DEVELOPMENT OF AGROFORESTRY MODEL USING WATER HARVESTING SYSTEM IN SEMI ARID AND ARID ZONES

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ABSTRACT

A study was conducted at Kharian to develop an agroforestry system by using water harvesting system in semiarid zone. Two slope lengths; 4m and 5 m and three slope gradients; 7%, 10%, and 15% of roaded catchments were tested for finding out optimum slope length and gradient for water resource development to increase crop and wood production. Results of the study showed that four meter slope length with 7% gradient are more effective in increasing the runoff and are economical to construct and maintain. It was also observed that water production to cropping area ratio at Kharian should be 1:2. The study indicated that crop production can be enchanced by 40% and tree growth can be increased by three time's by using the water harvesting system.

INTRODUCTION

About 65-70% area of Pakistan is arid or semiarid where agriculture is not possible without irrigation. Although Pakistan has world biggest network of canal irrigation system but only 21.02 million hectares area is cultivated , which is not sufficient to produce food for meeting the demand of the increasing population. For increasing the food production ground water is also used by installing tube wells wherever it is feasible. In other areas, only surface water resource have to be developed.

Rain water harvesting system, can be utilized for making waste land productive. Although rainfall is infrequent in arid zone but it comprises considerable amount, e.g. 10mm. of rainfall equals 100,000 litres of water per ha.

Harvesting this water can provide drinking or irrigation water in areas where there is no other source of water.

The water harvesting concept is not new as the techniques has been used as early as in 4500 B.C. by the people of Urand in Middle East (Harden, 1975). In fact researchers have reconstructed water harvesting system used for runoff farming in Nigev desert 4000 years ago (Evernari *et al.* 1968). American Indians used similar system 7000 to 900 years ago in the south west United States (Meyer, 1975).

Sometimes, rainfall runoff can be collected from an untouched natural catchment by digging ponds in small depressions to collect and store rainwater. Often, the catchment needs modification, usually by making the soil surface more impermeable to increase the amount of runoff. The simple method is clearing away rocks and vegetation to increase runoff as practiced in the Nigev Desert (Evenari, 1971). Compacting the soil surface can also increase runoff in Western Australia. Catchments are graded and rolled for shedding water with minimal rainfall (Anon, 1974).

Other method is treating the soil with chemicals that fill the pores to make the soil water repellent. Sodium salts cause clay in the soil to break down into small particles in many clayey soils. Sodium salts are prefered soil sealants due to their low cost, readily availability, and retardant of weed growth. Other commonly tried water repellant chemicals are silicone, latexes, asphalt, and wax (Cluff 1978, Fink, 1973, Cluff, 1974). In a study in Pakistan, mud plaster (soil and wheat husk) proved most efficient and cheapest as a catchment treatment (Sheikh et al., 1981).

Plants can grow in a region with too little rainfall for its survival if a rainwater catchment basin is built around it forcing rainfall from a larger than normal area to irrigate the plants. The practice is called microcatchment farming. Microcatchments used in the Nigev Desert range from 16 m^2 to 1000 m^2. Each is surrounded by a dirt wall 15 to 20 cm high. At the lowest point within each microcatchment, a basin is dug about 40 cm deep and a tree is planted in it. The basin stores the runoff from the microcatchment. The basins are fertilized with manure and its soil surface is kept loose to facilitate water absorption.

Desert and contour catchment farming is a modification of microcatchment farming. It employs a series of terraces that shed water onto a neighboring strip of productive soil. They are often tired up a hill slope; but on level terrain an artificial slope for catchment can be made by mounding soil between the strips.

Grapes are cultivated in drainage ways in desert strip runoff farming at Page Experimental Ranch near Tucson, Arizona. Catchment area treated with sodium chloride remains bare (Cluff, 1974). Rands et al.,(1979), reported a similar study with cultivated area at University of Arizona Ranch in South Arizona.

Runoff of water impounded in natural depressions in the Israel Nigev Desert is used to cultivate groves of trees, particularly Eucalyptus for fuelwood. Depressions are prepared first by levelling to distribute flood water evenly across the surface, followed by construction of earthen dams to impede water flow for planting of *E. camaldulensis, Tamarix* spp. and *Acacia* spp., (Kaplan, 1981).

In a study made at the Papago Indian Reservation, Arizona, jojoba was planted in rows down the center of 30 ft. wide drainage catchments with sides of approximately 10% slope. The catchment drained into a reservoir where water was stored and pumped back to the plants during winter and spring. The results showed good potential of the system and indicated that a larger installation would be justified (Cluff et al., 1972).

In an experiment conducted in the Thal Desert in Pakistan (Sheikh et al., 1982), maximum growth of plants was obtained by planting them in a trench with one meter sloping surface of 1 in 3 on each side. The trench was 0.3m wide and 0.3m deep. Plants also showed good performance in V-shaped sloping catchments without trenches.

An improved method was found in a water harvesting agrisystem in Avra Valley, Arizona, by the University of Arizona, (Dutt et al., 1972). V-shaped microcatchments were prepared with crop area in the center and bottom of the sloping surface. The major portion of the rainfall falling on the system was directed to the crop area and then to the storage reservoir. The sloping catchments were treated with sodium chloride to make them water repellent. The excess water stored in the reservoir was utilized to irrigate the plants during the periods of no rainfall through a drip irrigation system. The city of Tucson demonstration system has a catchment and cropped area of approximately 6 acres. Presently, high yield, high value, drought tolerant crops such as wine grapes, jojoba, olives, etc. are grown.

A study was laid out at Kharian, Punjab to develop a barani agroforestry system using roaded catchment for rain water harvesting. The objective of the study was to find out optimum slope length and gradient of roaded catchment for efficient production of water growing of agriculture crops, fuelwood and timber in a semiarid area.

MATERIAL AND METHOD

The study was laid out at Pabbi Forest, Kharian, District Gujrat. Pabbi Forest area lies near 32:8' North latitude and 73:7' East longitude. Average annual rainfall of the area is about 750 mm about 70% of which is received during monsoon. The experimental site has sandy loam soil supporting natural scrub vegetation with *Acacia modesta* as dominant species. The area is presently managed for grazing. After clearing the natural vegetation, the area was ploughed and levelled with the help of a tractor. Roaded catchments were prepared 30 meters in length and four meter wide cropping area (Fig. 1). The treatments of the roaded catchments were two slope lengths viz; 5 meter and 4 meter and three slope gradient, 7%,10% and 15%.

The experimental design was split plot with slope length as major treatment and slope gradient as minor treatment. The experiment was replicated three times with one roaded catchment taken as a single plot. A total of 18 roaded catchments were prepared for the study. At both ends of catchments trenches of 0.40 cm. width and 30 cm. depth were dug out for planting *Eucalyptus camaldulensis*. The length of each trench was 14 m in case of catchments with 5 m. slope length and 12 m long in catchments with 4 m slope length. From the center of the trench a metallic outlet was provided for collecting overflow into earthen dugout water tanks with a storing capacity of 4 cubic meter. As the outlet for outflow from cropping area was kept at 20 cm height above the flat cropping area, therefore, 10-20cm depth of water is retained in the cropping area at each event of runoff.

The runoff was measured in the storage tanks by measuring the depth of water in the tanks and adding to it the volume of water retained in the trench. The water retained in the cropping area was not included in the surface runoff. The data on sediment yield was collected by measuring the volume of sediment deposited in the tanks. The sediment measurement was not possible in the cropping area and trenches. Therefore, the erosion from the slopes was assessed by ocular observations of rill formation on the slopes.

The rainfall data was collected through a standard rainguage fixed in the meteorological observatory at about 400 meter distance from the study site.

Agriculture crops such as *Sunflower,* (Helianthus annus) *Taramira (Eruca sativa), and Mash (Phaleolus radiatus)* were cultivated in the cropping area during 1989-1991. Data on crop production were recorded for each plot. In 1992 the forage crops, *Sadabahar, Sorghum album* were grown but were damaged by wild bore and *Porcupine*. During the monsoon 1993 *Cenchrus ciliaris* was sown in the cropping area. Data on height growth of *E. camaldulensis* were collected every year at the end of growing season.

RESULTS AND DISCUSSION

The data on surface runoff, sediment yield, crop production, and *Eucalyptus camaldulensis* growth were recorded processed and are presented in the Tables 1-4. The results are discussed below.

Water Production

Table-1 gives the average of the four years data of surface runoff measurement (hydrological response) of the roaded catchments of different slope lengths and gradients. As the runoff water retained in crop production area was not included in surface runoff therefore, the figures on hydrological response are low. The method of measurements was not quite accurate even then the results give clear indication of the effect of slope lengths and gradients on water production of the roaded catchments.

The hydrological response (runoff as percentage of rainfall) of four meter long roaded catchments was higher than those having five meter slope length. The average hydrological response of catchments with 4m slope length and having 7,10 and 15 percent gradient was 30.3, 32.1 and 35.6% respectively. While it was 25.3, 27.1 and 30.1% of the catchments having 5 meters slope length and 7,10 and 15 percent gradient. The results indicate that there was direct relationship between slope gradient and increase in the hydrological response but the relative increase was not significant. There was about 5% more hydrological response in case of roaded catchments having 4m slope length as compared to those with 5 m slope length. While the hydrological response with respect to slope gradient was on average only about 2-3% with increase of 3-5% gradient.

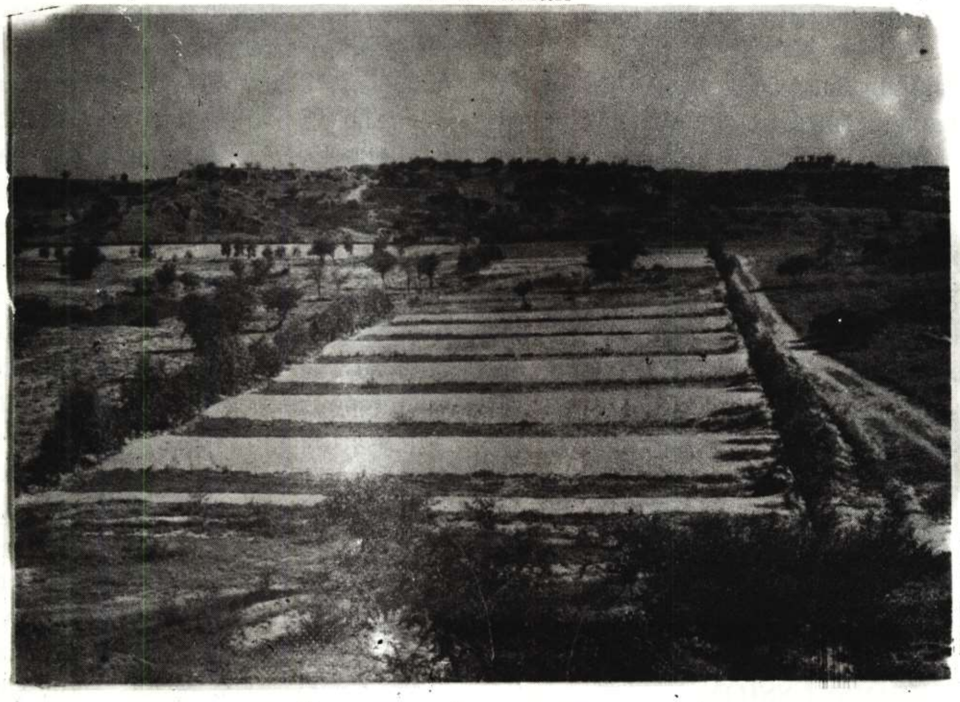
The ratio of water to crop production area was 2:1 in case of catchments with 4m slope length and 2.5:1 in case of catchments with 5m slope lengths. The results show that at Kharian where the average rainfall is about 750 mm the ratio of water production to crop production area should be 1:2 as there was always overflow from the cropping area even with rainfall of only 16 mm in monsoon season. Therefore, the cropping area can be kept 16 meter wide with roaded catchments having 4 meter slope length.

There was on an average of 30% hydrological response of the catchments with 4m slope length and 7% gradient. If it is assumed that about 30% of the runoff from the roaded catchments is retained in the cropping area then the actual hydrological response of catchments is 60%. When the system is used only for water resource development without incorporating crop production then one ha treated area can produce 2400 cubic meter (2.4 million litres) of water per year for annual average 400 mm runoff producing rainfall.

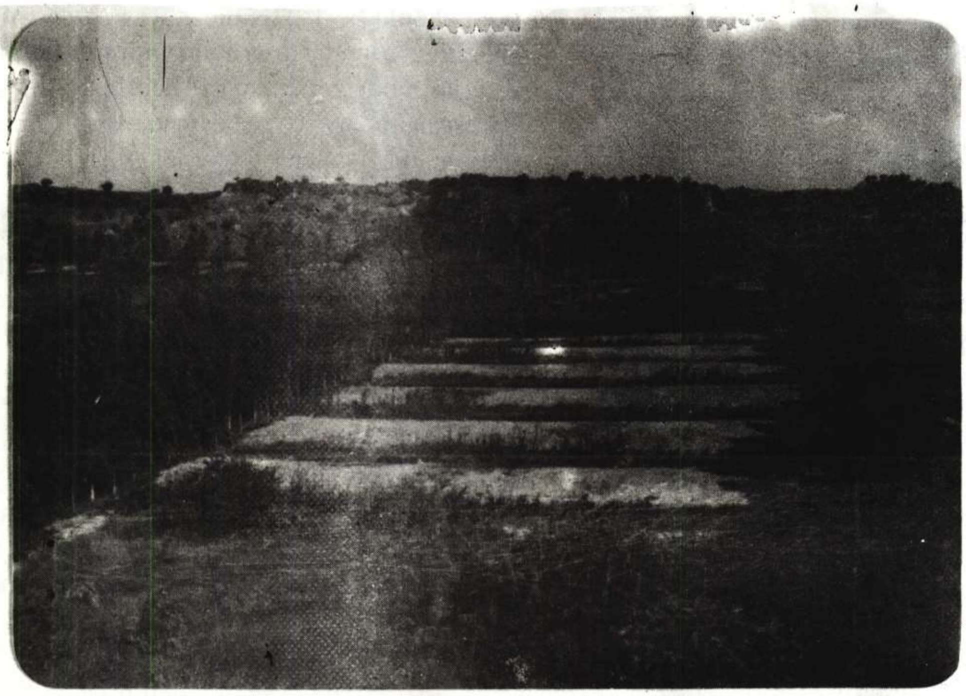
The system when used in the area having

Fig. 1

Fig. 1 Agroforestry Model with water harvesting system at Kharian



a. One year after establishment



b. Three years after establishment

only 120mm. runoff producing rainfall in the deserts like Thal, Cholistan, Thar or Baluchistan one hectare treated area can produce 720 cubic meter (0.72 million litres) of water per annum which can be stored and used for domestic or irrigation purpose, when other source of water is not available.

Sediment yield (slope stability)

Estimates of erosion rate from the artificial slopes of different gradients and lengths was made by measuring the sediment deposited in the dug out tanks only. Annual data are presented in the Table 2. From the table it can be seen that there was increase of erosion rate with the increase of slope length and gradient. The sediment yield was 0.47 and 0.56 cubic meter per roaded catchment of 5m. slope length with 7% and 10% and 15% gradient respectively. The sediment yield from the catchments having four meter slope length and with 7%,10% and 15% gradients was 0.42, 0.45 and 0.49 cubic meter per year respectively. The results show only the erosion rate, the actual sediment yield figures may be much higher. The fact is that most of the soil eroded from the slopes is deposited in the crop production area and the trench and only a fraction of sediment reached the tanks where sediment was measured.

Anyhow erosion from the catchments with 15% slope was quite evident where rill formation was observed as the slopes needed repair after every monsoon season. Therefore, the maintenance cost increased with the increase of slope gradient.

As the efficiency of water production increases with the decrease of slope length and the erosion rate increases with the increase of slope length, therefore, 4m slope length is the desired slope length. While there was no significant difference in the hydrological response of catchments of different gradients but the erosion rate was much higher from the catchments with higher gradients. Therefore, the minimum gradient tested e.g. 7% is proper gradient for the catchments.

Table 1: Effect of different slope lengths and gradients of roaded catchments on surface runoff at Kharian (Hydrological response in percentage)

Year	Precipi-tation*(mm)	Five meter slope length			Four meter slope length		
		7% gradi-ent	10% gradi-ent	15% gradi-ent	7% gradi-ent	10% gradi-ent	15% gradi-ent
1989	59	32.1	40.4	43.8	39.7	43.7	54.0
1990	590	25.2	26.34	31.3	29.6	32.2	33.8
1991	408	23.2	23.9	24.3	27.4	27.6	29.3
1992	349	20.6	20.7	21.1	24.5	24.9	25.5
Average		25.3	27.1	30.1	30.3	32.1	35.65

* Precipitation which produced surface runoff.

Table 2: **Effect of slope length and gradient of roaded catchments on sediment yield (m^3 per plot).**

	Five meter slope length			Four meter slope length		
	7%	10%	15%	7%	10%	15%
R-I	0.4	0.6	0.48	0.4	0.48	0.48
R-II	0.44	0.4	0.48	0.4	0.44	0.48
R-III	0.64	0.68	0.72	0.48	0.48	0.52
Total	1.48	1.68	1.68	1.28	1.40	1.48
Average	0.47	0.56	0.56	0.42	0.45	0.49

Crop Production

Both winter and summer crops were grown in the cropping area. The summer crop was *Mash* while winter crops were *Taramira* and sunflower. *Mash* crop cultivated during summer 1991 was damaged by heavy rains and runoff while Sunflower was cultivated during winter 1989-90 and *Taramira* during winter 1990-91. The data on *Taramira* production is presented in Table 3. There was positive effect on *Taramira* production with the increase in slope length and gradient of the roaded catchment. The production of *Taramira* in cropping area with catchments having 5m. slope length and with 7,10,and 15% gradients was 500, 583 and 694 Kg/ha respectively and it was 500, 513 and 652 Kg/ha in plots with catchments having 4m. slope length and similar gradients respectively. The production was only 383 Kg/ha in the plots having no water harvesting system. The same trend was observed in case of Sunflower production. The production was 333, 533 and 733 Gram/plot in cropping area associated with catchments having 5m. slope length and 7,10,and 15% gradients respectively. While the production in plots without water harvesting was only 200 Kg/ha. The *Mash* production was 383,458 and 500 Kg/ha in cropping area of the catchment with 5m. slope length and having 7,10,15% gradient respectively and it was 325,375 and 450 kg/ha in the cropping area of catchments having same gradient on 4m.slope lengths respectively. The plots without water harvesting had 225 Kg/ha.

There is no significant difference in the crop production in different catchments with different slope gradients and lengths but it was significantly higher in them as compared to that in the plots without water harvesting.

Growth of *Eucalyptus camaldulensis*

The data on *E. camaldulensis* growth is presented in Table 4. The results show that *E. camaldulensis* gave highly positive response to water harvesting system at Kharian. There was no significant difference in height and diameter growth of *E. camaldulensis* planted in catchments having different slope length and gradient, because with every outflow from cropping area of each catchment, the trenches were filled up irrespective of treatments of slope length and gradients. The growth of seedlings planted with water harvesting was almost three times than those planted without water harvesting system. Average height growth of plants at the age of 3.5 years planted in the trenches along the catchments having 5m slope length and with 7,18,and 15% gradients was 11.4, 10.8 and 11.2 meters with DBH of 15.3,13.4 and 13.8 cm respectively. The average height and diameter at breast height of the tree planted along catchment having 4m. slope length and with 7,10,15% gradients were 11.3, 11.6 and 12.2 meters and 13.5, 14.8 and 15.0 cm. respectively. While the seedlings planted without water harvesting system in simple pits gained an average height of 3.2m. and 5.4 DBH.

The average growth rate of *E. camaldulensis* planted with water harvesting system was 3m. per year in height and 4cm per year in diameter which is comparable with the growth rate of *E. camaldulensis* planted in irrigated plantations.

Table 3: Crop production cultivated in cropping area associated with different water harvesting treatments

A. *Taramira (Eruca sativa) Kg/ha*

	5 M- slope length			4 M-slope length			Control
	7%	10%	15%	7%	10%	15%	
R-I	6.5.	7	8	6	6.5	7.5	4
R-II	5.5	7	9	6	6	8.00	5
R-III	6.0	7	8	6	6	8.00	5
Total	18.00	21	25	18	18.5	23.5	14
Average	6.0	7	8.33	6	6.16	7.83	4.6
Production/ha	500	583.3	694.14	500	513.31	652.47	383
B. *Mash* (Kg/ha)							
R-I	400	500	550	325	400	450	215
R-II	400	425	450	300	325	400	250
R-III	350	450	500	350	400	500	210
Total	1150	1375	1500	975	1125	1350	675
Average	383	458	500	325	375	450	325
C. *Sunflower* (Grams/per plot)							
R-I	400	600	850	400	550	750	250
R-II	350	500	800	300	400	500	200
R-III	250	600	550	300	400	750	150
Total	1000	1600	2200	1000	1350	2000	600
Average	333	533	733	333	450	666	200

CONCLUSION

The results of the study showed that roaded catchment of water harvesting system can be successfully employed for developing an agroforestry system in semiarid and arid conditions for increasing the farm productivity. Roaded catchments of 4m long slope and with 7% slope gradient are most efficient in water production and are also cheaper to construct and maintain. The crop production can be increased by 40-60% and *Eucalyptus camaldulensis* growth can be enhanced three times. It was also observed that in areas like Kharian having average annual rainfall of 700-800 mm, the ratio of water production to cropping area should be 1:2. For water resource development the same system can be successfully used by taking away the crop production component. One hectare area treated with roaded catchment, having 4m slope length and 7% slope gradient can provide 2400 cubic meter of water per annum assuming 400 mm runoff producing annual rainfall at Kharian. In arid zone area like Thal Desert, Cholistan and Thar the system can be used for surface water resource development where there is no other source of water.

ACKNOWLEDGEMENT

Thanks are due for Mr. M. Munsha Khan, Forest Ranger and Mr. Shahzada Khan, Forester of Pakistan Forest Institute, Peshawar for their help in maintenance of the study and data collection. The author is highly obliged to Dr. K.M. Siddiqui, Director General, Pakistan Forest Institute, Peshawar for his guidance and encouragement during the course of study.

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