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POTENTIALS OF WATER HARVESTING IN THE DRY REGIONS

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ABSTRACT

The paper briefly describes basic needs, potential sites, systems design, production potential, and future research and development opportunities of the water harvesting technology. Studies carried out for six years at Jodhpur revealed that runoff, for catchment to cultivated area ratio of 0.5, varied from 38 to 68% of the growing season rainfall. Each hectare of the cultivated area thus received 140 to 636 mm of rainfall although the actual rainfall was 117 to 528 mm in different years. As a result, runoff concentration technology facilitated cropping under otherwise too dry a condition for agriculture, lead to increased and stabilised yields, lowered the risk of crop failures and saved production inputs. The total production from two-thirds cropping of a unit area (one-third going to the microcatchment) by runoff farming was the same as from the conventional cropping under flat surface control.

In water-deficient regions the land area is vast. The rainfall is low. The basic problems, therefore, stem from the imbalance between the vast land and the scanty water. To provide more water to the arid regions, there is the obvious need to adopt innovative water harvesting devices of the kind ancient agriculturists used to follow some 4000 years ago in the arid regions of the Middle East, southern Arabia and North Africa.

Water harvesting technology is location specific. A technology suited to one region cannot be applied, despite all optimism, to another for environmental, technical, and socio-economic reasons. Thus the *prima facie* need is to delineate dry regions with considerations for the climate, soils and vegetation, before a water harvesting technology suited to a location is developed. No suggestion is being offered here to bring whole of a given dry region under water harvesting plan which, of course, holds particular promise for the marginal lands.

BASIC NEEDS

Water harvesting for the agricultural use requires a portion of the total area under catchment and the rest under cultivation. If the rainwater from the slopy natural catchment is to be recycled, facilities for storage are needed. For crop production, 'storage in the soil' is necessary. Water harvesting has, thus two distinct but intimately related phases, each having specific prerequisites. In the first phase the catchment, natural or man-made, is left in the natural state or cleared off rocks (on hillsides) and vegetation. It can further have grassed waterways, polyethylene covering or hydrophobing for more water yields. Surface storage of water requires evaporation suppression and seepage control through the use of materials and techniques (Cooley and Myers, 1973).

If storage is not economical, harvested water is to be conveyed to the farm site. This type of water harvesting and distribution of runoff directly to the fields is being practised in the People's Democratic Repub'ic of Yemen. During conveyance, seepage losses are to be minimised. At the farm site, water resevoir is, in fact, in the soil. To store sufficient water in the soil, a minimum of 1.2-2 m depth with a high storage capacity is essential to support the crop till physiological maturity. The importance of soil depth, an increasingly potent factor related to water storage capacity, is often overlooked when a catchment with a certain degree of slope is constructed. For instance, in the process of making microcatchment with 5 or 10 per cent slope more than 50 to 75 per cent top layer of 1.2-1.5 m deep soil is removed. The water storage capacity declines by the same percentage. As a result, the additional harvested water (Tabe' 2) is lost as deep percolation in normal rainfall seasons. In dry season, on the other hand, the depth of harvested water plus rainfall may not exceed the water storage capacity of the soil. More runoff water from larger catchment will give more yield. Data presented in Table 2 and 3 reveal this fact.

Next to environmental requisites is the selection of crops and varieties on such considerations as rooting depth, resistance to drought, early maturity, ability to lie dormant during droughts and resume growth when moisture is available. In temperate deserts, fruit trees are preferred as these can tap water stored deep in the soil profile. For the same reason, the non-fruit trees viz. Jojoba [*Simmondsia chinensis* (Link) Schneider], *Prosopis cineraria* (Linn.) MacBride. *Albizia lebbeck* (Linn.) Benth., *Prosopis juliflora* (Sw.) DC., *Azadirachta indica* A. Juss., *Acacia nilotica* (Linn.) Del. and *Acacia tortilis* (Forsk) have adapted well to the arid and semi-arid tropics. In the Rajasthan desert, ber (*Ziziphus mauritiana* Lamk.), among horticultural crops, has the advantage of slashing its water requirement by undergoing dormancy during the summer (April to June) and resuming growth readily after the onset of the monsoon rains. It can flourish well on heavy rains not necessarily at interva's, unlike field crops that require soaking rains at the time of sowing and at intervals too and can, therefore, be fitted into alternative cropping systems matched to make the best of whatever water is available from rains and the runoff.

Among field crops and their varieties, 'BJ 104' pearl millet [*Pennisetum americanum* (Linn.) Leek], 'FS 68' cowpea [*Vigna unguiculata* (Linn.) Walp.], PS 16 mung been [*Vigna radiata* (Linn.) Wilczek], 'Sona' cluster bean (*Cyamopsis tetragonoloba* Taub.) and

'Pratap' sesamum (*Sesamum indicum* Linn.) have shown promise. Clusterbean has the advantage of high tolerance to soil water deficits. Pearl millet is most efficient in water use. The cultivar of cowpea and mung bean have the advantage of earliness. The 'FS 68' cowpea matures in 50 instead of 120 days needed for its late maturing variety 'C 152' and thereby rainfall, water storage and management requirements are reduced by 70 days. The following account of cropping by water harvesting at Jodhpur provides a good example. During the 1974 drought, late maturing variety CSH1 of grain sorghum [*Sorghum bicolor* (Linn.) Moench.] and C152 of cowpea did not complete the grain yield cycle. On the other hand, relatively short duration varities of pearl millet, cluster bean, sesamum and mung bean gave consolation yields.

To bring these good features of *ber* and field crops together in a water harvesting system, it is advisable to rotate pearl millet with cowpea, mung bean, cluster bean and sesamum and mark a portion of the area to *ber* cultivation. Until such time a most economical combination of these is found out through further research, tentatively 40% of a given area can be allocated to *bajra,* 40 per cent of area equally divided among cowpea, mung bean, cluster bean and sesamum, and the remainder 20% to ber.

A minimum of 300 mm of rainfall per season is required if it occurs during winter and 500 mm if it occurs during summer when evaporation is high. Exceptions are also there. Hybrid bajra has been found to yield as much as 2000 kg/ha in a dry season with a total rainfall of 208 mm at a typical site in western Rajasthan.

Before launching water harvesting projects at any location a prior need is to have information on probability level of intense rainfall, its intensity, duration and pattern. From the relationships between the rainfall intensity, duration and frequency, likely intensity of a storm at desired probability level can be determined for any duration (Fig. 2). Such curves can be used for runoff prediction. As for example, the infiltration rate of loamy sands at Jodhpur is 9 mm/hr. A frequency distribution analysis (Fig. 1) of 75 years records of growing season rainfall revealed that dependable 24-hour rainfall in 4 out of 5 seasons or 80% probability is equal to or more than 15 mm in July, 17 mm in August and 36 mm in the growing season (July to September). The maximum intensity for 80% probability level is 22 mm/hr for 5-minute duration and 17 mm/hr for 10-minute duration (Fig. 2). This shows that chances of runoff are bright.

Further, it may be seen that out of 50 intense rainfall events in four years recorded at Jodhpur, 44 are of advanced and four are delayed types (Fig. 3). The advanced rains bring high intensity initially when infiltration rate is high and, therefore, the runoff peaks are low. For runoff peaks from advanced pattern of rain, the catchment area is required to be sealed either by indigenously available materials like pond sediments or by chemical hydrophobes. In a study at Jodhpur, it was found that for catchment

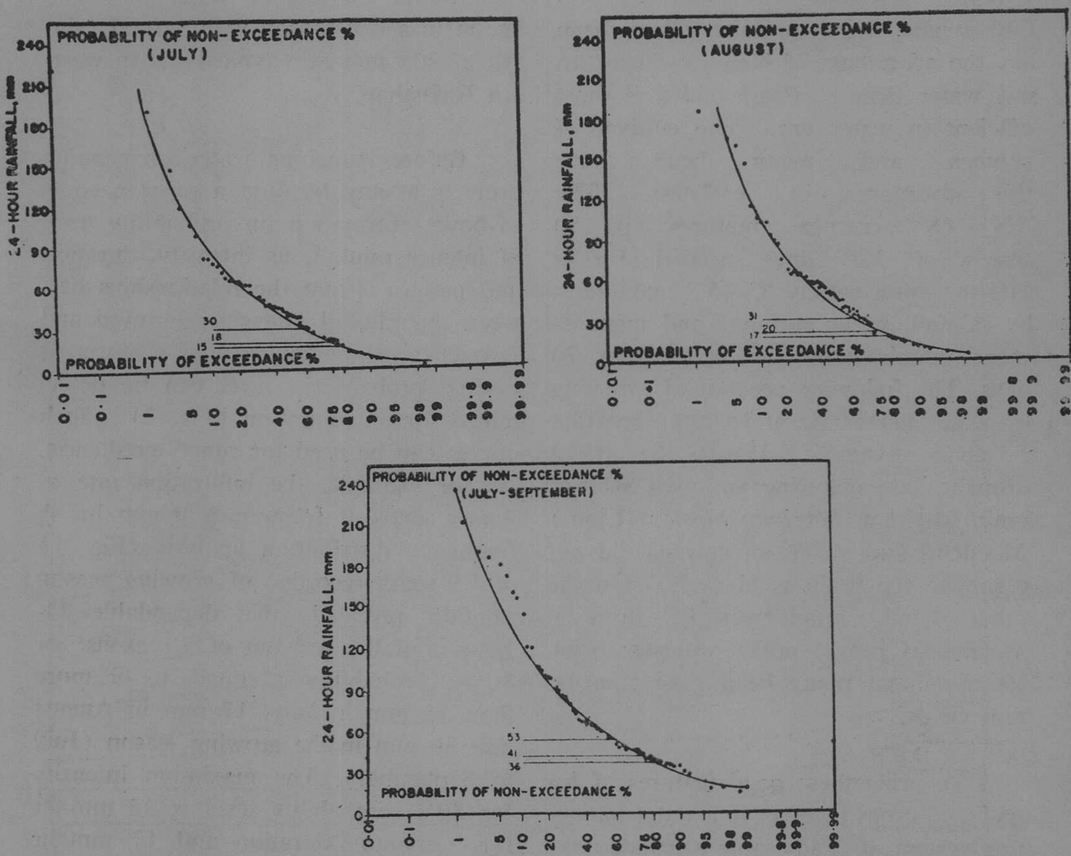


Fig. 1. Percentage of time that rainfall is equal to or greater than amount indicated

sealed with thin layer of pond sediments the threshold value is 4.5 mm, i.e., 4.5 mm of rainfall must precede the commencement of runoff. On the other hand, delayed storm patterns bring high intensity of rains at the time when infiltration rate is low and the desired water storage in the depression has largely been met with. Runoff peaks are likely to be more in such cases.

POTENTIAL SITES

Hillsides, hillocks and rocky plains in the dry regions are the potential sites for rainwater harvesting, storage and recycling. The major problem is the high evaporation rates in the dry regions. To reduce evaporation from the water storage tank, soft wax or foamed plastic has been suggested (Cooley and Myers, 1973). However, these and other materials used for evaporation control are costly. It seems we have no economical method as yet to reduce evaporation from harvested water stored in reservoirs. To convey the harvested water to the farm site and distribute it to different fields seems to be the best alternative.

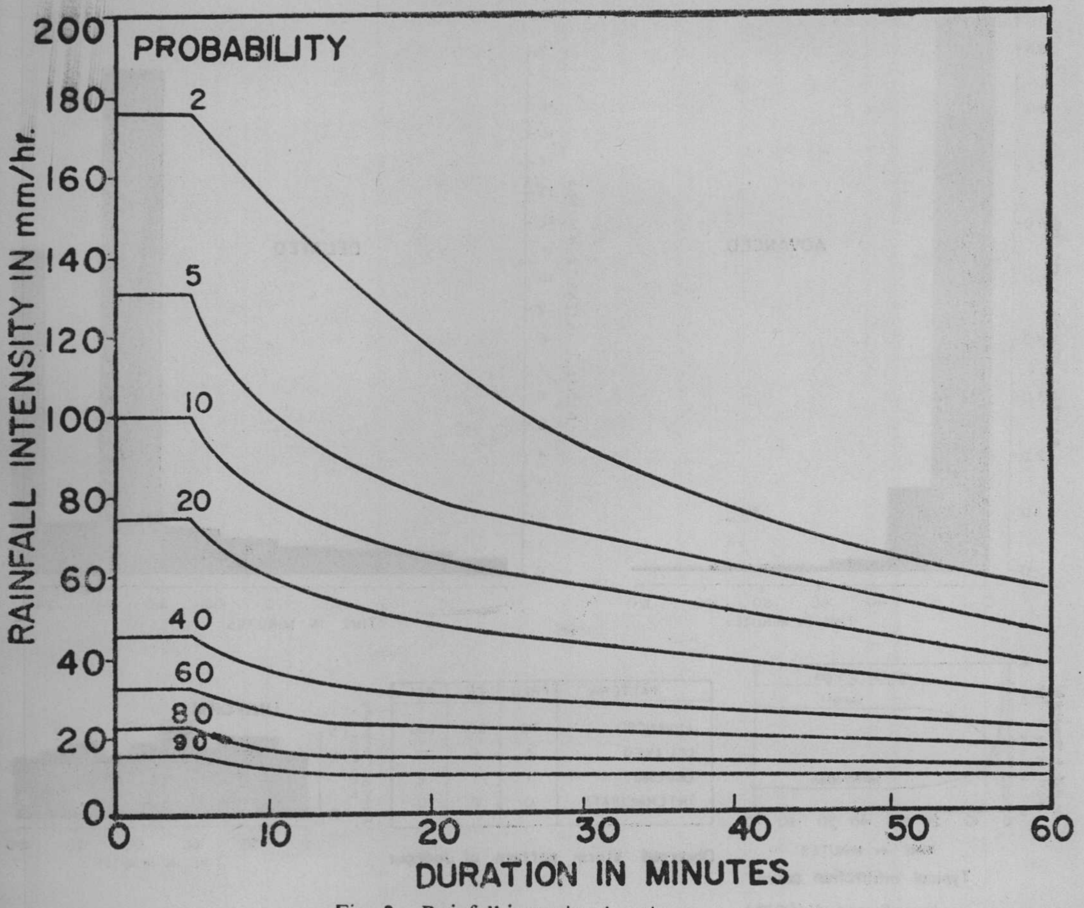
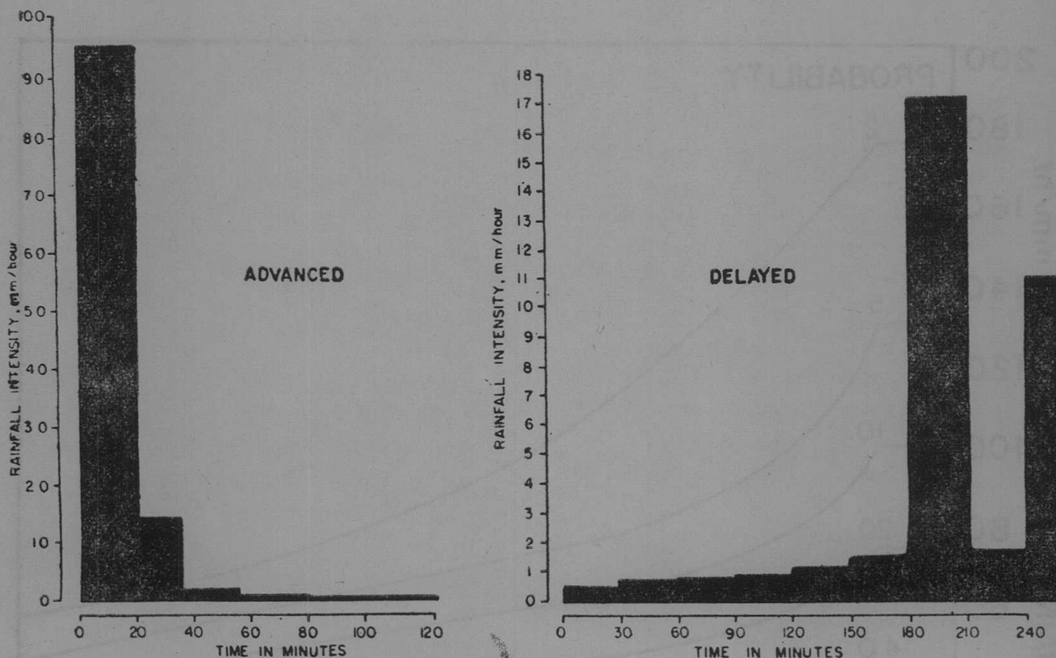
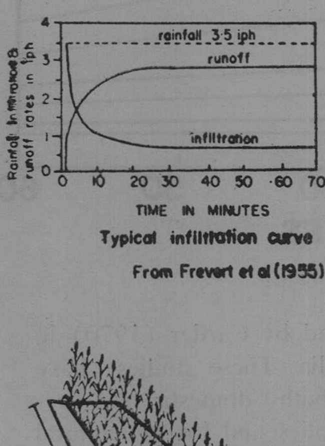


Fig. 2. Rainfall intensity-duration curves

This requires dividing the runoff contributing area into catchments and sub-catchments and integrating the cultivated area in such a way that each field has its own watershed. Called as "water spreading", this is probably the oldest practice of water harvesting believed to be the basis of agricultural civilization some 4000 years ago in the Arabian Desert. In recent years, this technique has been widely studied by the Agricultural Research Service of U.S.A. in the Great Plains arid area, by Evenari *et al.* (1971) in the Negev desert, and by Carder (1970) in western Australia. These studies have been made for both domestic and livestock water supplies and for agricultural crop production. The scale of adoption of this practice in the arid regions will, however, depend on how much runoff contributing hillsides, hillocks or other natural slopy waste lands are available. Delineation of such potential zones by aerial photos and integration of watersheds or multiple watersheds with cultivated area commensurate with its storage





Typical infiltration curve

From Frevert et al (1955)

PATTERN	FREQ	CF	RCF
ADVANCED	44	50	100
DELAYED	5	6	12
UNIFORM	1	1	2
INTERMEDIATE	0	0	0

Observed storm pattern of Jodhpur

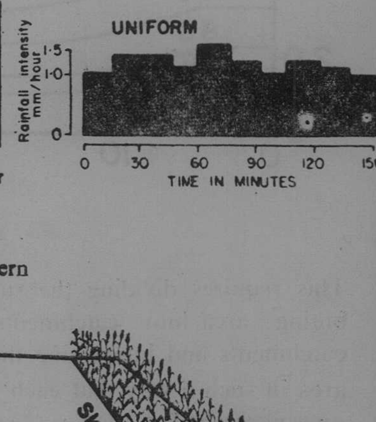


Fig. 3. Rainfall intensity pattern

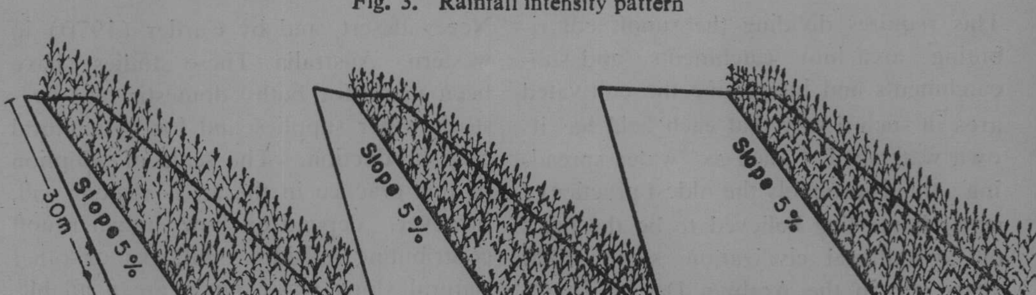


Fig. 4. Layout plan of microcatchment farming

capacity, will be the key to a successful operation of runoff farms.

In shallow soils with concretions underneath, the water storage capacity will be very low. Following a high intensity rain, the rain plus runoff from the catchment may, at times, stand for quite some time. As the profile storage capacity is little, a large portion of the harvested water will be gradually lost to deep percolation after causing damage to the crop at some stage and finally lowering the yield. It is amazing to see, in such cases, how water logging can be a factor negative to yield in dry regions. As seen from data in Table 1, fall in yield of hybird pearl millet and grain sorghum, in fields (heavy soil, 30-40 cm deep) bunded to impound rainwater, was noticed in 1967, a normal rainfall year.

Table 1. Grain yield of crops on heavy soils at Pali substation of Central Arid Zone Reseaach Institute, Jodhpur.

Crop	Yield (kg/ha)	
	Bunded	Non-bunded
Pearl millet	541	544
Sorghum	440	809

Possibly for similar reason, level bench terraces were not considered very successful for quite sometime in the Great Plains arid area of the United States of America, even though the installation had shown considerable moisture conservation and increased crop yields in isolated experiments by Houser and Cox (1962), Buchta *et al.* (1965), and Philips (1965). In its spatially modified and improved form, level bench terraces with a sloped contributing area are now being installed with a provision of drainage and temporary storage of spilled water for recycling. It seems that tank based agriculture on marginal lands of shallow depth may have future potential, provided seepage is not a serious problem in the region.

Highways can contribute enough water to keep roadside plantations green and growing. Highway edges dressed and plantation spacement so kept as each tree possesses its own catchment and receives water from road pavements and sides may be desirable.

Roaded catchments are being used extensively in western Australia for farm water supplies. The catchments yield runoff from as low rainfall as 7.5 mm. However, farm scale adoption of roaded catchments is ruled out in a developing country even though isolated examples of similar kind are encountered in some villages of Rajasthan desert. Some well-to-do farmers construct small cemented floors, circular or rectangular. From these rainwater is collected in small underground storage tanks locally known as *Tanka,* opening of which is covered with a cement lid. This water is used exclusively by the owner when the common source of drinking water in the village tank is exhausted. Many a times *Tanka* water is enough to keep some members of the family staying in the village for watching property in drought years that cause large scale human and livestock migration. On the lines of *Tanka,* Saudi Arabia had built a chain of water tanks

1000 years ago as way stations for Muslims on pilgrimage from Baghdad to Mecca.

In summary, a plan is too ambitious that envisages to change the entire face of a dry region to runoff farms. Nor the state economy can ever sustain it. In the wake of limitations imposed by vastness of the region and its stringent problems, small-scale water harvesting schemes located in marginal lands at the feet of hill slopes, in inter-hillock spaces and on undulating lands merit consideration. Roadsides can also be included. Often, nomad problem stems more from the lack of water points than by the shortage of fodder. Microcatchment farming and its variations can improve feeds and fodder and the rainwater harvesting by use of water collection aprons will improve the farm water supplies. Together these two practices can partially overcome nomadism and desert rehabilitation problems. Hopefully then, the agricultural civilization of an arid region can rely to survive on suitably located small-scale runoff farms.

DESIGN

Water harvesting refers to rainwater harvesting from natural or chemically treated hilly catchments. If water after harvest is used for crop production, the system becomes runoff farming. Runoff farming is done in a variety of ways e.g. microcatchment farming (Shanan *et al.*, 1970), desert strip (Morin *et al.*, 1973), contour catchment farming, water spreading and interplot and interrow water harvesting. These are the connotations assigned to the structures constructed/the practices followed for harvesting water and using it for crop production. These are perhaps variations of the system designed to concentrate, in cultivated area, the runoff collected from the natural or the man-made catchments. 'Interplot' water harvesting also appears to be a loosely coined term. As a matter of fact it is not the "interplot" water harvesting, but the tillage and the crop management practices manipulated to allow rainwater concentration in the proximity of the root system. The name "runoff concentration system" seems to be scientifically broad-based.

POTENTIALS

Machine power built water harvesting systems were designed at the Central Arid Zone Research Institute, Jodhpur, with a view to concentrate runoff in cultivated level fields on a loamy sand, 90-120 cm deep, and catchment treated with a thin layer of pond sediments and sloped (5 per cent) towards the cropped area (Fig. 4). Three catchment to cropped area (cropped area = 6 rows x 50 cm spacing x 30 m long, the same for all treatments) ratios, 0.50, 1.00 and 1.33, were compared with conventional cropping on a flat surface control.

Data presented in Table 2 elucidate how runoff farming increases the depth of water available for crop use. The runoff is 38 to 68 per cent of growing season rainfall depending upon the nature and the amount of precipitation. From catchment to cultivated area ratio of 0.5, each hectare of cultivated area received about 230-1080 m^3 of runoff water (1 mm equals 10 m^3 of water per ha) from the

Table 2. Growing season total rainfall (Rt), effective rainfall (Re), runoff (Q), depth of water (D) and effective depth of water (De) all in mm in cropped area for two catchment area (Am) to cultivated area (Ac) ratios

Year	Am/Ac	Rt	Re	Q	D*	De	Q (%)/Rt	Re (%)/Rt
1972	0.0	306	167	0	167	167	—	55
	0.5	306	167	208	271	171	68	55
1973	0.0	528	348	0	348	348	—	66
	0.5	528	348	215	456	409	41	66
1974	0.0	117	117	0	117	117	—	100
	0.5	117	117	45	140	140	38	100
1975	0.0	290	290	0	290	290	—	100
	0.5	290	290	126	353	353	43	100

$$* \ D = Re + Q\frac{Am}{Ac}$$

microwatershed in addition to 1170-5280 m^3 from direct rain. The cultivated area then received 1400-6360 m^3 of water which is equivalent of some 140-636 mm of rainfall, although the rainfall was 117-528 mm in different years.

Obviously, the microcatchment redistributed rainfall over cropped area where the water was concentrated and moved deep into the soil. The cumulative evaporation from cropped area is, therefore, reduced (Gardner and Gardner, 1969) and thereby more water was available for crop use. In the experiment by Fairbourn and Gardner (1974), runoff concentration technology togetherwith vertical mulching allowed infiltration of water deep into the soil and thus saved 41 per cent of soil moisture which accounted for 37 to 150 per cent increase in the yield of grain sorghum. In studies at Jodhpur, the mean production potential of sorghum was about twice as high (Table 3).

Table 3 Mean production potential (kg grain/cm of growing season effective rainfall) under Am to Ac ratios of 0.0 (flat surface control) and 0.5

Am/Ac	Pearl millet	Sorghum	Mung bean	Cowpea	Cluster bean	Sesamum	Sunflower
0.0	43	47	11	14	4	11	13
0.5	80	75	38	28	19	19	23

Over six years, the accumulated production benefit by cropping only two-thirds of unit area (one-third area under microcatchment) by runoff farming over conventional cropping on a flat surface control is + 2129 kg/ha (Table 4). The corresponding production gain is negligible in the case of grain sorghum, + 1235 kg from mung bean, + 875 kg from cluster bean, + 451 kg from cow-

Table 4. Yield (kg/ha) on a total area basis, accumulated gain over years (kg/ha) by runoff farming, and initial investment on catchment

Year	Pearl millet	Sorghum	Mung bean	Cluster been	Cowpea	Sesamum	Sunflower
			Flat surface control				
1970	1080						
1971	1526						
1972	0	0	229	225	171	147	
1973	2913	3644	1073	0	1236	698	742
1974	0	0	0	0	0	0	0
1975	2320	2302	0	0	330	373	510
				17790 (Forage)			
			0.5 catchment to cultivated area ratio				
1970	2390						
1971	2478						
1972	395	253	258	234	261	249	
1973	2352	3149	985	0	1176	911	782
1974	96	0	121	102	0	36	0
1975	2257	1559	1173	794*	751	238	698
				11951 (Forage)			
Added gain	+2129	+15	—1235	+875	+451	+216	+178
Investment (Rs/ha)	289						
Input saving ((every season)	1/3 of inputs required/ha						

*From second crop taken after cluster bean forage pea, + 216 kg from sesamum, and + 178 kg from sunflower. Thus, same total production was obtained by cropping in runoff farming as from cropping on flat surface control. In runoff farming there was, however, substantial added gain over years which varied from crop to crop besides one-third input saving every year, against an investment of Rs. 289/ha only once in the beginning. Saving in production inputs itself would pay off the initial investment on microwatershed installation. As indicated earlier in the preceding section, selection of suitable plant type for runoff concentration system is nearly half the success. As seen from production balance sheet over six years in the case of pearl millet and over four years in rest of the crops, the ranking in order of their decreasing adaptability to runoff system is as follows :

Pearl millet > mung bean > cluster bean > cowpea > sesamum > sunflower > grain sorghum.

It seems that pearl millet among the cereals; mung bean, cluster bean and cowpea among the grain pulses and sesamum among the rainy season oilseed crops form the best crop combination under runoff concentration systems. Plant types with general adaptability to moisture stress and earliness are the notable features a selected crop should possess.

RESEARCH AND DEVELOPMENT OPPORTUNITIES

Runoff agriculture, no doubt, is technically sound. For wider applicability, techno-economic evaluation with different climates, soils and crops is now needed to evaluate its potentials for the future. To define optimum catchment size for crops better suited to runoff agriculture, in relation to soil quality and hydrological parameters, it opens up opportunities for future research too.

Method of construction is a factor in designing water harvesting systems. In projects located in various parts of the world the objective has been, and is, to replace as much man and animal power as possible by machine power. In the shadow of energy crisis, labour intensive catchment has to be designed and constructed, in size and width less than that built so far by machine power. A simple design requiring no special skills and tools can help adoption at a faster rate.

There is a lot to learn about the feasibility of runoff collection from hydrophobed or surface-covered catchment, the effects of hydrophobes on quality of water intended to be used for drinking and on water-spread fields. Myers (1973), Myers and Frasier (1969), and Fuehring (1975) have evaluated a number of materials for ground cover, water collection aprons, hydrophobing the soil, improving water storage and reducing seepage and evaporation losses. Extravagant claims appear to have been made that some of the materials, e.g. asphalt-fiberglass and gravel covered polyethylene, have potential value for low cost water harvesting. Heavy cost of the materials so far employed rules out their use for agricultural crops. Research is, therefore, needed to identify low-cost, least bio-thermodegradable materials easy to use without sophisticated tools and implements. Development opportunities also exist for studies on the socioeconomic implications of this technology and the constraints in its transfer to the man behind the plough.

REFERENCES

Buchta, H. G., Broberg, D. E. and Ligget, F. E. 1965. Flat channel terraces for erosion control and water conservation. Presented at *Amer. Soc. Agric. Eng. meeting.* Athens, Georgia, June 1965. Paper No. 65-231.

Carder, D. J. 1970. *Roaded catchments.* West. Aust. Dep. Agric. Tech. Bull. 5, 13 pp.

Cooley, K. R. and Myers, L. E. 1973. Evaporation reduction with reflective covers. *J. Irrig. Drainage Div.* ASCE 99 (IR 3) : 353-364.

Evenari, M., Shanan, L. and Tadmor, N. 1971. *The Negav : The Challenge of a Desert.* pp. 95-119. Harvard University Press, Cambridge, Massachusetts.

Fairbourn, M. L. and Gardner, H. R. 1974. Field use of microwatersheds with vertical mulch. *Agron. J.* 66 : 740-744.

Fuehring, H. D. 1975. Yield of dryland grain sorghum as affected by antitranspirant, nitrogen and contributing microwatershed. *Agron. J. 67* : 255-257.

Gardner, H. R. and Gardner, W. R. 1969. Relation of water application to evaporation and storage of soil water. *Soil Sci. Soc. Amer. Proc. 33* : 192-196.

Hauser, V. L. and Cox, M. B. 1962. Evaluation of Zingg conservation bench terraces. *Agr. Eng. 43* : 462-464.

Morin, G. C. A., Parsons, D. K., Matlock, W. G. and Fangmeir, D. D. 1973. Desert strip farming-A way to make the desert green. *Progressive Agric.* Arizona University, Arizona.

Myers, L. E. 1973. Potentials and problems in water harvesting. Presented at the Conference on Science and Man in the Americas. American Association for the Advancement of Science and Consejo Nacional de Ciencia y Tecnologia, Mexico City, DF, June 20-July 4, 1973.

Myers, L. E. and Frasier, G. W. 1969. Creating hydrophobic soil for water harvesting. *J. Irrigation and Drainage Div. Proc.* ASCE 95 (IR1 : 43-54.

Phillps, R. L. 1965. Recent terrace development in Iowa. *J. Soil Water Conserv. 20* : 146-147.

Shanan, L., Tadmor, N. H., Evenari; M. and Reigniger, P. 1970. Runoff farming in the desert. III. Microcatchments for improvement of desert range. *Agron. J. 62* : 445-449.