ASAE Publication 04-90

VISIONS OF THE FUTURE

Proceedings of the Third National Irrigation Symposium held in conjunction with the 11th Annual International Irrigation Exposition

October 28 - November 1, 1990
Phoenix Civic Plaza
Phoenix, Arizona

Published by
American Society of Agricultural Engineers
2950 Niles Rd., St. Joseph, Michigan 49085-9659 USA

RUNOFF FARMING: IRRIGATION TECHNOLOGY OF THE FUTURE

Gary W. Frasier *
Member ASAE

Runoff farming is defined as the collection of runoff water from a portion of the land during precipitation events for use on a crop growing area. This irrigation technique can potentially provide sufficient water to grow a crop in areas where normal water supplies, precipitation and/or irrigation, are inadequate or unsuited for conventional farming practices. This crop watering technique is quite literally a "back to the future" technology that was used over 4000 years ago in the Negev desert of Israel. The ancient systems consisted of clearing rocks and stones from hillside to promote increased runoff (Evenari, et al., 1961). Some of these runoff farming techniques were practiced as early as 4500 B.C. by the people of Ur and later by the Nabateans and other people of the Middle East (Frasier, 1975a). Runoff farming techniques were used about 500 years ago by early dwellers in what is now the Mesa Verde National Park in southwestern Colorado (Myers, 1975).

A modified version of hillside runoff farming, locally termed dryland and floodwater farming, is being practiced on various parts of the Navajo Indian Nation in northern Arizona (Billy, 1981). Another version of runoff farming commonly referred to as micro-catchment, consisting of dedicating a small runoff area for providing water to an adjacent crop growing area, is being used in Israel and Mexico for growing nut trees or shrubs (Rawitz and Hillel, 1975; Carmona and Velasco, 1990). Water from the runoff area can be directly applied to the crop (runon) area by "flood irrigation" during the rainstorm. Some runoff farming systems can include facilities for storing the collected water in a pond or reservoir for later application to the crop growing area by an irrigation system (Dutt and McCreary, 1975). Other types of runoff farming systems exist but most are a variation of the previously described systems. Of all the runoff farming systems, micro-catchments have the potential for delivering the highest percentage of runoff per unit area of watershed by minimizing the length of run of the catchment area and maximizing the catchment slope (Dutt, 1981). The micro-catchment design also reduces potential soil erosion problems.

While runoff farming has the potential to be an effective crop production system, the practice is not widely used. There are numerous reasons for the limited acceptance of runoff farming systems but the main reasons are associated with system reliability, crop production level, and economics. For any water-development, agricultural-project to be successful at the small farm level there must be a yearly sustainable economic return. Runoff farming systems are highly dependent upon the timing and quantity of precipitation events. Without proper catchment sizing and/or crop selection, the systems can fail or have a low productivity level. Even with properly sized systems, crop failures may occur during periods of extended drought.

----

* Gary W. Frasier, Research Hydraulic Engineer, United States Department of Agriculture, Agricultural Research Service, Aridland Rangeland Management Research Unit, 2000 East Allen Road, Tucson, Arizona 85719

Recently, genetically improved drought tolerant small grains have been developed which can produce grain yields of economic benefit with only the water stored in a 2 meter deep soil profile at the time of planting (Ottman et al., 1988, Ottman et al., 1989). These plants make it possible to utilize runoff farming systems for providing an economic sustainable crop. This paper analyses and discusses an approach for designing and evaluating a runoff farming system for growing of small grains (barley, *Hordeum* sp.) in southeastern Arizona.

APPROACH

Frasier and Scrimgeour (1990), showed that using mean values of precipitation quantities can be very misleading in designing a runoff farming system. Any variability in the timing and quantity of precipitation events is transformed into a variability in the quantity of runoff water collected and available for plant growth (Fink and Frasier, 1975). The success of a runoff farming system depends upon its ability to provide sufficient water in the root zone for use during the growing season.

Frasier (1988), presented a concept for designing the relative size of the contributing area of a runoff farming system for growing barley. This procedure utilized a monthly water balance routine of collected water versus the plant's consumptive water use. The relative size of the runoff area was increased until there was sufficient water to meet the required water demands of the crop. Input data were the mean monthly precipitation quantities and plant water requirements derived from irrigated barley studies. No adjustments were made for precipitation variability, timing and/or quantity, that might occur among years.

This concept was extended with the development of a simulation model for estimating the quantity of available soil moisture with various runoff:runon area ratios and catchment runoff efficiencies. In the model the precipitation and collected runoff fill the soil profile from the surface down for each storm event. To simplify the water balance accounting within the soil profile, the model assumes that the water is withdrawn uniformly from the profile to the rooting depth of the crop at each stage of growth. If the soil profile becomes depleted it is assumed that there is a reduction in plant growth (production) and that the crop would eventually die with extended dry periods. This technique can simulate the interactions of the timing and quantity of precipitation events (actual or based on stochastic probabilities), soil water holding capacities, catchment runoff ratios, crop water requirements, and plant rooting depth characteristics for sustaining crop production.

Initial evaluations dealt with designing a runoff farming system for growing a one-irrigation barley (*Hordeum vulgare* L.) that was developed for use under climatic and irrigation conditions of limited water availability. With a single irrigation which fills the soil profile (estimated to be 100 to 200 mm) near the time of planting, the barley will produce a yield of 2000-3000 kg/ha (Ottman et al., 1988). The barley germinates and produces a plant with as little as 75 to 100 mm of water (personal communication, R.T. Ramage). These water requirements are 50 to 60% less than the normal water consumptive use of barley (Erie et al., 1982). The grain yields are less than would be desired for optimum production, but they are of sufficient size to be economically viable as a sustainable return.

The water requirement characteristics of the barley are a desirable feature for runoff farming applications. Water can be collected and stored in the soil profile prior to seeding. After sufficient water has been stored and the temperature/soil-surface conditions are favorable, the crop can be planted. This permits selecting various cultural practices (fertilizer, seeding rate, time of seeding, etc.) to meet the conditions prior to planting and reduces the risk of an economic loss from planting in times when there is insufficient water to produce a crop.

DESIGN CHARACTERISTICS

The conceptual runoff farming system consists of a series of contour strips with 1 meter wide cropping areas. The upslope water contributing area (catchment) is cleared and compacted on a 5-8 percent slope. For this example the soil is assumed to be a sandy loam with a bulk density of 1.65, a water holding capacity of; 1/3 bar = 18% by weight, 15 bar = 4% by weight, and a usable water holding capacity of approximately 2.3 mm per cm of depth.

The first step was to determine if sufficient precipitation could be collected to fill the soil profile prior to the planting date. The one-irrigation barley does not require any additional water after planting, providing there is sufficient soil moisture at the planting depth to germinate the seeds and provide initial root growth. In southern Arizona, barley is planted in November or December. The summer rainy season starts shortly after 1 July. The runoff farming system must be able to collect sufficient water to fill the soil profile during the period of 1 July through 30 November and store the collected water until needed by the crop.

The evaluation assumes a water loss of 5 mm per week by evaporation from the top 10 cm of soil until the soil moisture level is equivalent to 15 bars (Jackson et al., 1976). It is also assumed that the catchment runoff area requires a threshold rainfall value of 6 mm before runoff occurs (Frasier, 1975b). Runoff efficiencies, after the threshold was exceeded, of 40 and 60% and runoff:runon area ratios of 0:1, 1:1, 2:1, and 3:1 were evaluated. The ratio of 0:1 was included to provide a base for evaluating the effectiveness of additional area in providing soil water.

The simulation used the daily precipitation amounts measured at Tucson, Arizona for the 10 year period 1950 through 1959. Daily rainfall quantities (July through November) were totaled into weekly values, 4 weeks per month for a total of 20 periods per water year. This approach makes the assumption that there is only one rainfall event per week. For each weekly period, the soil water balance was calculated in 10 cm layers to a depth of 300 cm.

RESULTS

The yearly simulated quantities of total water stored in the soil profile for each area/efficiency combination for the period of 1 July through 30 November are presented in Figures 1a and 1b. Assuming that a total of 100 mm of water is required to maintain a viable plant, there were 3 years out of the 10 years when there was insufficient water from the rainfall alone (0:1 ratio). These levels of rainfall would probably not produce sufficient grain to be of any beneficial use. If it is assumed that 150 to 200 mm of stored water will provide a sustainable, economic level of production, then catchment ratios of 1:1 at 60% runoff and 2:1 at 40% runoff would be satisfactory in 8 out of ten years. Similar analysis can be developed for other quantities of required water. It is probably not economically feasible to design a system that would provide a sustainable return every year. Some type of risk analysis should be utilized to evaluate the effect of having a failure due to below normal precipitation quantities.

Since the barley does not require any additional precipitation if planted with sufficient soil water, it is possible to decide if it is worth the risk to plant by monitoring the precipitation and soil moisture accumulated up to the actual planting date. If there is insufficient soil moisture in the profile, the crop is not planted. With this criteria, the crop in this example might not have been planted in the years 1953 and 1956. The cost to the farmer for these two years would only be the maintenance of the runoff farming system. This approach does not provide a crop in the low rainfall years but it does limit the monetary loss to the farmer. Under some circumstances, the system can be enlarged which possibly would reduce the number of years with a complete failure. The added cost for a larger system

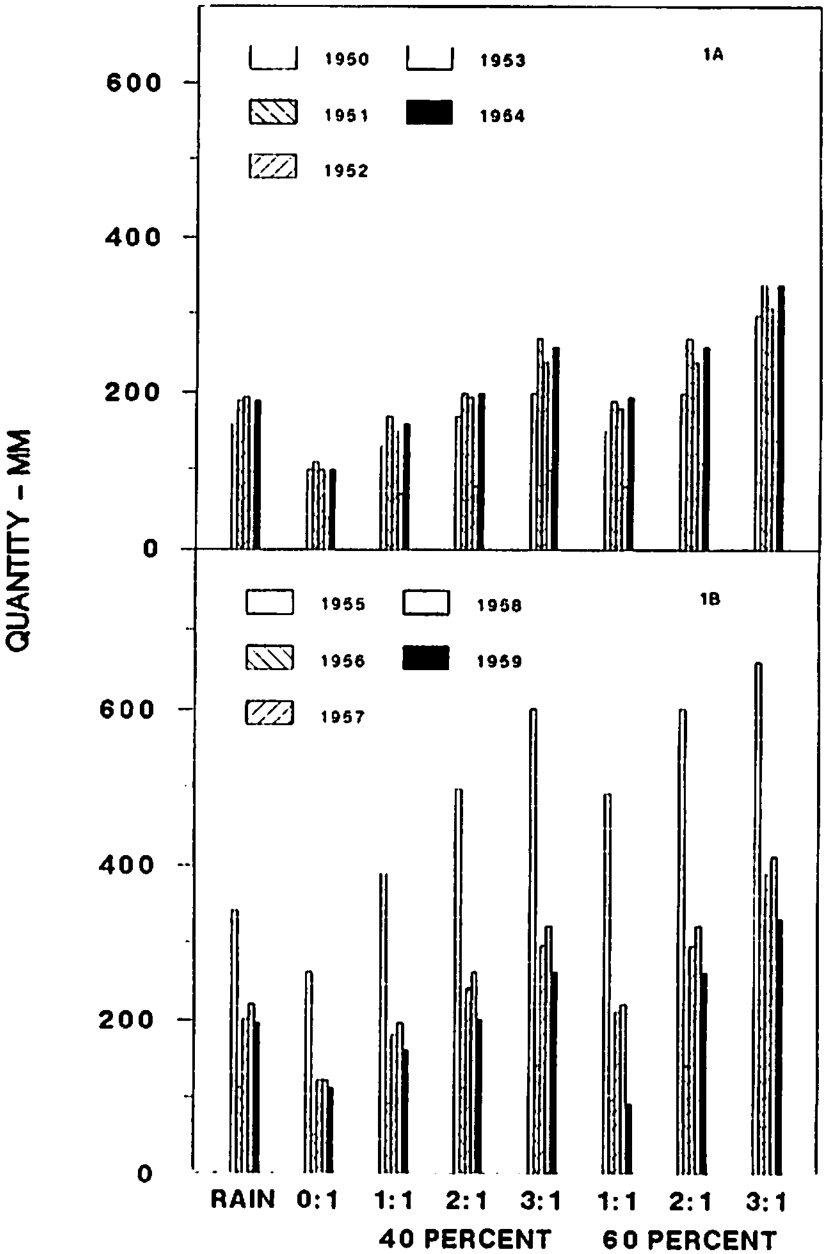

Fig. 1. Simulated quantities of water stored in the soil profile for various runoff:runon ratios and catchment runoff efficiencies using Tucson, Arizona precipitation for the years of a) 1950-54 and b) 1955-59.

would have to be balanced against the benefits of reducing the chances of a crop failure in low rainfall years. This is a decision that must be made at the farm level.

SUMMARY AND CONCLUSIONS

Runoff farming is an alternative to large irrigation projects and offers a means for the local people to gain some independence from Federal money (Billy, 1981). Runoff farming is most successful when the objective is to assure an acceptable and dependable harvest--not necessarily to increase unit yields (Anaya, 1981). Collecting surface runoff water during periods of excess rainfall and using it during subsequent dry periods in the rainy season or early in the dry season markedly decrease the risks involved in rainfed agriculture (Krantz, 1981). The crops selected for use with runoff farming systems should have a relatively low water requirement, be able to survive moderate droughts, be deep rooted to utilize deep stored moisture, and have a high economic (local) value (Mielke and Dutt, 1981).

A simulation model was developed that allows for the evaluation of a water balance in the soil profile. This technique permits the evaluation of the effect of precipitation variability (quantity and timing) on the potential performance of various farming system designs. The approach is illustrated by designing a runoff farming system for growing a low water requirement barley in southeastern Arizona.

REFERENCES

1. Anaya, M.G. 1981. Research Methodologies for Insitu Rain Harvesting in Rainfed Agriculture. IN: Rainfall Collection for Agriculture in Arid and Semiarid Regions, G.R. Dutt, C.F. Hutchinson and M. Anaya Garduno (eds.), Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, United Kingdom. pp. 43-47.

2. Billy, B. 1981. Water Harvesting for Dryland and Floodwater Farming on the Navajo Indian Reservation. IN: Rainfall Collection for Agriculture in Arid and Semiarid Regions, G.R. Dutt, C.F. Hutchinson and M. Anaya Garduno (eds.), Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, United Kingdom. pp. 3-9.

3. Carmona, G. and H.A. Velasco. 1990. Microcatchment Water Harvesting for Raising a Pistachio Orchard in a Semiarid Climate of Mexico. IN: Proc. International Conference on Dryland Farming, P.W. Unger, W.R. Jordan and T.V. Sneed (eds.). Amarillo, TX, 15-19 Aug 1988. 10 p.

4. Dutt, G.R. 1981. Establishment of NaCl-Treated Catchments. IN: Rainfall Collection for Agriculture in Arid and Semiarid Regions, G.R. Dutt, C.F. Hutchinson and M. Anaya Garduno (eds.), Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, United Kingdom. pp. 17-23.

5. Dutt, G.R. and T.W. McCreary. 1975. Multipurpose Salt Treated Water Harvesting System. IN: Proc. Water Harvesting Symposium, G.W. Frasier (ed.), Phoenix, AZ, 26-28 Mar 1974, ARS W-22, Agricultural Research Service, USDA, Washington, DC. pp. 310-315.

6. Erie, L.J., O.F. French, D.A. Bucks and K. Harris. 1982. Consumptive Use of Water by Major Crops of the Southwestern United States, USDA, Agricultural Research Service, Conservation Report Number 29, Washington DC. 40 p.

7. Evenari, M., L. Shanan, N. Tadmor and Y. Aharoni. 1961. Ancient Agriculture in the Negev, Science 133(3457):979-996.

8. Fink, D.H. and G.W. Frasier. 1975. Water Harvesting from Watersheds Treated for Water Repellency. IN: Soil Conditioners. Soil Science Society of America, Madison, WI. pp. 173-182.

9. Frasier, G.W. 1975a. Forward. Proc. Water Harvesting Symposium, Phoenix, AZ, 26-28 Mar 1974, ARS W-22, Agricultural Research Service, USDA, Washington, DC.

10. Frasier, G.W. 1975b. Water Harvesting for Livestock, Wildlife and Domestic Use. IN: Proc. Water Harvesting Symposium, G.W. Frasier (ed.), Phoenix, AZ, 26-28 Mar 1974, ARS W-22, Agricultural Research Service, USDA, Washington, DC. pp. 40-50.

11. Frasier, G.W. 1988. Technical, Economic, and Social Considerations of Water Harvesting and Runoff Farming. IN: Proc. Conference on Arid Lands: Today and Tomorrow, University of Arizona. Tucson, AZ, 20-25 Oct 1985, Emily E. Whitehead, Charles F. Hutchinson, Barbara N. Timmermann and Robert G. Varady (eds.), Westview Press, Boulder, CO. pp. 905-918.

12. Frasier, G.W. and F.G. Scrimgeour. 1990. Supplemental Irrigation by Runoff Farming: An Economic Assessment. IN: Proc. 1990 Watershed Management Symposium, 9-11 Jul 1990, Durango, CO. ASCE, Irrigation and Drainage Division. 10 p.

13. Jackson, R.D., S.B. Idso and R.J. Reginato. 1976. Calculation of Evaporation Rates During the Transition from Energy-Limiting to Soil-Limiting Phases Using Albedo Data. Water Resources Research 12(1):23-26.

14. Krantz, B.A. 1981. Rainfall Collection Utilization in Semiarid Tropics. IN: Rainfall Collection for Agriculture in Arid and Semiarid Regions, G.R. Dutt, C.F. Hutchinson and M. Anaya Garduno (eds.), Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, United Kingdom. pp. 53-61.

15. Mielke, E.A. and G.R. Dutt. 1981. Deciduous Tree and Vine Fruit Production Using Water Harvesting. IN: Rainfall Collection for Agriculture in Arid and Semiarid Regions, G.R. Dutt, C.F. Hutchinson and M. Anaya Garduno (eds.), Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, United Kingdom. pp. 31-43.

16. Myers, L.E. 1975. Water Harvesting--2000 B.C. to 1974 A.D. IN: Proc. Water Harvesting Symposium, G.W. Frasier (ed.), Phoenix, AZ. 26-28 Mar 1974, ARS W-22, Agricultural Research Service, USDA, Washington, DC. pp. 1-8.

17. Ottman, M.J., R.T. Ramage and G.W. Thacker. 1988. Culture Practices of One-Irrigation Barley at Marana, 1988. Forage and Grain, Series P-74, Agricultural Experiment Station, University of Arizona, Tucson, AZ. pp. 47-52.

18. Ottman, M.J., M.D. Sheedy and R.T. Ramage. 1989. Small-Grain Cultivar Characteristics. Arizona Farmer-Stockman 68(1):3.

19. Rawitz, E. and D. Hillel. 1975. Water Harvesting by Runoff Inducement for Irrigation of an Almond Orchard in a Semiarid Climate. IN: Proc. Water Harvesting Symposium, G.W. Frasier (ed.), Phoenix, AZ, 26-28 Mar 1974, ARS W-22, Agricultural Research Service, USDA, Washington, DC. pp. 223-233.