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DESERT STRIP FARMING: A MODIFIED DRY FARMING METHOD USING RAINFALL MULTIPLICATION

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SUMMARY:
Rainfall multiplication permits crop production in dry regions with suitable soils and climate. A computer model predicts possibility of success for the system in areas of known hydrologic and soil characteristics. Field test plots were installed on a Southern Arizona Watershed using grain sorghum.

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DESERT STRIP FARMING: A MODIFIED DRY FARMING METHOD USING RAINFALL MULTIPLICATION

W. G. Matlock and P. R. Davis*

Introduction

Since the beginning of recorded time, man has cultivated plants to supply him with food and fiber. Of the three constituents for plant growth -- energy from the sun, a fertile soil, and a dependable supply of water -- only the energy of the sun is found in abundance through the temperate and tropical zones. Civilizations developed in the areas which had arable soil and ample water. As the population increased additional productive land was needed. This problem still exists today. Suitable soil is easily found, for vast areas of the earth's surface are covered with native vegetation of little economic utility. Even arid and semi-arid regions of the world frequently have excellent soil characteristics for intensive crop production, but lack the water necessary for maximum utilization of watershed resources. For example, more than ninety per cent of the precipitation that falls on Arizona returns to the atmosphere as non-beneficial evapotranspiration, most of it from desert areas. Yet these same desert soils are highly productive, given adequate water.

Two alternatives are available for cultivated agriculture in the desert: either water must be imported from an area of surplus, or some means of concentrating or multiplying the limited rainfall must be found. The latter is usually more feasible from an economic standpoint since transporting water over long distances is extremely expensive and wasteful. By increasing the effectiveness of rainfall, man can produce crops in areas previously believed to be unsuitable because of water shortage.

The Desert Strip Farming Method

Increasing runoff to augment the existing water supply is called water harvesting. Desert Strip Farming is a modified dry-farming method which uses water harvested from a collector area to supply the needs of

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crops on a smaller area in a semi-arid desert environment. Although only a low percentage of rainfall reaches the major stream channels in such regions, considerable runoff occurs on the gently sloping lands above the river bottoms. Immediate on-site water use eliminates the losses usually inherent in collection, storage and distribution.

An artist's concept of Desert Strip Farming is shown in Figure 1. A narrow farmed area lies at the base of a large collector area. The cultivated area, which is kept small to minimize the distance water must move, may be any width determined only by the operating practices of the local farmers. In underdeveloped countries a one-row cultivated zone may be appropriate while in Southern Arizona the width would probably be determined as some multiple of machine width. The catchment area can be left in the natural state, cleared, treated to increase runoff, or planted to range crops. Surface runoff is distributed evenly to the cultivated area by means of a level border or basin irrigation system. To prevent prolonged ponding on the crop and over-irrigation with subsequent deep percolation loss, the fields are constructed so that only a fixed amount of water can be applied at one time. Any excess runoff spills to a lower lying collector area for a similar system or could be used for artificial recharge.

Previous Investigations

Runoff farming, which is similar to Desert Strip Farming, has been practiced for centuries. In most applications of runoff farming a steep hillside area is used as the collector area and the water is transported some distance to the farmed area. Some types of runoff farming use a fairly complex distribution system. The distance water is transported before application to the crops is a fundamental difference between the two systems.

Ancient runoff farming sites were reconstructed in the Negev Desert of Israel several years ago.[1] Normal rainfall in this area is only 100mm, but despite problems with uneven distribution of water, crop production was possible in several experimental areas. Smaller catchment areas were used for orchard crops. Studies of runoff farming are also being conducted in Northern Mexico.[2]

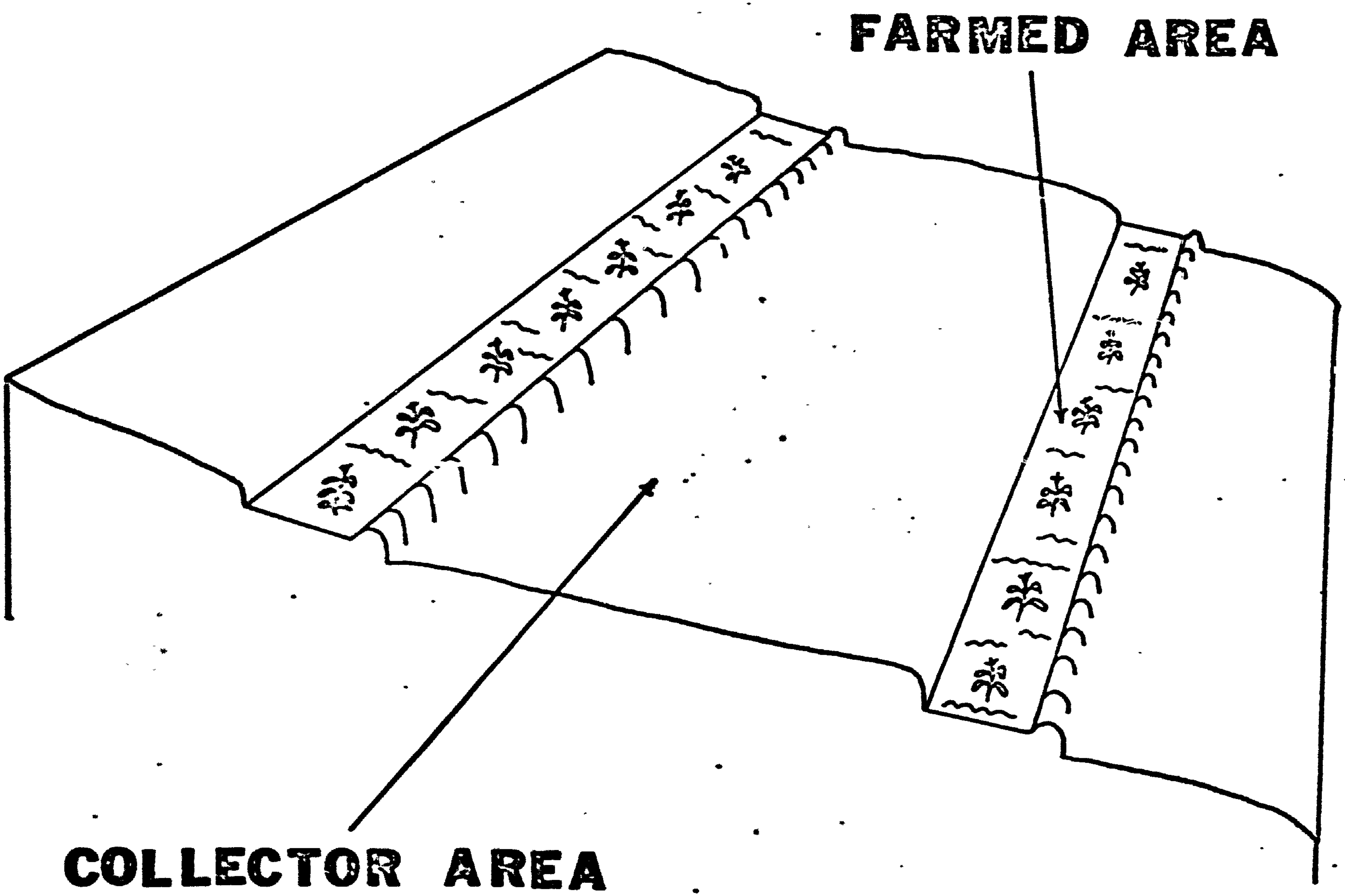

Figure 1. Artist's Concept of Desert Strip Farming

The conservation bench terrace developed and tested by personnel from the Soil Conservation Service in several states is also similar to Desert Strip Farming in that a level area or bench is constructed below a naturally sloping area.[3] They are used in areas of generally higher precipitation including some snowfall and were tested with perennial forage crops on the bench and conventional dryland cropping on the contributing slopes. Storage of winter moisture is thus an important factor. No appreciable benefit has been noted from varying the size of the contributing area.

Model for Desert Strip Farming

A conceptual model was developed to determine the most successful crop and ratio of collector area to cropped area for any region of known hydrologic and soil characteristics. Referring to the block diagram of the model shown in Figure 2, rainfall from the collector area produces runoff which is added to the direct rainfall to make the available supply for the farmed area. Immediate losses are to evaporation and excess runoff. Infiltration provides soil moisture in layers 1 to n. Excess soil moisture goes to deep percolation loss. Extractions from the soil moisture reservoir are made by evaporation when no crop is growing and by consumptive use (evaporation + transpiration) of the plants. The accuracy of the model in representing the real system is limited only by the accuracy of the equations describing the individual moisture transfer processes and the values of the parameters.

The equations of the model basically deal with the conservation of matter and are essentially arithmetic in nature. For the most part, the mathematical model is a bookkeeping operation.

The information necessary as input for the model is: 1) rainfall: time distribution, actual or that with some probability of occurance; 2) runoff: relationship to rainfall and soil infiltration; 3) evaporation; 4) soil: infiltration characteristics, total depth, layering, water storage capacity; 5) crop: drought tolerance in seedling and growing plant stages, consumptive use requirements in time and space, yield vs. actual water use.

In most practical situations all of the desirable input data will not be available and estimates must be used. With real or estimated data

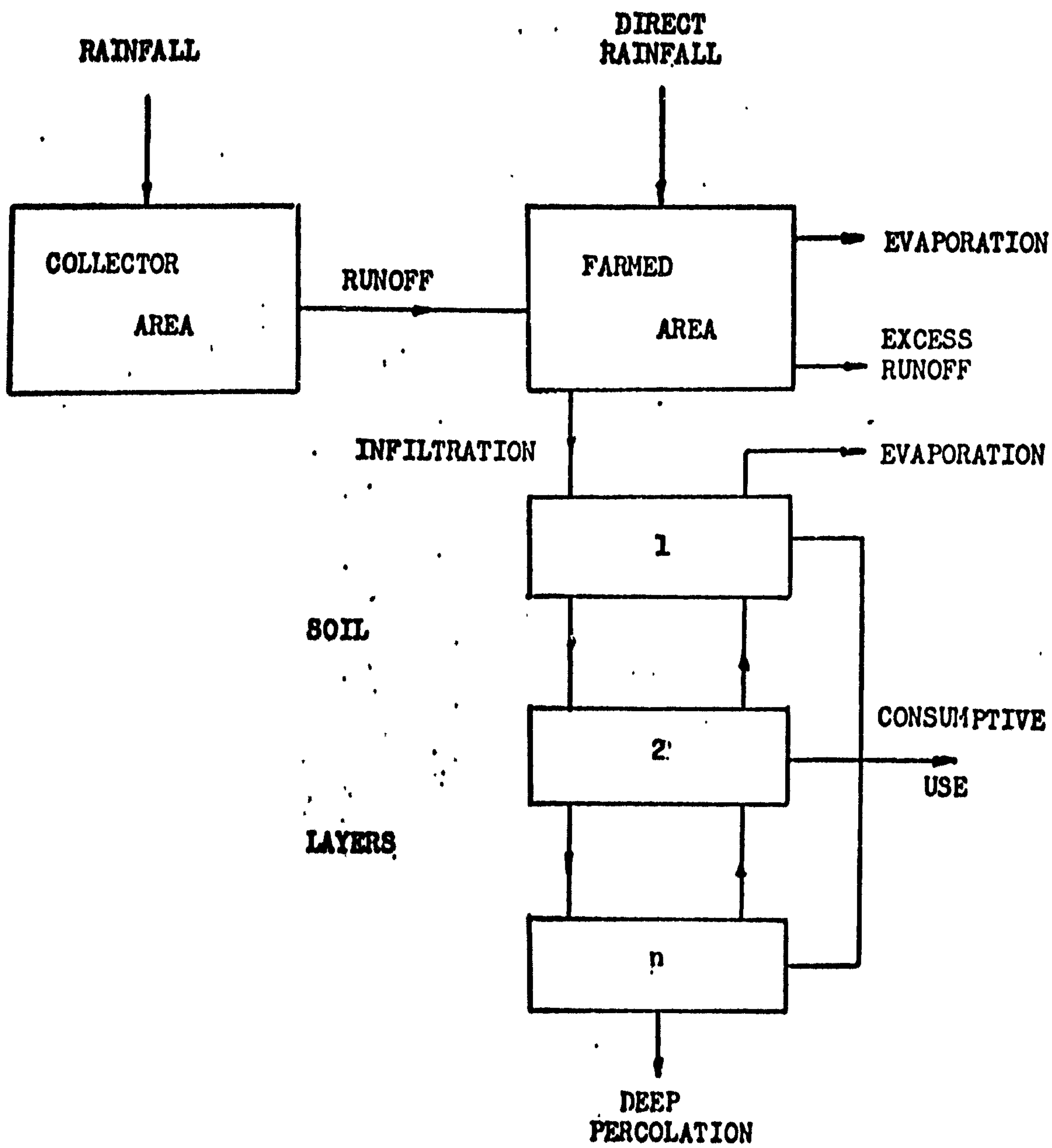

Figure 2. Block Diagram of Desert Strip Farming

supplied, the model can now be used to predict the success of a proposed field operation and to determine the optimum area ratio for maximum crop production.

Computer Program for Testing Model

A digital computer program representing the model was written to permit testing of a large sample of input data. The program begins on a date coincident with the beginning of the crop season and continues until the end of the calendar year cycling repeatedly through a set of calculations until the crop matures or dies, or the program ends. Each cycle represents an arbitrary time period. In the first trials a period of five days was used. This value was believed short enough so as not to overlook any unexpected disturbances in the program while being long enough to greatly simplify the calculation.

An optimum planting date is assigned to each crop used in the program. If sufficient rainfall has not occurred prior to this optimum date, the crop is planted in expectation of rainfall in the immediate future. Should sufficient rainfall occur before the optimum planting date, then the crop will be planted when the conditions are satisfactory for field operations. Once the crop has been planted, it can grow and mature or die as a result of drought. For each time increment the program calculates the moisture input, the consumptive use by the crop, the amount of moisture stored, and the moisture outflow, if any.

If the crop should not receive water for a period of time greater than its drought tolerance, then the crop will die. Two drought tolerances are specified for each crop. One represents the tolerance during the seed or seedling stage and the other represents its tolerance after the seedling stage. If the second, or growing plant drought tolerance, is exceeded, the program continues on the basis that although the crop failed to reach maturity under optimum growth conditions, some benefit will be derived from the partially grown crop.

The available soil moisture for any time increment is water stored in the root zone available to the crop plus the additional moisture from rainfall and runoff. If the available soil moisture equals or exceeds the potential consumptive use by the crop for that time increment, then actual water use by the crop is equal to the potential use and the excess is stored for possible use in the remaining time increments. However, should the available soil moisture be less than the potential use, the actual use by the crop is equal to the existing soil moisture, thus emptying the soil moisture reservoir. If at any time the amount of moisture available exceeds the maximum amount which can be stored in the root zone, then the excess water is lost by deep percolation. When the crop matures, the yield is calculated by a production function with the actual amount of water used by the crop.

Output from the computer includes the totals for the water applied, losses of deep percolation and excess runoff, the actual water use by the crop for each time increment, the status of the soil moisture reservoir before and after water use in each time increment, the yield of the harvested crop, and the needed ratio for maximum production.

The programmed model was first used to determine the possibility of producing grain sorghum near Tucson, Arizona. Grain sorghum was selected as a trial crop because of the close correlation time-wise between the consumptive use curve for sorghum and the average summer rainfall for Tucson. (Figure 3).

Although the model had been simplified somewhat, the results were encouraging. For the particular values of the parameters used in the model, successful crop production would be expected for an area ratio of 13 or greater with average summer rainfall. Figure 4 shows the relationship between area ratio and the total consumptive use by the crop. Doubling the area ratio from 10 to 20 only increased the consumptive use by 20 per cent. The additional water applied was lost by deep percolation and excess surface runoff. Maximum crop production is obtained in the model for an area ratio which supplies sufficient water to meet the needs of the crop in both quantity and time.

Field Validation Tests

Tests are being conducted to determine the validity of the model in predicting successful operation of the Desert Strip Farming system. The first area selected for operation is on the Atterbury Watershed located about ten miles southeast of the City of Tucson in Southern Arizona (Figure 5). The watershed is located largely on the valley slopes and is not ideal for Desert Strip Farming because it is typical of only a limited area and does not have any large area suitable for crop production. However, it does have certain advantages. It is conveniently close and is already instrumented for rainfall and runoff measurements. Other research activities including runoff increasing treatments on the watershed provide regular attendance in the area.

The climatic zone is semi-arid with average annual rainfall of about 11 inches. Summer rainfall of about 6 inches occurs from late June through September. The average slope on the watershed is about 3 per cent. Creosote bush (covillea tridentata) is dominant on the upper slopes with grass in the wide flat channels. The vegetation is very sparse and offers little protection to the soil. Interception is negligible.

A site of about one-half acre was selected just downstream from the runoff measuring flume for a 16-acre sub-watershed now being calibrated for future treatment. The desert growth was cleared and some leveling of the surface was done. The natural channel from the flume was diverted and lined with plastic to prevent any losses in applying the water to the cultivated area. This would not need to be done on a more appropriate site.

Three individual basins were constructed with separate inflow and overflow structures because of the great elevation difference between the ends of the plot. The entire area was fenced to keep out rabbits, livestock and other animals.

Soil samples were taken at several locations and depths and analyzed in the laboratory to provide data on maximum soil moisture storage. Textural classifications varied from sandy loam to clay loam. Infiltration tests were made which showed infiltration capacity of about 0.6 inches per hour. Bouyoucos blocks were installed to monitor soil moisture. Rainfall and runoff data are provided by the cooperating watershed project.

The grain sorghum was planted with a grain drill in cooperation with personnel from the Department of Agronomy who are studying the effect of plant density under conditions of water shortages.

Other sites have been selected at different Southern Arizona locations for future field tests. Similar tests are planned for the State of Ceara in Northeast Brazil.

Conclusions

There are no results on yield or even survival in this first year of field testing. The crop is planted and everything is ready for the advent of the summer rainy season.

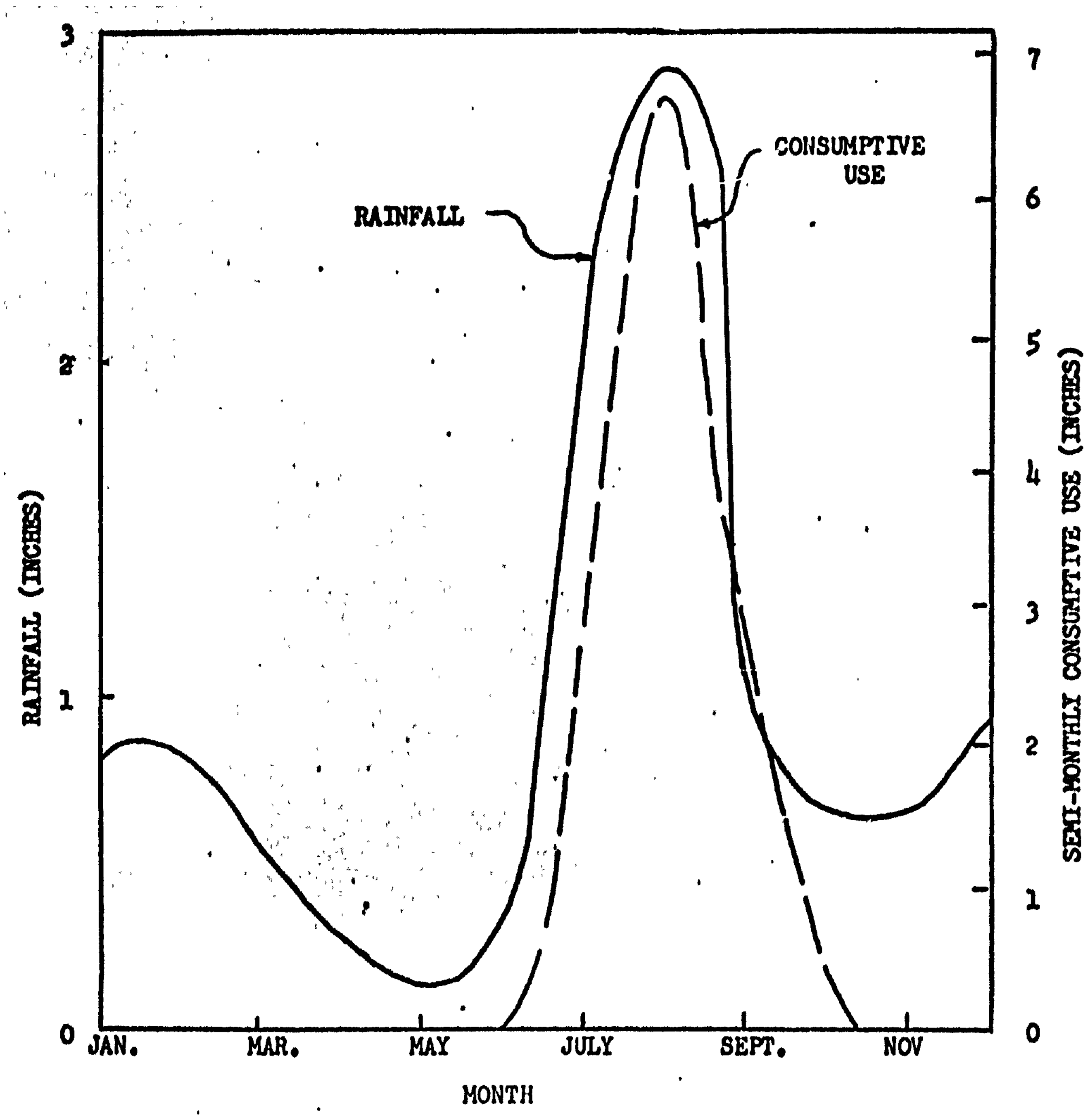

Figure 3. Average Monthly Rainfall and Consumptive Use of Grain Sorghum for Tucson, Arizona.

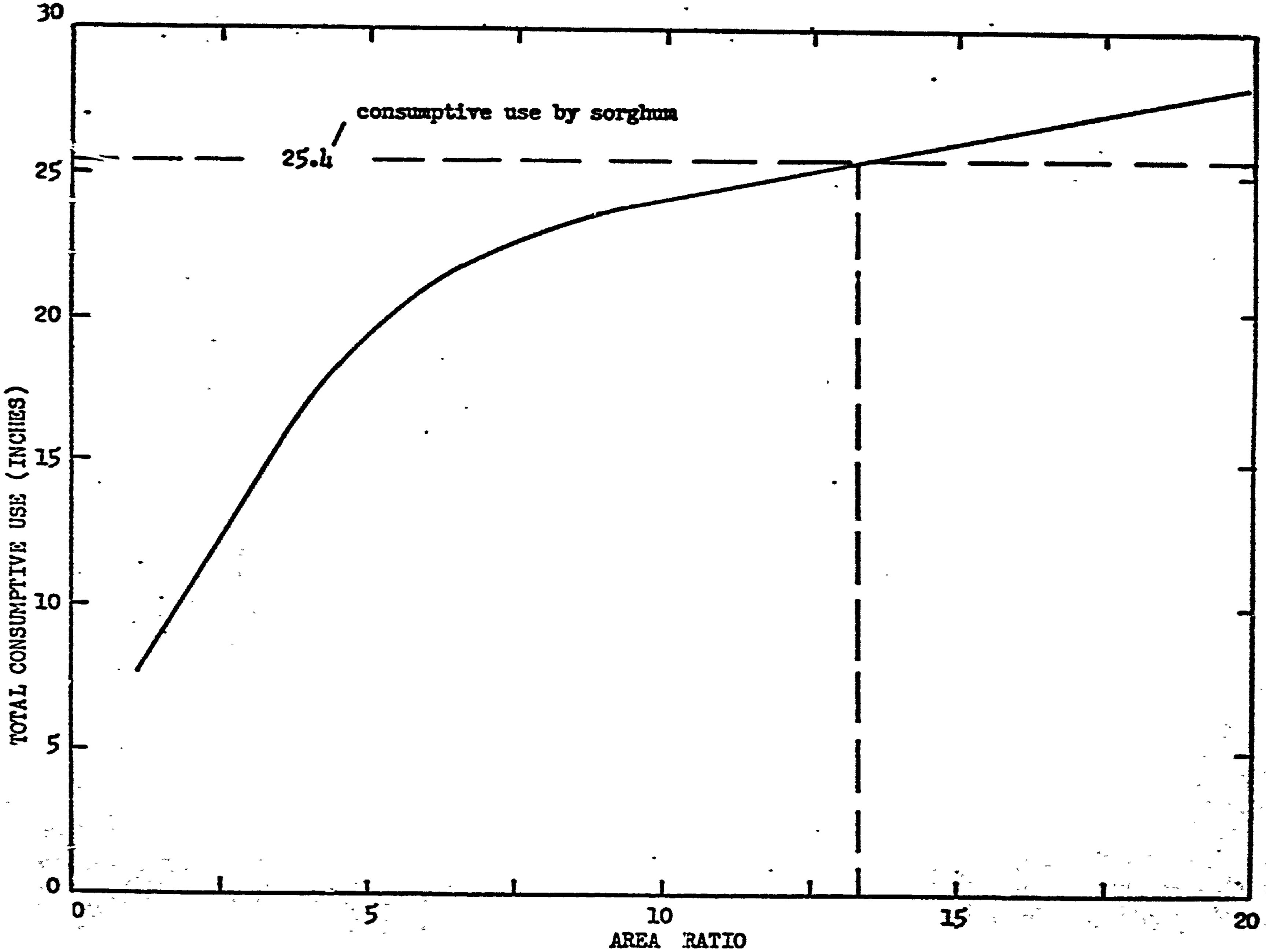

Figure 4. Area Ratio vs. Consumptive Use

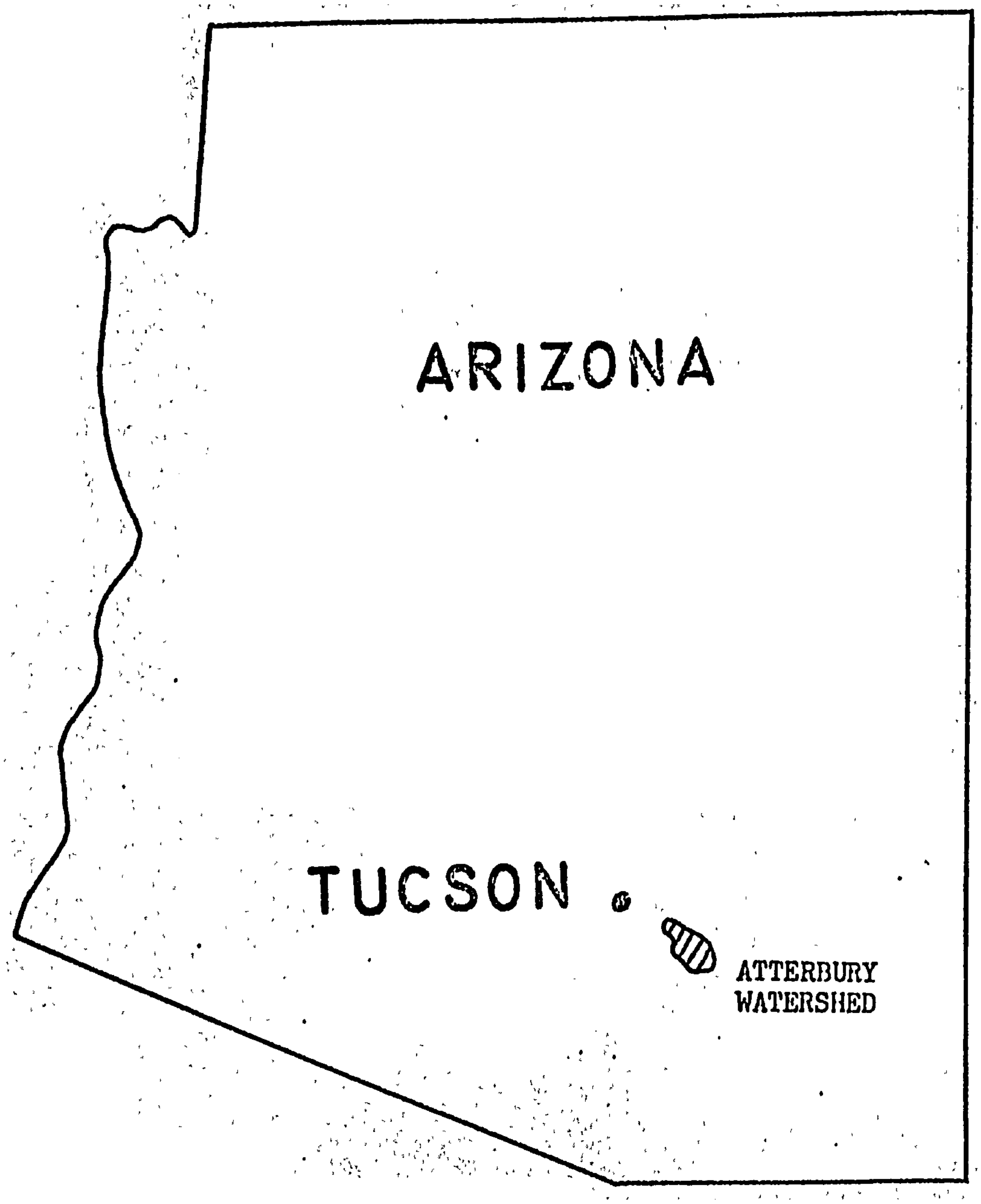

Figure 5. Location Map of Atterbury Watershed

Computer output from the conceptual model suggests successful production for Southern Arizona desert areas with a 13 to 1 area ratio and grain sorghum as the crop. Other areas and other crops with sufficient data can be tested, first by the computer program and then in field studies.

The accuracy of predictions will increase as the equations describing the moisture transfer processes between elements in the block diagram are improved. The assumed values used where data are not complete, are not necessarily invalid. They are based on the "best" estimates, and the effect of corrections in most cases will be minor.

Input data can be markedly improved, particularly as regards the rainfall-runoff relationships for semi-arid areas and the drought tolerance and production function for various crops. Extensive research has been conducted on defining rainfall-runoff relationships for desert areas, but only meager data are available to describe the production of these crops under conditions of limited water supply. Hopefully additional research will be forthcoming in these two areas of vital importance to increasing production in water deficient areas.

Many questions of economics remain unanswered. If present production from the land is negligible any crop production will be an improvement. However, economic evaluation will be necessary before any large scale adoption of the method. The limited production per unit of land is not going to create any vast differences in U. S. agriculture, but underdeveloped areas of unlimited land resources may benefit readily from this production system.

Some farms in the arid Southwest were abandoned when the groundwater levels dropped because of excessive pumping. Crop production might be restored to some of these areas through the Desert Strip Farming concept.

Many cattle feedlots are moving to isolated desert areas in the United States to avoid problems of pollution and waste disposal near the urban centers. A combination of Desert Strip Farming with disposal of manure from feedlots may prove feasible in the near future.

Acknowledgements

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