A Way to Make the Desert Green

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Introduction

Man has always relied on plants to directly supply many of his food and fiber requirements. His supply of plant material is dependent upon the amount of solar energy, nutrients and water available for plant growth. In large areas of the world, deficient water resources have restricted the development of intensive crop production.

In arid and semi-arid regions where solar energy is plentiful and nutrients generally available, water is the limiting factor. In Arizona, for example, it is necessary to store water behind large dams or to mine existing groundwater supplies to maintain crop production. The collection of local rainfall as runoff for use on nearby cropped areas offers an alternate and little used means of meeting a crop's water requirements in such regions.

Capturing natural runoff to augment the moisture supplied by precipitation is called water harvesting. Desert Strip Farming uses water harvested from a collector area to help supply the moisture requirements of a cultivated crop on a smaller, farmed area. The technique was used by inhabitants of the Negev Desert of the Middle East prior to the time of Christ to support a population of over 50,000 city-dwelling flood-plain farmers. Water harvesting was also used in northern Arizona by the native Indian population over 1,000 years ago. It is used to a limited extent in isolated areas of Arizona and northern Mexico today.

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Table 1. Predicted yield of grain sorghum for three collector-area to farmed-area ratios for selected years and for selected weather stations in the Tucson area.

Year[1]	*Rainfall*[2] *(inches)*	*Yield (Pounds of grain/acres)* *Ratio* = 8	*Ratio* = 12	*Ratio* = 16
1900 T	3.0	0	0	0
1905 T	0.2[3]	0	0	0
1910 T	7.2	1200	1200	1200
1915 T	6.0	750	1100	1500
1920 T	4.7	450	760	1000
1925 T	8.2	990	1100	1300
1930 U	4.1	440	760	1100
1935 U	0.0[3]	0	0	0
1940 U	7.6	1400	1500	1500
1945 U	4.1	960	1100	1200
1950 C	6.6	1400	1600	1600
1955 C	9.3	2100	2200	2300
1960 C	5.1	900	1100	1300
1965 C	3.6	150	370	590
1970 A	7.5	1400	1500	1500
1970 C	8.6	1900	2000	2100
1971 A	9.7	1500	1500	1600
1971 C	9.1	1600	1700	1800
1972 A	5.4	650	730	810
1972 C	11.9	1800	2000	2100
Maximum yield[4]		2100	2200	2400
Average yield[4]		860	1000	1100
Number of years with crop failure[4]		16	15	14

[1] *Letter following year indicates name of weather station.*
A — Atterbury Watershed
C — Campbell Avenue Experimental Farm
T — Tucson Weather Bureau
U — University of Arizona

[2] *Rainfall is from June 1 until crop is ready for harvest.*

[3] *Crop died during seedling stage. Rainfall is for 20-day seedling stage only.*

[4] *For all years and all weather stations (76 data sets).*

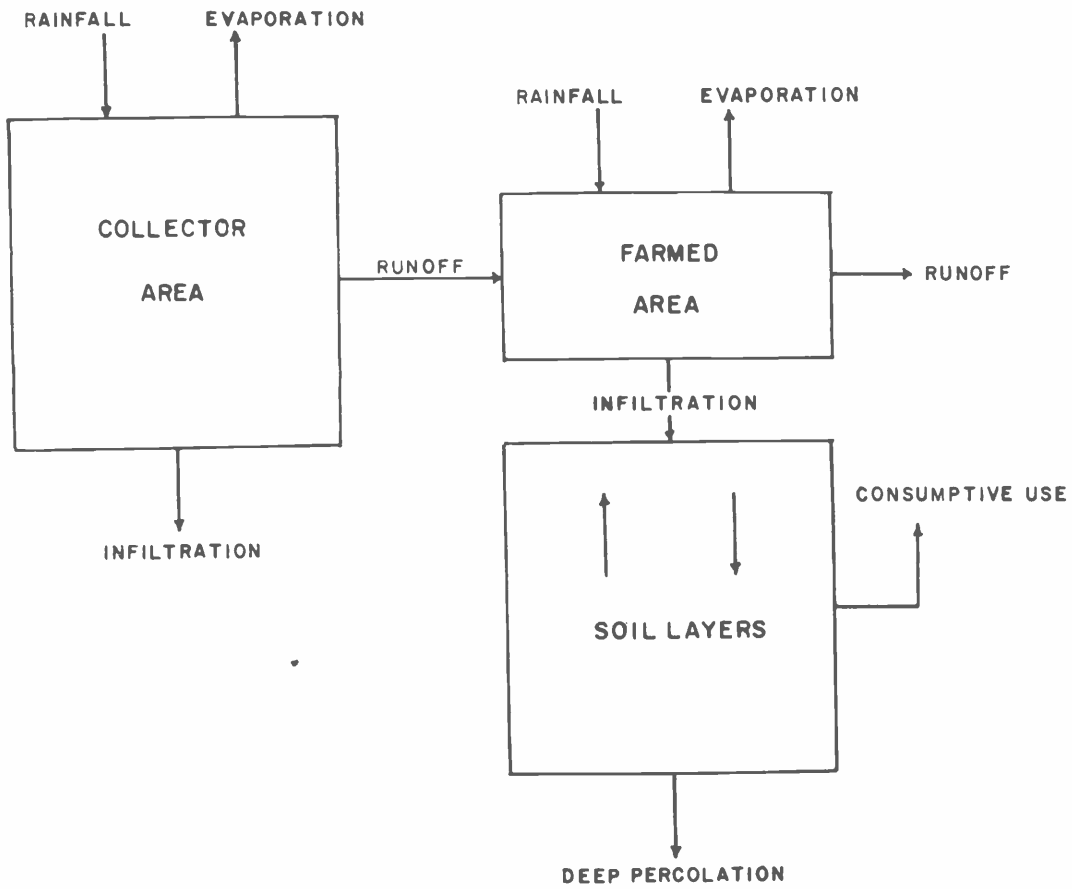

Figure 1. Block diagram at left illustrating the various inputs and outputs which are considered in the Desert Strip Farming model.

Computer Model

To better understand how crop moisture requirements are met by the water-harvesting method of irrigation, researchers in the Soils, Water and Engineering Department at The University of Arizona have developed a computer model of the water supply and crop systems. The computer model considers the various water sources and losses, and the soil and crop characteristics to calculate the yield of a crop (Figure 1).

The water supplied includes actual rainfall and the volume of runoff from the collector area. The losses include consumptive use by the crop, evaporation from the land surface, deep percolation below the maximum root depth, and surface runoff leaving the farmed area. The soil characteristics include moisture-holding capacity and infiltration rate. Crop characteristics include root depth, potential daily moisture needs, drought resistance, and production function (yield versus actual water use).

The computer model has been used to predict the success of the Desert Strip Farming system by obtaining the yield of grain sorghum for several collector-area to farmed-area ratios based on rainfall records in the Tucson area for the years 1900-1972 (Table 1).

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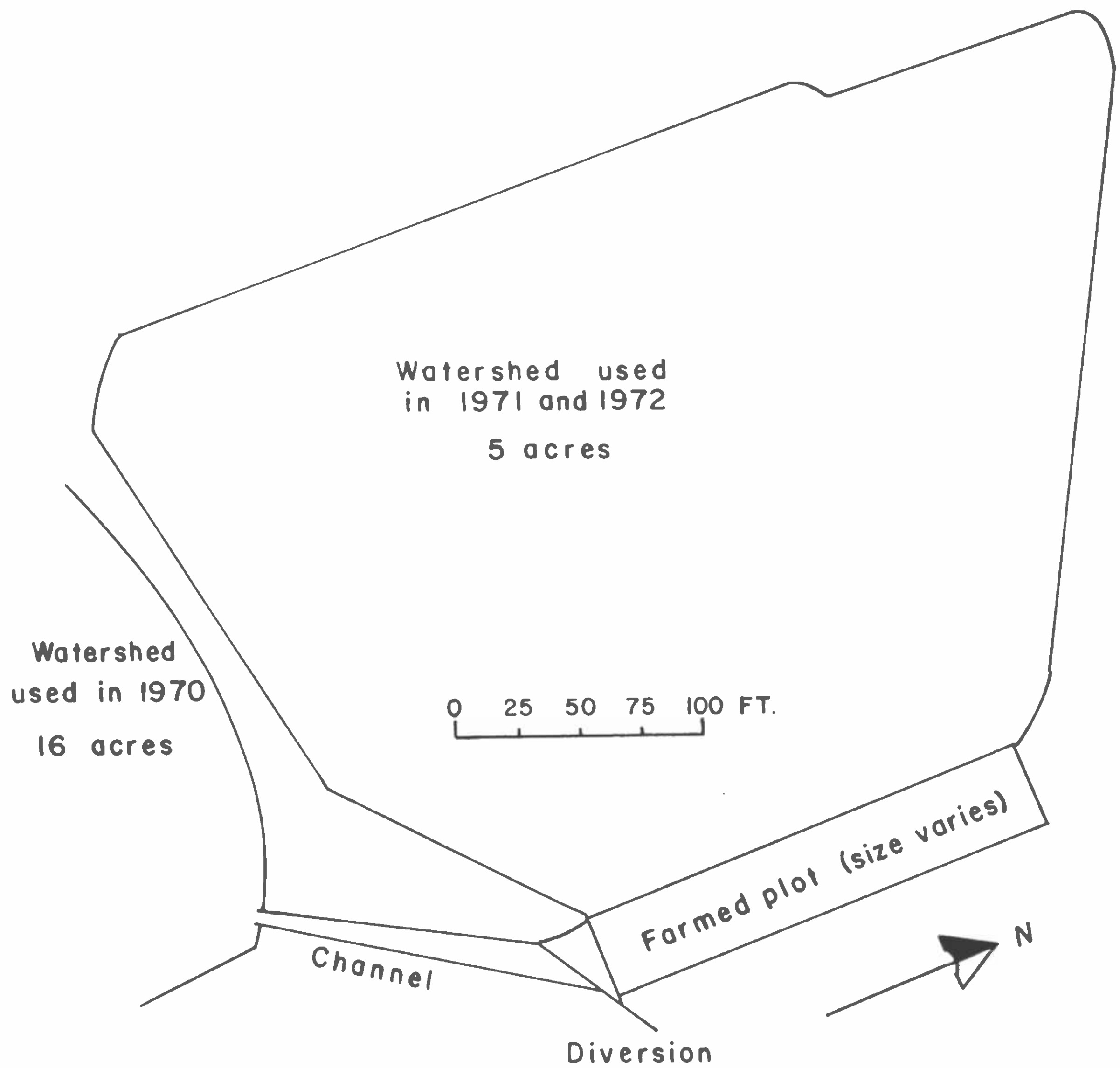

Figure 2. Overall view above showing relative position of watersheds and farmed plots at Atterbury Watershed.

Experimental Verification

To test the validity of the computer program field studies were conducted at Atterbury Watershed (Figure 2), approximately 16 miles southeast of Tucson, and small plots (Figure 3), were established at The University of Arizona's Campbell Avenue Experimental Farm.

The cultivated plots at Atterbury Watershed are located near the headwaters of Atterbury Wash in an area where stockraising is the predominant economic activity. The topsoil throughout most of the cultivated area is a clay loam with a caliche zone

Figure 3. Overall view of cultivated plots at Campbell Avenue Experimental Farm during the summer of 1972.

at a depth of four to five feet below land surface. The cultivated plots are fenced to protect the crop from livestock and rabbits. Soil moisture was monitored by gypsum blocks and by taking gravimetric samples. Rainfall records were obtained from a recording rainfall gauge, and runoff for 1970 was measured with a flume. These instruments are maintained by the Water Resources Research Center at The University of Arizona.

The collector areas were left in their natural state (Figure 4), except for the construction of earthen dikes which directed the runoff water to the cultivated plots. Cattle were allowed to graze in the collector areas which had a stony topsoil and a caliche zone within two feet of the land surface. During 1970, a 16 acre watershed was used for the collector area and the farmed area totaled one-half acre. In 1970 and 1972, a five-acre collector area and one-third acre farmed area were used (Figure 2).

The cultivated plots at Campbell Avenue Experimental Farm were constructed on a level area with a three-foot-deep sandy loam topsoil. Below the topsoil is a gravelly sand zone. Because of the small area available at Campbell Avenue natural rainfall was augmented by pumped water. This water was used to simulate runoff from a catchment area. Soil moisture was monitored by gypsum blocks, by tensiometers, and by taking gravimetric samples. Rainfall records for all years were obtained from a recording rain gauge installed near the center of the farmed plots.

Irrigated short-season grain sorghum, which has an average yield of 4,000 pounds of grain per acre in the Tucson area, was used as the first test crop because of the close correlation between its moisture requirements and Tucson's average summer rainfall distribution (Figure 5). The Tucson area normally receives about six inches of rainfall during July, August, and September. Grain sorghum requires about 24 inches of water to mature, thus a minimum of four times the amount of moisture supplied by the average rainfall is needed for optimum crop development.

Results

Atterbury Watershed

During 1970, there were 7.5 inches of rainfall and a measured total of .66 inches of runoff. Using the collector-area to farmed-area ratio of 32:1, approximately 21 inches of runoff water was supplied to the crop. Thus it received a combined total of 28 inches of water. Dike maintenance was a major problem, especially during the first month of the growing season and an unknown amount of water was lost. Soil moisture measurements and the computer model indicate that the crop water requirements were not met during late July and most of August. The actual yield

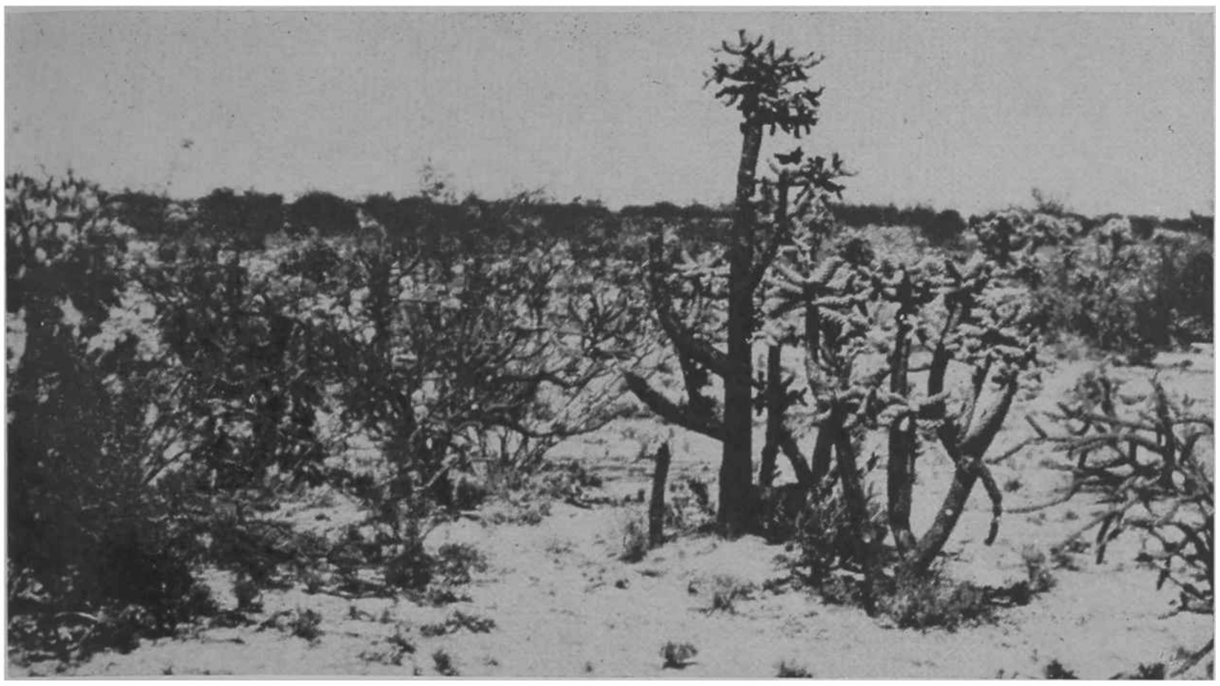

Figure 4. Runoff collector area at Atterbury Watershed.

for the grain sorghum planted at a population of 10,000 plants per acre averaged 1400 pounds of grain per acre and varied between 700 and 2000 pounds of grain per acre. The variation in yield was attributed to uneven delivery of water to the crop and to changes in soil type within the field. The computer model predicted a yield of 1600 pounds of grain per acre for that year.

During 1971, there were 9.7 inches of rainfall and a calculated total of 1.0 inch of runoff. Using the ratio of 15:1 approximately 15 inches of runoff water was supplied to the crop. Thus the crop received 25 inches of water. Soil measurements and the computer model indicated that crop water requirements were not met during the last half of August and most of September. However, these measurements and calculations indicated that soil moisture conditions were very good during the critical seedling stage of the grain sorghum. The actual yield averaged 1800 pounds of grain per acre and varied between 700 and 3900 pounds of grain per acre. The variation again resulted from uneven water delivery and differences in soil type. The computer model predicted a yield of 1500 pounds of grain per acre.

During 1972, there were 5.4 inches of rainfall and a calculated total of 0.60 inches of runoff. Using the ratio of 15:1 approximately 9 inches of runoff water was supplied to the crop. Thus it received 14 inches of water. Soil moisture measurements and the computer model indicated that the crop water requirements were completely met for less than a week during July and August. In addition, these measurements and calculations indicated very poor moisture conditions immediately following the seedling stage. The actual yield averaged 450 pounds of grain per acre and varied between 0 and 1000 pounds of grain per acre. The computer model predicted a yield of 750 pounds of grain per acre.

The results of 1970, 1971 and 1972 tests for Atterbury Watershed are summarized in Table 2.

Campbell Avenue Experimental Farm

During 1970, there were 8.6 inches of rainfall. Of this total, approximately 6.5 inches of rainfall was multiplied with simulated runoff water. One plot which had a rainfall multiplication factor of four, received 28 inches of water, the other plot, which had a multiplication factor of six, received 40 inches of water.

For both plots soil moisture measurements indicated that the crop moisture requirements were satisfied with the possible exception of mid-July. Because of heavy bird damage, yields were difficult to estimate. The yield of the first plot was estimated to be 3100 pounds of grain per acre. For the second plot the yield was estimated to be 3200 pounds of grain per acre. The computer model predicted 2200 and 2400 pounds of grain per acre, respectively.

During 1971, cultivated plots were constructed which had multiplication factors of three, four, five, and six. There were 9.1 inches of rainfall. Of this total 7.2 inches of rainfall was multiplied with simulated runoff water by the full factor for each plot. One rainfall event totaled 1.9 inches, and was only multiplied by a factor of three for all of the plots. Thus the total amount of water applied to the plots was 27, 33, 40, and 47 inches, respectively.

During the seedling stage soil moisture measurements indicated that soil moisture was deficient. In addition, the measurements indicated stress during late September. As a result, the yield varied from 900 pounds of grain per acre for the plot with a factor of three to 2000 pounds of grain per acre for all other plots. The computer model predicted yield between 1600 and 1800 pounds of grain per acre.

The results of the 1970 and 1971 tests with grain sorghum at Campbell Avenue Experimental Farm are summarized in Table 3.

During 1972, cantalope, watermelon, cucumber and zucchini and Mexican squash were planted. Rainfall of

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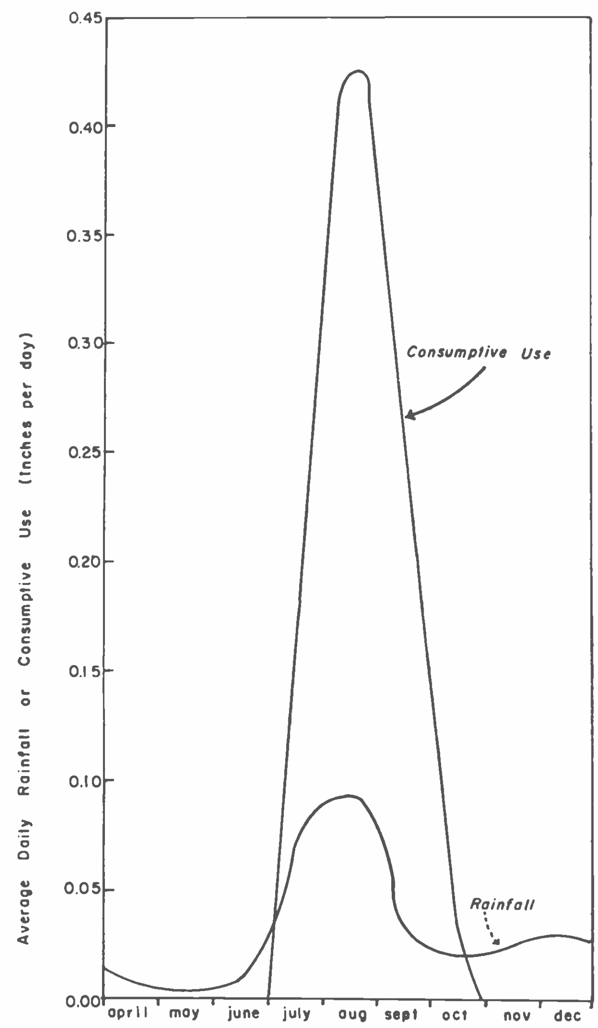

Figure 5. Correlation between grain sorghum's moisture needs and Tucson's normal rainfall distribution.

Table 2. Comparison of actual and predicted yield of grain sorghum at Atterbury Watershed for the 1970, 1971, and 1972 growing season.

Year	*Collector-area to Farmed-area Ratio*	*Rainfall (Inches)*	*Water Supplied (Inches)*[1]	*Actual Yield (Pounds of grain/acre)* Range	Average	*Predicted Yield (Pounds of grain/acre)*
1970	32:1	7.5	28	700-2000	1400	1600
1971	15:1	11.2	25	700-3900	1800	1500
1972	15:1	5.4	14	0-1000	450	750

[1] *Water supplied to the crop as rainfall or runoff from a collector-area.*

sufficient volume to produce germination did not occur until July 15th. This, plus too deep a planting depth, resulted in poor germination.

All of the plots received approximately 11.9 inches of rainfall and 17 inches of pumped water or a total of 29 inches of water. The rainfall was not augmented with pumped water after October 1 since soil moisture remained near field capacity and any additional water would have been lost as deep percolation.

The zucchini and Mexican squash grew rapidly after germination. However, the zucchini fell prey to the squash-vine borer and only a few immature squash survived. The Mexican squash, although more resistant to the vine borer, also suffered severe damage.

The cucumber, cantalope and watermelon plants developed more slowly than both varieties of squash. The cucumber maintained a long period of productivity and had a high yield. Production of cantalope was good; however, more fruit were left in the field than were harvested because they did not mature. Watermelon yield was highly variable with many fruit not maturing.

The late rainfall resulted in uneven germination and prevented maturity of the crop. These factors reduced yield and resulted in greater variation between the plots than would normally have been expected.

Discussion

Desert Strip Farming is a method of increasing agricultural productivity in arid and semiarid areas of the world by using water harvesting to augment rainfall. It is not competitive with irrigated agriculture. A digital computer program was developed to predict the success of the method in regions of the world where rainfall patterns and soil characteristics are known. Data for several stations in the Tucson area indicated that for a collector-area to farmed-area ratio of 12, there will be appreciable production of grain sorghum in four of five years. Only a very small improvement in the success rate can be expected for larger collector-area to farmed-area ratios.

Field experiments at Atterbury Watershed tend to confirm the validity of the computer model. The results from Campbell Avenue Experimental Farm are slightly less conclusive. The use of a different root development function which allows for a more rapid and extensive development of the root system may be necessary for that location.

Other problems with the computer model are that it predicts drying of the soil more rapidly than the actual field measurements show and a determination of how much weight soil moisture conditions during the seedling stage should be given to the production function is not completed. The results from the field tests indicate that having good soil moisture conditions as the crop germinates is an important factor in the production of a successful crop.

The computer model and the field studies indicate that regardless of the collector-area to farmed-area ratio, the yield will be highly variable from year to year and that crop failures will occur in certain years because of poor rainfall distribution.

The experiment at Atterbury Watershed points up an advantage of leaving the collector area in its natural condition as it can be used in its traditional manner, i.e., livestock raising while the crop is being grown. If the crop is a failure, only a small amount of land is lost to the livestock raising activity. If a crop is produced, then the land has been successfully used for both economic activities.

Future project work will include improving the computer model as a predictor of success, identifying other crops which can be successfully grown with the Desert Strip Farming system, and further field tests.

Table 3. Comparison of actual and predicted yield of grain sorghum at Campbell Avenue Experimental Farm for the 1970 and 1971 growing seasons.

Year	*Multiplication Factor*	*Rainfall (Inches)*	*Water Supplied (Inches)*[1]	*Actual Yield (Pounds of grain/acre)*	*Predicted Yield (Pounds of grain/acre)*
1970	4	8.6	28	3100	2200
1970	6	8.6	40	3200	2400
1971	3	9.1	27	900	1600
1971	4	9.1	33	2000	1700
1971	5	9.1	40	2000	1700
1971	6	9.1	47	2000	1800

[1] *Water supplied to the crop as rainfall and pumped water.*