique system of agricultural exploitation in a desert environment (Evenari and Koller 1956). In this case, the steep lands were left bare to encourage runoff during the brief, intense rain storms characteristic of the region. Small "catchment runoff farms" were constructed in catchment areas located on slopes and in cultivated areas in the drainage bottomlands below the catchments. The ratio of catchment to farm plots varied according to the amount of runoff. The farm plots were constructed with rock dikes across the water courses, thus accumulating and conserving soil inside the plots. The catchment slopes were modified to maximize runoff. Stone conduits were built to carry water to various parts of the bottomland farm plots in needed amounts (see Fig. 20). The cropping systems varied according to the size of the watershed and its drainage channels. Records show that a variety of crops were grown, including barley, wheat, legumes, grapes, figs and dates. The success of this system seems to be the result of relatively simple technological manipulation of the natural landscape in a manner that deals simultaneously with the problems of both water and nutrients (Cox and Atkins 1964).

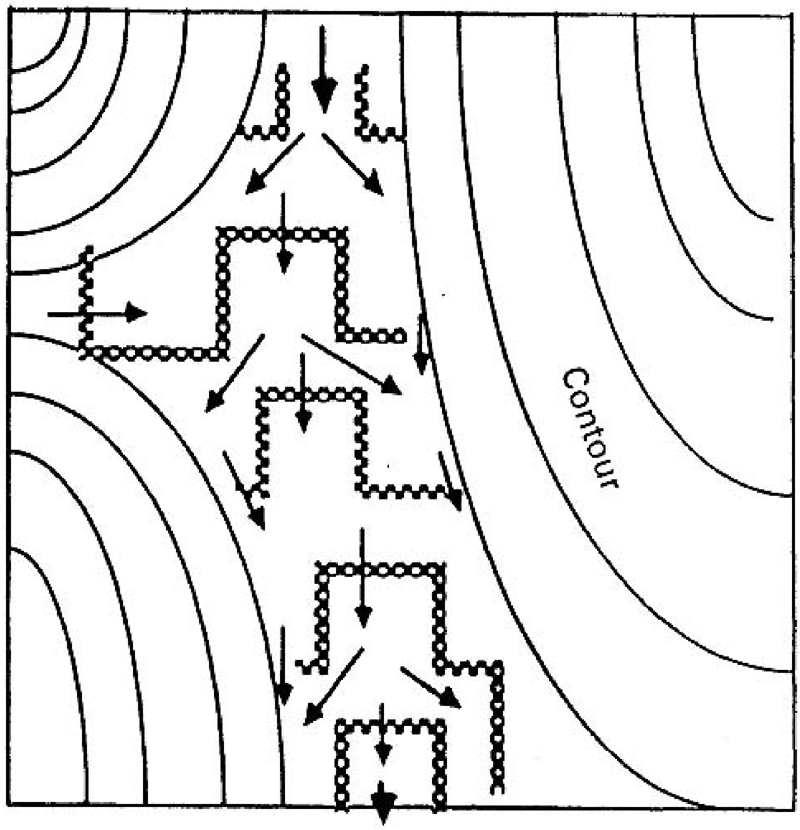


Fig. 20: Runoff Farming in the Negev Desert. A schematic diagram showing the design of rock barriers used to spread water in large shallow wadis onto lateral portions of the flood plain in runoff farms of the Nabateans in the Negev Desert. Redrawn from Evenari and Koller (1956).

The Israeli experience was reviewed by Ben-Asher (1988) within the World Bank Sub-Saharan Water Harvesting Study. Their research work focused on (Prinz 1996):

* testing of specific water harvesting techniques, especially microcatchments (Fig. 21)
* studying soil surface characteristics, especially crust formation
* studying and modelling runoff behaviour
* analyzing the economy of water harvesting techniques.

Fig. 21: Water harvesting research on agroforestry in Wadi Mashash, Israel. Photo: Lövenstein

The first aspect deals with the water content regime within the planted area, while the other one has to do with the availability of runoff to the planted area. On Wadi Mashash farm, a long term project with the aim of developing a model agroforestry system having medium-sized catchment water harvesting was carried out (Zohar et al., 1987, Lövenstein 1994). Developing the design criteria of microcatchments and limans is also receiving attention (Boers 1994, Fig. 22).

Fig. 22. Sheep grazing a liman at Wadi Mashash Experimental Farm, Negev, Israel. Photo: Lövenstein

Jordan

In Jordan, earth dams have been constructed since 1964 in order to force runoff to infiltrate for pasture improvement. At the final stage the total area flooded shall be about 2,500 ha (Al-Labadi 1994). In 1972, a project known as "Jordan Highland Development Project" was initiated. Rock dams, contour stone bunds, trapezoidal bunds and earth contour bunds were used to increase soil moisture around the trees planted on steep lands (Shatanawi 1994). The total area utilized since its inception is estimated to be 6,000 hectares (Prinz 1996).

Between 1985 and 1988, Jordan's Ministry of Agriculture, in collaboration with ACSAD, used contour terraces and ridges for pasture and range improvement in the Balama district. Better growth of olive, almond and pistachio was recorded (Shatanawi 1994) on the experimental site. In 1987 the Faculty of Agriculture of the University of Jordan initiated the construction of earth dams to impound and store flood waves for irrigation purposes. The catchment area is about 70 km^2 and the annual precipitation is 150 mm. Currently there is a collaborative research project aimed at developing an integrated optimization prediction model for water harvesting, storage and utilization in dry areas in Jordan. Oweis and Taimeh (1994) report on further water harvesting reseach activities in Jordan (Prinz 1996).

Other Middle East Countries

In the South Tihama of Saudi Arabia, flood irrigation is traditionally used for sorghum production. Today, approximately 35,000 ha land, supporting 8,500 to 10,000 farm holdings, are still being flood irrigated (Wildenhahn 1985).

In the Dei-Atiye community of Syria, rainwater harvesting was established in 1987 on an area of 130 ha. The project site was sub-divided into four parts for tree crops, range plants, cereals and runoff research (Ibrahim 1994). The International Centre for Agricultural Research in the Dry Areas (ICARDA) in Syria, is currently working on the improvement of various WH techniques and on the identification of water harvesting areas suitable for various West Asian and North African (WANA) environments (Oweis and Prinz 1994).

In the North-West Arabia, a local system known as "Mahafurs" is still in use. This system is simply a shallow excavation of 20 - 100 m in diameter surrounded on three sides by earthen bunds 1 - 4 m high. The open side is pointed in the direction of water flow inside the wadi bed and used to collect water for animal consumption and moisture for plant production (Barrow 1987).

America

USA and Mexico

In Arizona a lot of research was conducted recently on surface treatment to increase the runoff coefficient of catchments (Prinz 2002).

Traditional runoff farming water harvesting was also practiced in the Sonoran desert by the Papago Indians and other groups. The Papago fields were located on alluvial flats, fan aprons and fan skirts of ephemeral washes, where large catchments then became concentrated. Brush weirs were used to spread the floodwaters (Nabhan 1984). Elsewhere, fields were irrigated by gravity-fed channels (arroyos) leading water from earth and stick diversion weirs (Nabhan and Sheridan 1977, Doolittle 1984). For the Eastern Sonora Region of North Mexico, an evolution in techniques took place. Brush water spreaders were gradually replaced by rock bunds as the fields' clearing was increased and the supply of brush was depleted. A highly sophisticated distribution system was demonstrated by the floodwater diversion system of Chaco Canyon, New Mexico (Fig. 23) (Prinz 1996).

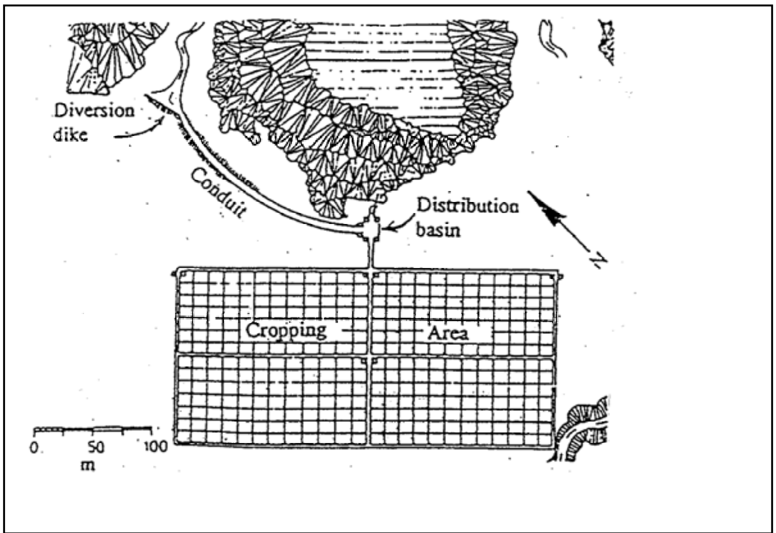


Fig. 23: Runoff farming system in Chaco Canyon, New Mexiko (175 mm annual precipitation, CCR = 470:1,9 ha horticultural area) Source: Vivian 1974

In the United States of America, research emphasis is on runoff inducement from catchments and the reduction of seepage losses (Frasier 1994). Combined and supplementary systems have been tested (Fig. 24).

Fig. 24: Inter-row water harvesting with treated catchment in North-Central Mexico. Photo: Frasier

The traditional check-dam known as "Bolsa" is still used in the cultivation of crops in some parts of Mexico. "Bolsas" are earthen-walled basins which catch water diverted from seasonal creeks ("arroyos") (Barrow 1987).

South America

After the arroyos have wetted the bolsas, plants are cultivated on the bolsas and mulch of dry sand is spread on it to avoid evaporation. In NE-Brazil, a modified form of the "zay" systems was introduced in 1986 (Prinz 1996).

Australia

In Western Australia, topography modification in the form of catchment treatment has been practiced for a long time. These are known as "roaded" catchments. They consist of parallel ridges ("roads") of steep, bare and compacted earth, surveyed at a gradient that allows runoff to occur without causing erosion of the intervening channels (Burdass 1975, Laing 1981). In 1980, it was estimated that there were more than 3,500 roaded catchment systems in Western Australia, and many of them have a top dressing or a layer of compacted clay to increase the runoff efficiency (Frasier 1994).

Successful runoff farming projects

Many case studies of water harvesting including runoff farming methods show positive results, these methods have yet to be widely adopted by farmers. Some projects may require inputs that are too expensive for some farmers to supply. In addition, many farmers in arid or semi-arid areas do not have the manpower available to move large amounts of earth that is necessary in some of the larger water harvesting systems (Rosegrant et al., 2001).

Negev desert in Israel

Runoff farming has been successful in the Negev desert in Israel (in winter), in the south-western United States, and in other countries (notably India, which may offer the most relevant experience for other tropical areas). One key to identifying successful conditions for runoff farming is the balance between rainfall and evaporation during the growing season, and the distribution of storms. Areas with occasional heavy rainfall but hot growing seasons may be less suited for runoff farming than areas with less heavy but more consistent rainfall and lower temperatures
(http://villageearth.org/atnetwork/atsourcebook/chapters/watersupply.htm),
(http://www.agnet.org/library/data/eb/eb448/eb448.pdf).

Contour bunds and the traditional planting pits in Burkina Faso

The success of contour bunds and the traditional zaï planting pits in Yatenga, Burkina Faso is widely acknowledged (Ouedraogo and Kaboré 1996; Critchley et al., 1992; Barrow 1999; Wright 1984 and 1985; Atampugre 1993; IFAD 1992; Pacey and Cullis 1991). Since the early 1980s zaï have been rapidly revived and adopted by farmers in the Yatenga region, resulting in over 8000 hectares of degraded land being brought back to productivity by the late 1980s (Postel 1992). The Yatenga has some of the highest population densities in the country, variable rainfall (average is over 700 mm) and suffered recurrent drought in the late 1960s and 1970s (Ouedraogo and Kaboré 1996). Large areas of lateritic soils have a low infiltration capacity, are hard rock and crusted with a hard pan surface (Ouedraogo and Kaboré 1996). Farmers use stone contour bunds to reduce the speed of runoff allowing infiltration into the zaï which collect and concentrate the runoff. Zaï usually have a diameter of 20-30cm and a depth of 10-15cm (Wright 1982) and number between 12,000-25,000 per hectare. The larger the planting pits and the bigger the spacing, the more water can be harvested from the uncultivated micro-catchments. Where barren land is rehabilitated yields can attain 1200kg/ha in the first season (Critchley et al., 1992). Interestingly, the project started by OXFAM 'Project Agro-Forestier' was a forestry project based on microcatchment techniques from the Negev, however, farmers were not interested at all and were concerned with improving food production (Critchley et al., 1992). The project was participatory from the start and the farmers were involved in designing the 'improved zaï', testing and evaluation. They had a clear preference for using stone bunds, which are basically an improvement of a traditional practice (IFAD 1992; Atampugre 1993), (http://www.bangor.ac.uk/~azs80f/556_Land-husbandry/2002-Assessments/WH-indig.doc).

Tahoua, Niger

Runoff farming has been introduced to the area of Tahoua, about 650 km northwest of Niamey. Average annual rainfall is about 400 mm. Tahoua is on the boarder of the desert steppe with very sparse vegetation. Crescent shaped micro-catchments spaced 4 m apart with a 4 m diameter and 40 cm depth have been constructed. Within this area sorghum is planted and has given yields of up to 300 kg/ha. The particular size and shape of the plots enables construction by one person, who can dig the half circle and easily throw soil from the inside of the catchment onto the low runoff-retaining walls. Initial testing of the method was done on a 4 hectare area protected by fencing. Millet, sorghum, beans and local herbs were planted. Interest among the local people in this technique has grown rapidly, resulting in the creation of over 15,000 similar micro-catchments (Bruins; Evenari and Nessler 1986).

The project in Niger started as a food for work scheme comparing contour bunds and demi-lunes. Tassa (see Fig. 25) were not mentioned in the project proposal at all (Hassan 1996). Through a participatory approach the project completely changed course. Trials demonstrated that in most cases, millet yields were greater under the 'improved' tassa compared with the original design of the specialist. Similarly, a project in Ourihamiza, Niger using demi-lunes (see Fig. 26) was not adopted by local people (Critchley et al., 1992). This was attributed to labor requirements being perceived as too high, the cultivation of crusty loamy soils deviating considerably from their present food production strategy (cultivation of dunes) and novel planting patterns and changing crops outside cultural expectations (Critchley et al., 1992), (http://www.bangor.ac.uk/~azs80f/556_Land-husbandry/2002-Assessments/WH-indig.doc).

Fig. 25: Newly dug tassa, prepared at the end of the rains When soils are still easy to work, Taboua, Niger (Source:http://www.bangor.ac.uk/~azs80f/556_Land-husbandry/2002-Assessments/WH-indig.doc)

Fig. 26: Demi Lunes (half-moon) basin rehabilitate degraded land and support a crop of millet, Niger (http://www.bangor.ac.uk/~azs80f/556_Land-husbandry/2002-Assessments/WH-indig.doc)

Rainwater harvesting -- Laikipia District, Kenya

Farmers were encouraged to practice runoff farming in Laikipia District in Kenya. It is a semi-arid district, and soil moisture is the most limiting factor in crop production. The technique involved directing runoff from roads and upper slopes into groundwater tanks or directly onto the gardens for macro-irrigation using bunds made of soil and stones. Maize production was increased as a result of improved land use and runoff farming techniques. In the Machunguru area, for example, yields were 1,778 kg per hectre prior to the initiation of the project, while, today, good farmers can attain yields of 4,446 kg per hectre. The additional maize stover produced is fed to livestock during dry periods. Prior to the water augmentation programme, vegetables were not grown in the area. Improved land use and runoff farming techniques have enabled vegetable production to meet household requirements and provide surplus for sale to augment household incomes. In addition, farmers have diversified their crops from the traditional maize and beans to include potatoes, carrots, onions, soya beans, millet, bananas and fruit. This diversity has contributed greatly to food security and balanced diets, (http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/augumentation.asp).

The Laikipia District lies on the leeward side of Mount Kenya and has an annual average rainfall of approximately 700 mm. Rain falls in two distinct seasons, known as the long rains and short rains. The area is categorized as semi-arid. The communities comprise subsistence farmers growing crops (mainly maize and beans) and keeping livestock (cattle, sheep and goats). There are frequent droughts, resulting in frequent crop failures and decimation of the livestock herd. Prior to the initiation of the rainwater harvesting project, most of the people living in the three locations did not have access to clean water. Rainwater harvesting was considered a feasible option which addressed not only water supply issues but also other areas of social and economic development, such as the improvement of health and agriculture. Likewise, prior to the water augmentation project, the semi-arid area had very few trees, the original trees having been cut down for building, charcoal burning and for fuel wood. As part of the development package, the project encouraged production of tree seedlings and planting of trees within homesteads, along farm boundaries and contours, and in farmed woodlot, as well as afforestation on communal hilltops. Enterprising farmers derived considerable income from the sale of seedlings.

Several independent evaluation teams state that, after 10 years of implementation, the program has considerably improved the living standards of the communities, with regard to water availability, public health improvement, farm management, and overall socio-economic status of the people. The project was planned and implemented in such a manner that the activities initiated should be self-sustaining, replicable and sustainable (http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/augumentation.asp).

Socio economic aspects

One might consider weighing the benefits of spending **$5 billion** dollars on constructing a Man-made River Project in the Libyan Desert for irrigation with using the funds to construct household roof tank systems and simple runoff farming plots and microcatchments for **20 million** rural African families (Gould, J.; et al., 2000).

Labour is often the most important economic factors if local material is used. The construction of contour ridges of 0.2 m height with an horizontal intervall of 1.5 m needs 90 man days (MD) per ha in the first year and 50 MD in the second year (Experience from Kenya; Reij et al., 1988). The accessibility of the site has also to be considered: If a construction needs big machinery like heavy lorries, areas far from paved roads have to be excluded.

There are a number of reports that water harvesting can be economically very profitable; Rodriguez (1996) e.g. showed that wheat grown under micro-catchment runoff farming in highland of Balochistan is more viable and profitable than any of the traditional methods. One of the crucial social aspects for the success of the runoff farming system is the participation of the beneficiaries (Oweis; Oberle and Prinz 1996). According to Prinz (2002), cooperation between farmers, the State and the scientific community is needed to arrive at a wider use and a higher efficiency of runoff farming water harvesting system (see Fig. 27)

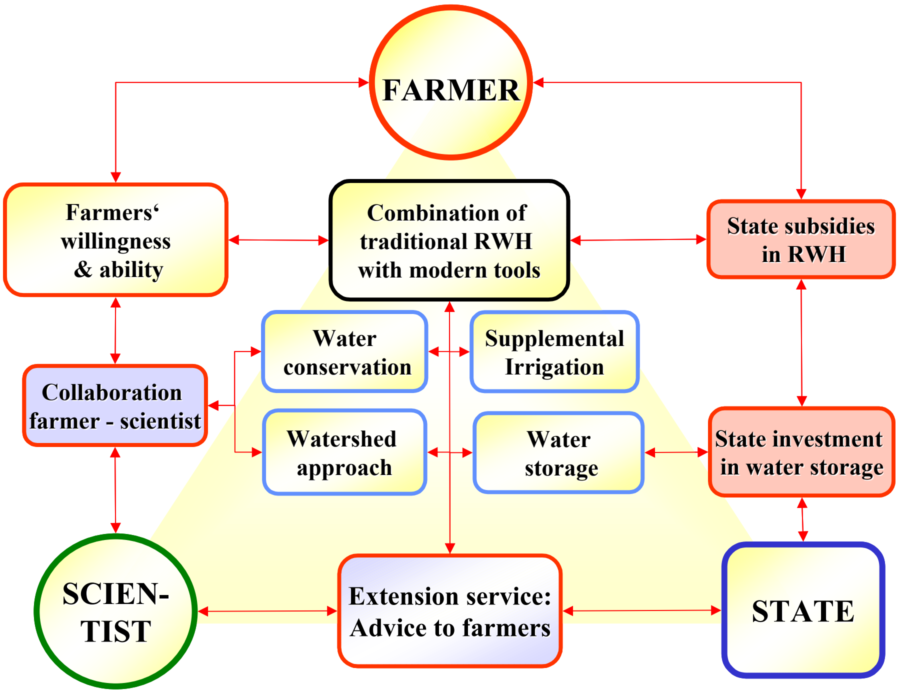


Fig. 27: The cooperation between farmers, the State and the scientific community is needed to arrive at a wider use and a higher efficiency of runoff farming water harvesting (Prinz 2002).

A comparison between (runoff farming) water harvesting techniques and the construction of large or medium dams shows that (Prinz and Singh 2000):

(1) Through the introduction of (runoff farming) water harvesting, water resources in upstream watershed can be managed more efficiently.

(2) Water harvesting can supplement irrigation water supply during water scarcity or low water availability periods. Its proximity to cropping area can be an important point in improving water use efficiency and avoiding field losses.

(3) Water harvesting may be of small scale but certainly have edge over dams due to its suitability for immediate local environment, they are labour intensive (*local employment generating*), democratic and participatory in nature.

(4) With the small scale of (runoff farming) water harvesting technology, no foreign investment is needed (but banking facilities are sometimes needed).

(5) Some of the benefits of large dams like generating hydropower energy, supplying drinking water for big cities etc, can not be offered by (runoff farming) water harvesting.

To make runoff farming water harvesting to be a successful project, requires local capacity building and agriculture extension services, training and credit facilities for resources users, co-operation and extensive participation (see Fig. 27).

Runoff farming water harvesting New developments

During recent years some technological developments took place in regard to runoff farming water harvesting which might have some impact on the future role of runoff farming water harvesting in general (Prinz 1996):

(1) Supplemental water system:

Runoff water is collected and stored offside for later application to the cropped area using some irrigation method. The water stored allows a prolongation of the cropping season or a second crop.

(2) Dual purpose systems:

In a dual purpose system the runoff water flows first through the crop area, then the excess water is stored in some facility for later irrigation use.

In Arizona, USA, runoff irrigation was combined e. g. with trickle irrigation, using sealed soil surfaces to increase runoff rates.

(3) Combined systems:

If the irrigation water from aquifers or from rivers/reservoirs is not sufficient for year-round irrigation, a combination with runoff-irrigation (during the rainy season) is feasible. The combination of runoff- and furrow irrigation is reported from North Central Mexico (Frasier 1994).

(4) Modelling:

If more information on hydrological, soil and crop parameters is available, models can be developed and applied to water harvesting for certain environments (Boers 1994).

Recommendation for the improvement of runoff farming water harvesting system

Numerous water harvesting projects have failed because the technology used proved to be unsuitable for the specific conditions of the site (Siegert 1994).

The present social and economic frame conditions for farmers differ strongly from those in ancient times, when runoff farming water harvesting was more common, whereas the natural conditions remained approximately the same (Prinz 1996). According to Prinz (1996) following are the recommendations for the future runoff farming system development:

* Farmers need scientific and institutional support to start new projects.
* The failure of runoff farming water harvesting projects in the past was sometimes due to technical failures but more often the attention was given to social and economic aspects was insufficient.
* There should be a global cooperation between scientists and practitioners involved in water harvesting. By learning from failures and successes, a high degree of sustainability might be reached, similar to the one which apparently existed in the past and remained for a thousand or more years.
* The advantages of water harvesting remain valid and farmers in dry areas have to utilize them if they want to be able to master the future.

Future prospects for runoff farming water harvesting system

Although water harvesting and runoff farming irrigation has attracted scientific attention mainly after the issue of alleged desertification arose in the seventies, the principles have been applied for 2-3000 years in the arid to semi-arid Negev Desert and other places. Large-scale water harvesting schemes were built in Australia prior to 1950. Since then, runoff farming has been developed in many other countries including Israel, India, USA, Pakistan, Sudan, Botswana, and Afghanistan (Esser 1999).

Water harvesting for runoff farming has the potential in some regions to improve rain-fed crop yields, and can provide farmers with improved water availability and increased soil fertility in some local and regional ecosystems, as well as environmental benefits through reduced soil erosion (Rosegrant et al., 2002).

All the runoff farming water harvesting techniques have the advantage to increase the amount of water available for agricultural and other purposes, and to ease water scarcity in arid and semi-arid areas. They require relatively low input and, if planned and managed properly, can contribute to the sustainable use of the precious resource water. The results of traditional irrigation methods are encouraging and should be promoted, but the methods described have to be supplemented by application techniques of high efficiency. All the engineering skills of scientists and practitioners are asked for to offer cheap and efficient supply systems (Prinz 2002).

The success of runoff farming depends very much on rainfall and soil type. Runoff irrigation is carried out mainly where the annual precipitation ranges between 300 and 500 mm. It is possible however, to employ this method for areas where the rainfall is as low as 100 mm per annum and even if the rainfall is very erratic (Prinz; Tauer and Vögtle 1994).

Investment in rain-fed areas, policy reform, and transfer of technology such as water harvesting runoff farming require stronger partnerships between agricultural researchers and other agents of change, including:

* local organizations,
* farmers,
* community leaders,
* NGOs,
* national policymakers and
* donors (Rosegrant et al., 2002).

Conclusions

Runoff farming water harvesting has proved to be a valuable tool especially in dry marginal areas (Prinz 1996):

* to increase crop yields and reduce cropping risk,
* to improve pasture growth,
* to boost reafforestation,
* to allow a higher degree of food production,
* to fight soil erosion,
* to make best use of available water resources,
* to suppress soil salinity and, in a few cases,
* and to recharge groundwater.

There are also some problems associated with runoff farming water harvesting (Prinz 1996):

* a higher labor input than in the case of rainfed farming,
* higher difficulties due to unfamiliarity with the technology and/or an unreliable water supply,
* a negative impact on soil and vegetation resources in the catchment area due to clearing or treatment,
* the possibility of increasing number of livestock which could cause more desertification,

* a loss of individual control in large runoff farming water harvesting catchments and In comparison to former times, farmers today have to produce in a very different social and economic environment. Nevertheless, the positive elements of runoff farming water harvesting remain valid and they can be used in future for the well-being of people in the dry areas of the world. Precondition is an adequate coverage of all technical, social, economic and environmental aspects of runoff farming water harvesting in planning and implementation (Prinz 1994) - as it was apparently the case in ancient times, when sustainability was reached for many centuries.

By learning from failures and successes experiences, a high degree of sustainability might be reached, similar to the one which apparently existed in the past and remained for a thousand or more years (Prinz 1996).

Runoff farming water harvesting is the key to making better use of rainwater for agricultural purposes (Prinz; et al., 2001), it:

* increases the amount of water available per unit of cropping area,
* reduces the impact of drought, and
* uses runoff and flood water efficiently.

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