Economic use of limited water and land resources in cotton production

ECONOMIC USE OF LIMITED WATER AND LAND RESOURCES IN COTTON PRODUCTION

by

Yaaqov Goldschmidt

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SIGNED: Yaaqov Goldschmidt

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

M M Kelso
M. M. Kelso
Professor of Agricultural Economics

July 9, 1959
Date

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CHAPTER I

INTRODUCTION

This study is conducted in Arizona and is relevant to the conditions in that state. The author on the other hand is a citizen of the State of Israel. A problem common to both states brought about the subject for this thesis.

The over-all quantity of water is limited in Arizona as in Israel. By the same token, the situation varies in different areas within a country as follows:

A. Land is limited and water unlimited.

B. Water is limited and land unlimited.

C. Both are limited or unlimited.

Analyzing this problematic situation requires several steps -- (a) analyzing the various situations for each crop, (b) analyzing a farm or an area in which the crops are considered as a composite, (c) finding the proper way to combine the goal of the individual farmer (maximizing income from the resources which are at his disposal) with the goals of the society, which can be in different directions. The goal of the society can be (a) maximizing income from the over-all resources over time, (b) maximizing agricultural production from the over-all resources--as the situation exists in Israel. The practices of the individual farmer in using the water and land which are at his disposal for maximizing his income may come in conflict with the goals of the society. The reasons for such conflict may be (a) different goals, (b) the same resource (water) may be limited to society but not to the individual farmer. Therefore, problems of policy regarding the best use of these resources must be studied also.

In this study only the first step of the analysis--production of cotton in the various situations of land and water supplies--is considered. The other steps are beyond the scope of this thesis.

Usually, the biological and the physical scientists conduct their experiments and make their recommendations in the direction that will obtain maximum yields from a specific element(44). This maximum yield may not be the most economical yield. Experimental efforts usually are directed toward obtaining the maximum product per unit of input--per unit of fixed input in field crops (per acre) or per unit of variable input in animal husbandry (unit of feed). Animal husbandmen also are interested in the production per fixed unit (per animal) but agronomists seldom analyze the average yield per variable unit (water, fertilizer).

These two efficiency goals in combining resources, i.e., maximizing returns to fixed or to variable inputs, cannot be economically efficient at the same time (27, pp. 94-98).

This study tries to find the physical relationship of cotton output to both fixed and variable inputs. Land and water are considered, each at a time, one as fixed and the other variable, or both as variables. The economically efficient point in each case is considered and estimated.

This study is concerned with cotton production. Cotton is considered as the main agricultural enterprise in Arizona. Arizona has the record of the highest average yield of cotton per acre in the United States (over two bales per acre for the entire state). Although the acreage of cotton is held down by acreage allotments, this crop provides 36 per cent of the gross agricultural income of the state, and it uses 31 per cent of the planted acreage (51). On the other hand, this crop is an important young enterprise in Israel. Cotton has a long growing season and it can be produced with various amounts of water.

There are some limitations in studying this crop. (a) Climate and weather are very important factors in the production of cotton. Therefore, the nature of the yield response to water differs among areas and among years. (b) The data available for cotton yields for different levels of water applications are limited. (c) A further difficulty arises because the output from cotton production is composed of two products--lint and seed--which complicates the valuation of the output.

The source of data is experiments in cotton production conducted in the Salt River Valley in Arizona in the years 1954-1958 on fine textured soils with the variety Acala-44. The experiments have been conducted by L. J. Erie and K. Harris of the Agricultural Research Service, U. S. Department of Agriculture, Phoenix (Unpublished Reports, 18).

The review of literature is embodied in the text.

Assumptions.

In this study the following conditions are assumed.

A. The analysis is in terms of income rather than other satisfactions.

B. The practices of cotton production prevailing in the Salt River Valley are assumed such as lack of crop rotation, methods of cultivation, systems of irrigation, altering the soil productivity, weed and insect control, etc. No attempt is made in this study to analyze or to find the more efficient practices concerning use of water or land.

C. No special consideration is given to variations in soil and water conditions such as salinity or hard pan. The regular favorable conditions are assumed.

D. No consideration is given to risk and uncertainty, to interference of management in the irrigation schedule and administration problems, to inadequate capital supply, etc.

E. It is assumed that the farmer has the opportunity and capability of applying the water at the time of his own choosing, in a definite number of irrigations, and in whatever quantity he desires.

F. It is assumed that no acreage allotments exist.

G. It is assumed that a production function in general, even if it is statistically reliable, cannot accurately predict yield response to the variable input for each farmer. The reason for this lies in the specific conditions that each farmer confronts, where many factors, controlled and uncontrolled, vary. Factors that vary among areas and fields and among the years are (1) climate and weather, (2) soil and water type, (3) fertilizer application, cultivation practices, and plant population, and (4) weeds, insects, and disease pests, etc. Hence, it is assumed that the production function must serve only as a guide, and its preciseness is not of major importance.

Procedure.

This study is composed of two parts: (a) a study of the physical production, which includes Chapters II and III, and (b) an economic study, which includes Chapters IV and V.

In Chapter II the water-yield relationships are analyzed. This is a pure agrotechnical study. Attention is given to the production function, to the biological effects of water on cotton plants, and to irrigation problems. It provides a general background to an understanding of the physical relations of water and cotton plants. The consequence of these relations is the production function. In Chapter III the production function is analyzed. The meaning and limitations of the expression of yield response to water are analyzed. This is a transition section to Chapter V. In Chapter IV, the costs of production and the prices of the products used in this study are estimated. Chapter V is the main part of this study. Here the production function (the consequences of Chapter III) and the costs and prices (the consequences of Chapter IV) are incorporated to find the optimum level of production (of irrigation) under the three situations of land and water relationships described earlier in this chapter.

CHAPTER II

WATER-YIELD RELATIONSHIPS

The Production Function

In this step of the study the yield response of cotton to varying quantities of irrigation water will be analyzed. The production function will express the plant-water relationship. It refers to the relationship between the input of factor (resource) services and the output of product. It can be shown arithmetically as a table, geometrically as a graph, or algebraically as an equation. The production function states the amount of output (Y) resulting as one factor (X) is varied in amount, while other factors are held constant in quantity or otherwise do not change cost considerations.[1] This is a purely physical relationship. For economic study, price relationships must be incorporated to find the point on the production function which yields maximum profit.

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[1] Adapted from Heady, E. O. (27) pp. 28-32.

The Production Function for Irrigation

Although irrigation is an ancient practice, scientific approach to this practice is relatively young. In Europe and in most areas of the United States, irrigation is not used. Only 7.5 per cent of the arable land in the United States is under irrigation (30 million acres irrigated out of 400 million acres of arable crop land), although a larger proportion of agricultural production is obtained from irrigated land; therefore, the farmers and scientists have been more concerned with studying other factors of production. However, it seems that where irrigation is practiced, irrigation water is one of the most important factors amenable to control in cotton and other irrigated field crops production. Moreover, it seems that irrigation and its influences on plants are more connected to and in interaction with the other factors than any other single factor of production.

There are many studies of the plant and yield responses to fertilizer application, and many economic analyses of these responses. But similar studies in water application are limited. The farmer's concern, scientific research, and extension work are first directed toward agrotechnic production practices. Only after considerable achievements in agrotechnic practices are obtained is more concern directed to the economic problems of production. This has been the history of studies of fertilizer application and this is the reason for increasing concern in farm management. The same is true for irrigation.

Difficulties in studying the production function for water.

The most important set of difficulties in studying the production function for water arises out of complications of soil, water, plant relationships.

1. The water in the soil is applied by irrigation and by rain, before planting or during the growing season.
2. The water put into the soil may be used by the plant or by weeds. Part of it will be evaporated or lost by deep percolation.
3. The plant uses only part of the water in the soil (the available water). The quantity of available water (i. e., the water-holding capacity) differs according to the soil type.
4. Technical problems in applying definite quantities of water, determining irrigation efficiency (see section; Consumptive Use), and problems in the measurement itself may be overcome by conveying the water in pipes and sprinkle irrigation. There are even problems in this method, however, due to wind and evaporation during sprinkling.

When the measurement of water can be in terms of consumptive use, some difficulties can be overcome.

There are other variable factors associated with irrigation that complicate the study of water quantity-crop yield relationships. Examples of such are: (1) timing of irrigation, (2) rate and kind of fertilization, (3) cultivation practices, (4) climate and weather conditions (temperature, length of season, hail, wind, frost, early rains, etc.), (5) soil and water type, (6) diseases, insects, and weeds, and (7) management problems (labor, crop rotation, availability of water in time, etc.). These considerations and others cause changes in response of production to irrigation among different areas, farms, and years.

Irrigating Cotton in the United States

Most of the cotton in the United States (90 per cent[1]) is produced in the South where the soil moisture is supplied by rain. However, the importance of irrigation exists also in these rainy areas. Many studies show increase in yield when supplementary irrigation was used in the southern states (58). Supplementary irrigation of cotton has expanded greatly in this decade (39).

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[1] In 1956-58 out of 13.7 million acres, 12.4 millions were in the southern states (including Texas). The production in these states was only 80 per cent of the total (9.4 million bales out of 12 million). Rounded figures from Agricultural Outlook Charts 1959, U. S. Printing Office, Washington, D. C., 1958. p. 70.

Under southwest desert conditions, cotton is produced only with irrigation. (These conditions are found in California, Arizona, New Mexico, and parts of Texas and Oklahoma).

The annual rainfall in the cotton-growing areas in Arizona and California range between 3-10 inches. In Arizona it is distributed over the whole year, in California only over the winter.

This rainwater cannot be considered as essential in the production of cotton, and economically it is ignored. All the water needs are supplied by irrigation.

Studies of the Production Function in Cotton

Although the importance of irrigation in cotton production in the southwest is well-recognized, well-controlled studies of the production function (yield response to water) are limited.

No economic analysis of the production function in irrigation was found, and only one discussion of the method for developing production functions in irrigation (19). There are several reasons for the scarcity of such analyses:

1. The high price of cotton lint and relatively low price of water. A relatively small increase in yield will pay for a large additional quantity of water which is applied for getting this small increment in yield.

2. Adequate supply of water for cotton.

   a. Because of the high price of lint, cotton bids water away from other field crops.

   b. Acre allotments limit the acreage planted to cotton on each farm and in the area.

3. The general effort to get maximum yield by scientists, as mentioned before, and by farmers to enhance their prestige. This is especially true in cotton with its artificially high prices on one hand and acreage allotments on the other hand. This has resulted in new practices as skip row planting, a method which wastes resources to society, and in many cases is noneconomic to the farmer (60).

4. The problem of timing in irrigation which is of importance and complicates the study of the best rate of application.

5. The rapid change in cotton yield and agrotechnic practices. In seven years the yield has almost doubled.[1] The large change in practices and yields eliminate the possibility of using former data for this study. For producing the higher yield, the plants

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[1] Up to 1947 the average yield of upland cotton in Arizona was close to a bale (500 lb.) per acre. Since 1954 the average yield is about two bales per acre. Data from K. Harris, ARS, USDA, Phoenix, Arizona. The average yield for California, Arizona, and New Mexico was:

Years:	1936-38	1946-48	1956-58
Bales per acre	1.1	1.2	2.25

Data from Agricultural Outlook Charts 1959, ibid.

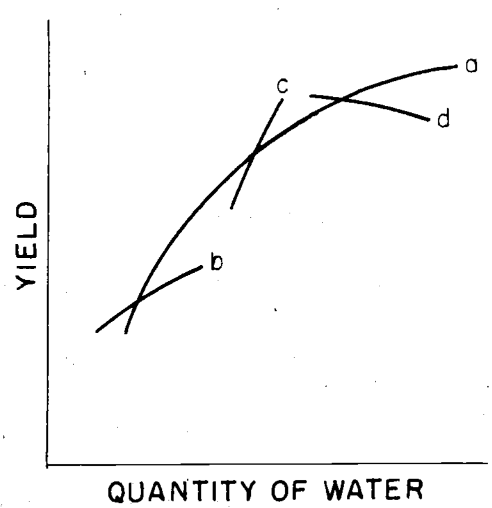
need more water in a longer season. Moreover, the nature of the production function itself is modified. It is well-known that change in practice (change in rate and ratio of the different factors) causes change in the function, e. g., one gets different functions (in nature and height) for yield response to fertilizer under different soil moisture conditions, i. e., the function for fertilizer is changed when different practices of irrigation are used.

The importance of the study of the production function in Arizona increases for several reasons:

1. The over-all quantity of water declines or at least does not further expand in many areas.
2. Costs of water increase with the drop of the underground water level.
3. Possibility for removal or increase of the acre allotments, with the result of declining price for lint and increase in acreage planted to cotton (greater needs for water).
4. Production has reached an apparent temporary stage of equilibrium. No significant change in yield and practices has occurred since 1954.
5. Recent experiments have developed a recommended irrigation schedule which helps to overcome the problem of timing.

Survey of Yield-Water Relationships on the Farms

A farm survey for finding the actual conditions of quantities of water applied and resulting yields on the farms in a community would not give the necessary information. It would give a picture of the situation in the community and general approximations of yield responses to water. It would not give a production function which expresses water-plant relationship (19, p. 7). The large differences among farms, especially in soil and management, would eliminate the possibility of drawing conclusions from such a survey. Suppose a curve like "a" in the following graph is derived.



This does not mean that increase in irrigation will cause higher yield along the curve. This curve may be a collection of points of different production functions. Increase in irrigation by one farmer may cause a smaller increase in yield along curve "b". By another farmer it may cause a larger increase in yield along curve "c", or still in another case, a decrease in yield along curve "d".

Such a survey was conducted in Arizona for different field crops (including cotton) by T. C, Marr in 1920 (40). This pioneer work shows the usual relationship of water-yield expressed in a decreasing additional returns curve.

There are administrative problems in conducting such a survey:

1. Farmers usually do not have accurate measurements, especially of water.
2. There are large differences in irrigation efficiency.
3. The farmer's fear of giving information because it may influence cotton price and production policy.

Effects of Irrigation on the Cotton Plant

This section and other sections to come are introduced as a general agrotechnical background for better understanding of the physical relations to which this chapter is devoted.

Effects on roots

The cotton plant will develop deep roots down to six feet if environmental conditions are favorable: moisture, aeration, soil temperature, plant nutrients, and absence of obstacles (hard pan, toxic effects). In rainy areas, the roots penetrate according to the rain water penetration. In the desert conditions, the upper six feet of the soil is wetted to field capacity by preplanting irrigations of about one acre-foot of water (39).

The practice to stress the plant and force the roots down by delaying the first post-plant irrigation is not well-founded. In an Arizona study (25) a similarity in root development was found by checking the extraction of water from soil depth of two to six feet late in the season between irrigated plants and plants stressed early in the season. In a New Mexico study (23) such delay caused a reduction of approximately 125 pounds of lint per acre. Similar results have been found in Egypt, but in Greece there was no difference in yield (16).

It seems that regardless of the total consumptive use, the proportional percentage used (i.e., the use from different depths) is nearly the same for different irrigation schedules and for different years in Arizona (75% of water in the upper three feet) (18, 1955). A study in Texas (13) shows that the cotton gets water mainly from the second and third foot.

C. O. Stanberry[1] suggests that future research must be in the direction of studying the effects of irrigation on the different characteristics which are responsible for yield, e. g., number of flowers, per cent of boll set, boll size, per cent lint, size (cross section of stem, number and length of branches and stem), and insect damage. The measurement of the ultimate product--lint--does not give enough explanation, because in two experiments the same yield can be obtained from different and contradictory effects on the plant, e. g., high boll set in one case and larger bolls in another case. Only if these detail relationships are known can inductive inference be made to other conditions and places in the world. (Experiments in this direction: 5, 22, 25, 26, 41, 56).

Plant size

Perhaps the most significant effect of irrigation on the cotton plant is on size and height. The more water the larger is the plant. But different studies indicate different correlations between irrigation and height. Some studies show correlation of heights to water application in California (5, 56), but in Yuma, Arizona (22) no correlation is found. It is suggested in Arizona that the general size but not the height of the plant is influenced because after a stress irrigation causes quick terminal growth which compensates for loss of height.

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[1] Personal communications, Univ. of Ariz., Dept. of Agr. Chem. and Soils, Tucson.

It is harder to conclude about the correlation of height and yields. There is an idea that a larger plant will produce a higher yield only to a certain size of plant (or height),but not necessarily in cases where the plant becomes higher. Two studies in California (55, 56) verify this, but a study in Yuma (22) shows no difference in heights but does show differences in yields. On the other hand, a study in Arizona (38) shows a strong correlation between plant height and boll number.

It seems that in most of the cases, a small quantity of water at the early season (growing stage) will build small plants; a larger quantity (but restricted) will build larger plants which have capability to produce a higher yield.

If a farmer has a small quantity of water, he will apply the water less frequently (it is assumed that in each irrigation all the water extracted is placed), his plants will be small, and, consequently, may produce a smaller yield.

Indirect effects

High moisture levels cause more damage by diseases. Early heavy irrigation in California caused severe verticillium wilt and yield reduction (55). In Arizona boll rot is severe in cases of high moisture. Lint quality is also reduced. When the plants are large, good conditions are established for boll rot, insects, etc. In California there were less lygus bugs in the dry plots compared to the wet plots (55).

Insect control is harder and more expensive. Lodging and reduction in picking efficiency also results. With large plants the problem of late weeds and their control is reduced.

Physiological factors

Preponderant accumulation in the plants of carbohydrates over mineral elements and especially nitrogen stimulated blossoming and subsequent fruit production. Abundant soil moisture, if not overdone, is accompanied by high intake of soil plant food. This combination stimulates rapid vegetative growth, which is desirable during early plant growth in order to provide sufficient plant structure for heavy fruiting. Maximum fruiting and rapid growth cannot be accomplished simultaneously; consequently, conditions conducive to rapid plant growth should not be provided during the fruiting period (25, pp. 421-2).

A study in Arizona (25) shows that the plants which grew most rapidly from planting to July 31, and continued growth at a moderate to low rate from July 31 to September 10, were the highest in production. Those plants with slow growth in both periods were lowest in production. Plants making intermediate growth prior to July 31, and comparatively rapid growth later, were intermediate in production.

L. J. Erie[1] found that irrigation until July influences directly the yield of the first pick and that practices stimulating early season

[1] Personal communications, ARS., USDA, Phoenix.

growth up through the first half of July were good practices from a production standpoint.

Another study in Arizona (26) shows that the amount of available soil moisture, through its influence on food conditions within the plants, was a major factor in regulating the fruiting behavior of cotton plants. This study, concerned with the physiological factors affecting fruiting, found the following relations: (1) the osmotic pressure was usually correlated with the available soil moisture, except under certain conditions, (2) relatively high osmotic pressures of the leaf sap were followed by high percentage of boll set, (3) extremely high osmotic pressures brought about by severe reduction in moisture were followed by low boll set, (4) low osmotic pressures were practically always followed by decreased boll set, (5) cambial activity was directly correlated with available moisture, and (6) rapid vegetative growth was accompanied by decreased boll set, probably owing to the lack of sufficient food for vegetative and fruiting requirements.

Flowers and boll set

A study in California (5) shows that when water was applied at 50 per cent available water, the number of flowers and percentage of boll set were higher than in cases of applications at higher soil moisture tension. It seems that highest boll set is achieved with medium irrigation (16).

A study in California (56) shows that only extremes in cultural practices caused changes of 10 per cent in boll set. A large amount of nutrients and water tended to reduce the per cent of boll set; stress tended to increase it. Less frequent irrigation resulted in more efficient boll set.

In Arizona attention was given to the fact that after irrigation the number of flowers fell to a low level. The number increased gradually after the irrigation. In experiments at the Cotton Research Center (Salt River Valley) in 1958, L. J. Erie found in blossom and boll count through the season that the irrigation level affected the number of blossoms but did not affect the per cent of boll set[1], i.e., the higher the number of blossoms (higher level of irrigation) the higher was the yield.

Effects on bolls

L. J. Erie found in 1958 that in the drier treatments the bolls were smaller than in the wet ones.

It seems that more irrigation causes a higher percentage of five lock bolls among the usual four lock bolls (5, 16).

Effects on the growing season

It seems that when more irrigations are applied, the growing season is lengthened, and with it the possibility of higher yields (if

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[1] In all the treatments, 34-35% of blossoms in Acala-44 produced bolls. In Pima S-1 the boll set was 57-61%.

weather conditions permit). In a 1954 experiment in Arizona (18, 1955) the growing season with three irrigations was 182 days; with seven irrigations it was 222 days.

A study in California (5) shows that there was no effect on date of beginning flowering with different quantities of water. Studies in Greece (16) show that irrigation caused late maturity. Lengthening the season and late maturing of bolls may cause danger to the crop in areas of weather and insect hazards.

L. J. Erie suggests that early stresses on cotton plants (before June 15) will cause earlier blossoms, but not necessarily a big first picking.

Lint quality

Since cotton is priced on the basis of lint grade and staple length, these properties are of great importance. Irrigation may influence fiber properties as length, strength, fineness, and maturity. Irrigation influences quality much less than it influences yield. Some studies show contradictory effects of irrigation on quality (16). But no study shows effects of sufficient significance to be considered of economic importance, when regular irrigation treatment is used. Cotton lint produced under irrigation has wide variation in staple length, but average length is greater than it is for unirrigated cotton (24). In Arkansas irrigation improved lint quality (53). There is an idea that because irrigated cotton can be grown under controlled moisture conditions, it is likely to produce fiber which will meet top yarn specifications (32).

A study in California (5) shows small but significant differences in lint quality. When water was applied at 50 per cent available water, the staple was longer than in cases of applications at higher soil moisture tension.

In Arizona (22) and in three locations in California (55), the extremes in irrigation treatments did not affect lint quality materially.

Another study in California (56) shows that irrigation does not appreciably affect lint quality unless extremes in irrigation are considered. Poor irrigation which permits the plants to wilt lowered the quality (35). Excessive water also lowered the quality (32).

Oil content of the seeds

Studies on this question are limited. One study (39) shows that the oil content was higher with adequate moisture than in cotton grown in deficient moisture.

Timing of Irrigation

Timing seems to be an important factor in irrigation. Two variables exist--quantity and timing--which are closely connected and interact in a wide range. It is hard to distinguish and separate them. To a certain degree, timing can affect yield more than quantity.

The irrigation intervals are dependent on: (1) the consumptive use rate, (2) water-holding capacity of the soil, (3) rooting depth of the crop, and (4) the level of available soil moisture in the different stages of plant growth (49).

> Two treatments in which the same quantity of water is applied in the same number of applications, but at different dates, may produce different yields. On the other hand, two treatments in which twice the quantity of water is applied in one as in the other, may produce nearly the same yield if the smaller quantity is applied at critical periods. (45)

This is the case with a determinate plant like corn. It is similar with cotton except that the critical periods are not as sharp as in corn. A study in Texas (8) shows that similar yields were produced with different quantities of supplementary irrigation. The plant requirements for water differ during the season mainly according to the stage of development of the plant and the weather. Levels of water too high or too low in different periods of plant development will harm the plant and reduce yield.

Early and late irrigation

A study in California (55) shows that lack of water in the early stage of growth caused yield reduction due to small plants at the flowering state. On the other hand, it showed that heavy early irrigation resulted in more plants infected with verticillium which caused yield reduction.

In Arizona, early irrigation will cool the soil and retard growth, thus reducing yield significantly. On the other hand, delaying the first post-planting irrigation reduces early boll set and stimulates excessive vegetative growth later in the season, thus reducing yield (5, 25) (see former section, discussion on roots and physiology). Late irrigation (end of September) in Arizona and California does not increase yield (18, 1954 and 56). Late irrigation causes undesired vegetative growth with its consequences and also delays maturing of bolls (16, 39).

Irrigation schedule

The sensitiveness of the plant to water differs in the different stages of its growth. Therefore, different moisture tension (percentages of available water) in the soil are needed during the season. There are critical periods in cereal crops (mainly in the flowering stage) in which shortage of water will affect yield much more than in any other period. Cereals have a short flowering season, but in cotton this period covers two and one-half or more months (16).

There is an idea that "cotton plants should never be allowed to become stressed until most of the bolls have set" (39). On the other hand, there is an idea that a very frequent schedule of applications will cause continuous vegetative growth and low yield. But a study on fine textured soil in California (39) shows that with irrigation every five days, with ample nitrogen supply, the cotton did not become unduly vegetative and yields were not reduced.

A study in New Mexico on fine textured soil (23) shows that except for treatments in which the plants were stressed by delaying the first post-planting irrigation, the total amount of irrigation water affected the yield more than the frequency of applications. The highest yield was obtained by irrigating thirty inches in four-inch irrigations applied as the readily available moisture was depleted from the 6-12-inch depth. It may be that the importance of schedule and the schedule itself differs among areas.

K. Harris and L. J. Erie conducted experiments for many years in the Salt River Valley (fine textured soil) to find the best schedule of irrigation (18, 25, and personal communications). They came out with recommended schedules, mainly for six and three applications. The schedules are given in dates for the given climate (see Appendix).

In 1958 they tried to incorporate measurements of the available water into the timing and schedules. They found that the highest yield was obtained when irrigation was applied when 65 per cent of the available water in the three top feet was used. (Average of the three feet). In the same experiments, over the years, they found that the third foot is a good indicator for such a measurement. It seems that the third foot is the critical zone, since it is the drier one after July 1 on this particular soil (deep fine textured).

As yet, it is not possible to determine the best timing, according to dates, according to different levels of available water during the season, or according to one level of available water (say, 65 per cent). However, these experiments provide very important information for cotton irrigation. The date schedule is applicable in the Salt River Valley. It seems that timing according to soil moisture tension (per cent of available water) will be used in the near future, when the experiments will provide more information, and when farmers will use more widely the soil moisture tension as a guide for irrigation.

The data used in derivation of the production function for cotton-irrigation relations later herein are derived from experiments with the recommended schedules, according to dates (see Appendix).

It is assumed that each irrigation in the schedule is a full irrigation, i. e., that all the extracted water is replaced and the three-foot zone is refilled to field capacity. If a 3-irrigation schedule is utilized, in each irrigation more water is applied than when a 6-irrigation schedule is utilized. When furrow method is practiced, generally each irrigation cannot apply less than about six inches of water at a time.

In a sandy soil irrigations have to be applied more frequently than in heavier soil for the same consumptive use. There will be complications in applying timing recommendations in the field.

Plant as indicator for timing

The time to irrigate can be determined by the appearance of the plant. According to some evidence, withholding water until the plants change color depresses yield (16).

A study in California (55, also 56) points out the possibility of using the plant as an over-all indicator for soil moisture deficiency without reducing yields. In this case the plant integrates many soil and climatic conditions such as soil type, hard pan, salinity, poor water penetration, nematodes, varying temperatures, and other factors which are difficult to evaluate. The color change in foliage is due primarily to the lack of new terminal growth.

Moreover, the irrigation guide in California (35) suggests that irrigation must be applied according to the terminal growth.

> Ordinarily there should be 3-4 inches of tender, green stem between the terminal bud and the reddish coloring of the stalk. An extension of this reddish coloring toward the terminal bud indicates a checking of growth and need of irrigation--before signs of wilting occur, foliage of the plants will have a slightly bluish tinge and in drier spots it appears somewhat darker--serve as a guide to follow.

This color change due to stress affects older leaves also, at least in Arizona.

Management interference

There are many technical and managerial problems which may cause irrigation to deviate from the best schedule or best time. Size of water stream, time allotments by water company, cultivation, insect control, weed seed germination, weed control, labor problems, and many other factors can interfere.

Fertilization

In irrigated and semiarid soils many fertilizer experiments on cotton have shown a consistent response to nitrogen, relatively little response to phosphorus, and no response to potash (1, 41).

The range of fertilizer application is very wide--so are the recommendations. For the Salt River Valley, Arizona, the recommendations for nitrogen application are 50-150 pounds per acre[1]. In soils where deficiencies of phosphorus exist, 50 pounds per acre of P_2O_5. The general recommendations for California (42) are 50-100 pounds per acre of nitrogen.

Cotton following alfalfa seldom needs any fertilizer (42). Experiments in Arizona (9) show no significant difference in yield of cotton

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[1] The recommendations by H. E. Ray for actual nitrogen are: (a) (46) 50-125 pounds per acre in Salt River Valley (in Yuma 50-150, in the higher areas 50-100); (b) (47) 50-150 pounds per acre; and (c) (1) 75-100 pounds per acre (in Yuma more, in the higher areas 30-50).

(1) planted on papago peas as green manure, (2) fertilized with nitrogen in a rate equal to the quantity of nitrogen which was added to the soil by the papago peas, or (3) planted on fallow with 100 pounds per acre of nitrogen fertilizer. But a yield lower than any of the above is obtained from cotton planted after barley as green manure.

On the other hand, experiments show increase in cotton yield when planted in crop rotation compared to cotton grown continuously (33). However, most of the cotton generally is not planted in crop rotation.

In this thesis further reference and analysis will be only to nitrogen fertilizer. Many studies show the yield response of cotton to different rates of nitrogen applications (1, 22, 41, 57) in Arizona and California (42). Some of the studies indicate negative returns beyond a certain level of nitrogen applications. However, the recommendations are roughly according to the applications of nitrogen which produce the highest yield.

Interaction of fertilizer and irrigation

Blaney and Criddle (6) claim that increase in soil fertility will cause increase in yield and increase in water requirements. But increase in fertility, causes a decrease in the water ratio (water needs per unit of crop).[1]

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[1] Further discussion on this point can be found in (54).

W. L. Parks (44) says:

> There are several factors that may affect the fertility level desired for optimum yield when the moisture regime of the crop is controlled. Some of these factors tend to counterbalance others, but considerably more information is needed to determine where the equilibrium point lies. One school of thought is that with an ample supply of available moisture, larger and more rapid plant growth will result, bringing about a need for a greater supply of plant nutrients. On the other side, tending to counteract this increased nutrient requirement, there is a more extensive root system. This enables the plant to feed from a larger volume of soil and results in an increased efficiency in use of nutrients in the soil and of those added as fertilizers. There is a great need for information that will evaluate these counteracting factors.

There is an idea that both schools of thought are right; it depends on the conditions. In a sandy soil, the more water applied the more fertilizer is needed (because of leaching), and there will be interaction. This is not so in heavy soils. In broadcast application of fertilizer it is reasonable that the more water applied, less fertilizer is needed, or at least the same amount is needed. In band application interaction is reasonable.

In Sudan (21), several experiments show clearly the interaction effects of water and fertilizer. Yield increased significantly for nitrogen with increase in the water applied. In the absence of nitrogen the effect of increases in water on yield was very small.

In Yuma, Arizona (22), an experiment on sandy soil shows a significant interaction. The increase in yield due to increase in nitrogen was much larger in the wet treatments than in the dry treatments. On the other hand, another experiment in Yuma (41) on a heavy soil did not show such interaction. Increase in water and increase in nitrogen respectively increased the yield, but there was no significant interaction between them. Still another study in Yuma (20) shows in one year no interaction and in another year some interaction. Different consequences have been found in the Imperial Valley and in Mississippi (3), and in Arkansas (10). A study in Texas (34) shows a highly significant interaction between fertility and moisture level, as is shown in Figure 1. The same data can be plotted for varying amounts of water (Figure 2). If the two curves for 80 and 160 pounds per acre are considered, it is seen that for the low level of moisture 80 pounds per acre are better than 160 pounds per acre. It seems that 160 pounds per acre are detrimental to yield. For high level of moisture, 160 pounds per acre are better than 80 pounds per acre.

In experiments at the Cotton Research Center (Salt River Valley) in 1958 (57), any nitrogen application to the dry plots was detrimental to yield. In the wet plots, 50 and 100 pounds per acre nitrogen application caused an increase in yield.[1]

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[1] The dry plots were given 31 acre inches and the wet plots 66 acre inches as post-planting irrigations. Through a very rough estimate it may be compared to the extreme water applications in the production function in this thesis.

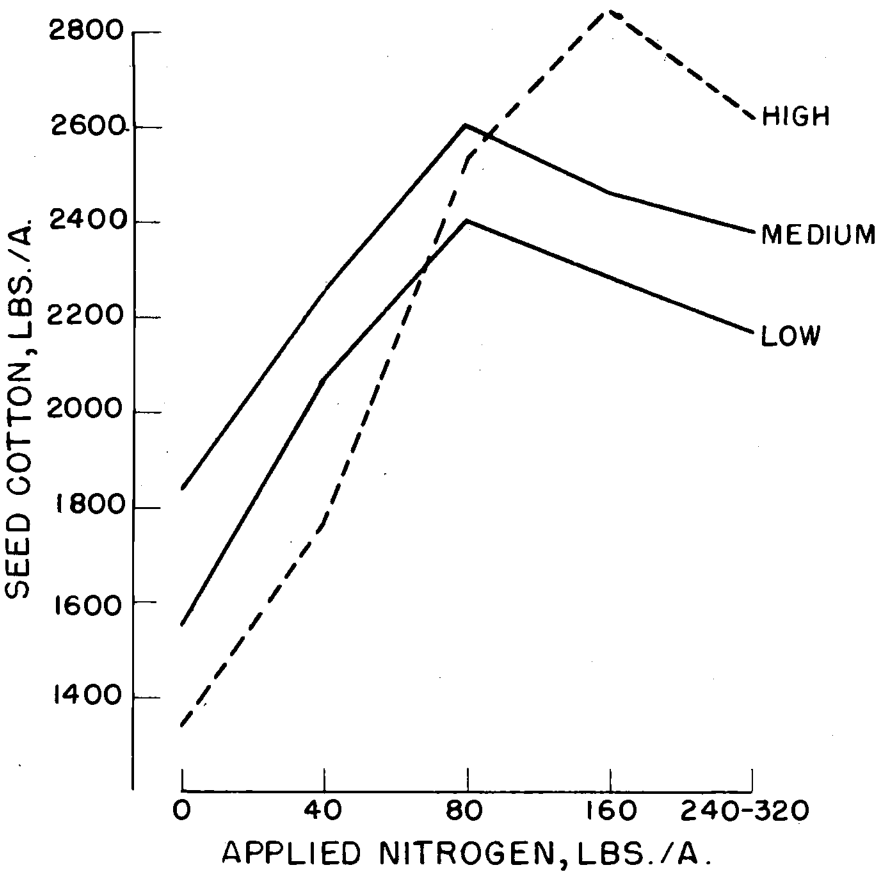

Figure 1. Cotton yield versus nitrogen with three levels of moisture.[1]

[1] Adapted from Hohn, C. M. et al. (36).

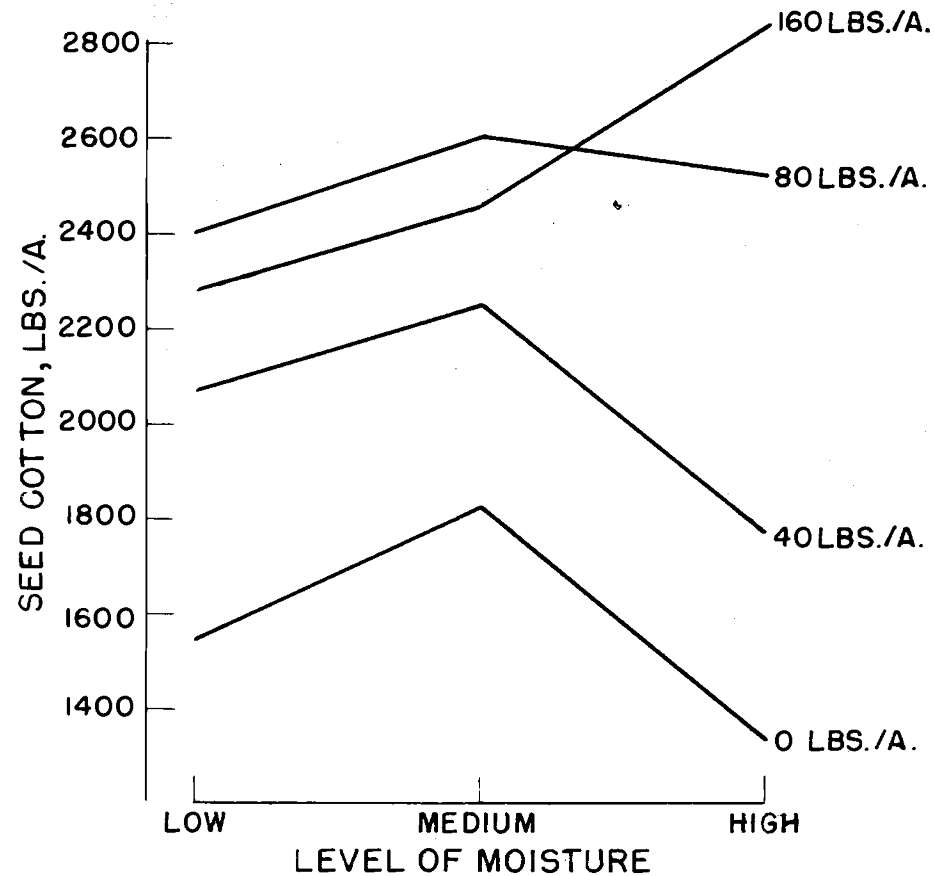

Figure 2. Cotton yield versus moisture level with four levels of nitrogen.[1]

[1] Transformed from Figure 1.

Although no firm conclusions can be drawn from the whole list of experiments mentioned above, they suggest that for the low water applications less nitrogen must be applied than for the high water applications. This seems also to be the practical procedure followed by farmers. The significance of this matter lies in its influence on the cost figure to be established later in this thesis. However, no quantitative figures of this relationship are available. It is assumed that the various practices of applying different amounts of fertilizer do not affect the production function derived later in this study. One can suggest that there is a probability that the high level of fertilization with the low applications of water, in the experiments which provided the data for this study, was detrimental to yield.[1] This probability is not considered here.

Hence, in the cost analysis of this study, a higher level of nitrogen fertilizer for the higher levels of irrigation will be assumed.

Consumptive Use

Consumptive use (evapo-transpiration) is the quantity of water used by the plant for transpiration and building the tissue, and that evaporated from adjacent soil surface. It is expressed in inches per acre. The consumptive use is influenced by: precipitation, temperature,

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[1] In most of the experiments a rate of 100 pounds per acre nitrogen was applied to all the treatments.

humidity, wind, growing season, length of daylight (latitude), available irrigation water supply, soil fertility, and pests.[1] The consumptive use figures are specific for each crop and differ between varieties.

The procedure used for getting the figures of consumptive use in the experiments which supply the data for this study is as follows: Two points five and fifteen inches away from the row are chosen for sampling. This makes possible integration of the soil moisture for the whole zone between the rows. At each point, for each foot of the root zone (six-foot depths) a sample is taken. Samples are taken before irrigation and four days after irrigation. For covering the four-day gap, extrapolation is used. In this soil, no deep percolation occurs.

Blaney and Criddle developed a formula--CU = KxF--whereby the consumptive use for any crop in any period is found by multiplying the empirical consumptive use coefficient (K) by a consumptive use factor (F), which is derived from the average temperature and per cent of daytime hours.[2]

The F factor may be computed for areas for which monthly temperature records are available. The daytime hours are given by the latitude. Then by knowing the K value for a particular crop (and with

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[1] Adapted from Blaney, H. F. and W. D. Criddle (6).

[2] For details see (6) and (7).

allowance for abnormal conditions) for some locality, an estimate of the consumptive use by the same crop in some other area may be made by application of the formula.

Consumptive use and K value figures

Consumptive use varies: (1) in history, (2) among areas, and (3) according to the quantity of water applied. The K value varies according to history and to the level of irrigation.

The consumptive use for cotton in California, Arizona, New Mexico, and Texas for the years 1927-40 was 23.6-30.3, and the K value was computed to be .58-.63 (6, p. 44).

In Mesa, Arizona, the consumptive use was 31 inches for the years 1935-36 and K was .62 (F = 50) (7), but for the period 1954-58 the consumptive use was 32-49 and the K value was about .59-94.[1] There is a considerable increase in consumptive use and K value, possibly because of the large increase in yields, that have occurred since 1927-40.

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[1] For 1954 $K = \frac{32.7}{44.12} = .74$ (3 irrigations); $K = \frac{47.1 \text{(est.)}}{48.82} = .94$ (6 irrigations). For 1955 $K = \frac{32.8}{48.82} = .67$ (5 irrigations). For 1956 $K = \frac{42.1}{48.86} = .86$ (6 irrigations). For 1958 $K = \frac{32.21}{54.15} = .59$ (3 irrigations); $K = \frac{41.6}{54.15} = .77$ (6 irrigations); $K = \frac{48.97}{54.15} = .90$ (7 irrigations).

Data from (18).

In New Mexico for the period 1951-55 on the average the consumptive use for the highest yield was 23 and K was .65.[1] The yield was 1,185 pounds per acre.

The figures for the K value applicable to Arizona and New Mexico are close.

In Arizona (average of 1954-58, fine textured soil) for the 6-irrigation schedule, the consumptive use was 42 to 47 inches with K = .77-.94. For the 3-irrigation schedule, the consumptive use was 33 inches with K = .59-.74 in two years, and in the other years there is evidence for lower consumptive use figures, which are estimated to be as low as 28 inches. When different levels of irrigation are practiced, different yield, consumptive use, and K value emerge.

Since the consumptive use includes evaporation, the figures for a sandy soil will be higher than for a heavy soil, because more irrigations must be applied in order to supply the transpiration requirements.

Irrigation efficiency

The quantities of water are given as number of irrigations and as consumptive use. Whether the quantity of water is given as number of irrigations or as consumptive use, it has to be interpreted to actual figures of water which the farmer applies to his cotton.

[1] Consumptive use equals irrigation plus rain minus deep percolation which was calculated by the formula, when K = .65 (F = 44). Data from (23).

Irrigation efficiency is the percentage of irrigation water delivered to the field that is available in the soil for consumptive use by the crops (6). This efficiency is affected by: (1) soil type--in sand, deep percolation; in heavy soil, surface runoff, (2) crop--higher for close growing and deep rooted, (3) method of irrigation, and (4) irrigation practice--surface conditions, slope and length of furrows, weeds and other obstacles, rate of application, evaporation during irrigation, etc. In general, field efficiency on heavy soil is 65 per cent (farm efficiency in this case 60 per cent).

In the Salt River Valley, irrigation efficiency is considered as 60-70 per cent (14). It will be considered for this study as 67 per cent, i.e., that each consumptive use figure has to be multiplied by 1.5 to determine the quantity of water that must be applied for this level of consumptive use when the irrigation efficiency is 67 per cent. If there is a different irrigation efficiency in a specific case, another number must be used for the multiplier.

Salinity

Excess of salts either in soil or in the irrigation water requires extra water to leach the salts. Cotton is tolerant to salt (14) and leaching of salts is related only to the problem of accumulation of surplus of salts in the soil. Since this study assumes no saline soil or water, the extra water requirements for leaching salts is not considered.

Limitations of the Data

The number of well-controlled studies of the production function is limited, especially studies of the consumptive use of cotton. In most of the experiments the frequency of irrigation was studied and by applying the inches of water per irrigation, the quantities of water were figured. A study in New Mexico (23) shows that the total amount of water affected yields more than the frequency.

In Arizona, only one set of experiments exists which is applicable to the present conditions of cotton production. The data of these experiments (see Appendix) which are used in this study have the following limitations:

(a) These experiments were set up for many objectives such as best schedule, value of late irrigation, effects of stress, the method of skip row irrigation, and consumptive use. For this reason only part of the treatments (see Appendix) can be used in this study for getting homogeneous data.

(b) The experiments provide mainly data on yields for 3- and 6-irrigation schedules. Data on yields for 4- and 5-irrigation schedules, and for irrigation schedules below 3 and above 6 are scarce or do not exist.

(c) In these experiments the water applied to the plots was not measured (except for Ph 5,1955). Since the water was applied at a very high irrigation efficiency, the quantity of water applied was estimated at six inches per irrigation. For some treatments consumptive use was measured. Also, the high irrigation efficiency enables one to make some rough estimates of consumptive use for some of the treatments but not for all of them.

(d) The data show that the number of irrigations and the consumptive use figures are not always directly related as one might think.

In 1955 the consumptive use was low. In a 5-irrigation treatment that year, the consumptive use was 32.8 inches, the same as the consumptive use in 1954 and 1958 in a 3-irrigation treatment.

In 1958, in a 5-irrigation treatment, the consumptive use was 35.9 inches and in a 4-irrigation treatment the consumptive use was 38.7.

(e) These experiments cover a period of five years. However, the 1957 experiments cannot be used because of error of a laborer. An exceptionally good year with high yield was recorded in 1954. In 1955 a hail storm occurred, which is exceptional.[1] In 1956 an early frost was exceptional (second to earliest in century).

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[1] In 1917-54, no hail occurred during the growing season in Mesa Farm. In Tempe Citrus Farm in 1943-54 it occurred twice (52).

(f) As yet, the quantitative interactions of water-fertilizer are not known. Therefore, in these experiments the same quantity of nitrogen fertilizer was applied to all the treatments. This problem was discussed in the section on fertilizer.

Conclusions and Summary

1. Few studies of consumptive use of water by crop plants and water-yield production functions are available. Needs for such data are increasing.

2. A farm to farm survey of water-yield relationships in a community would not supply useful information for computing water-yield production functions.

3. Irrigation affects many plant characteristics. However, this study considers only the over-all effect of yield.

4. Different levels of irrigation do not affect lint quality sufficiently to include it as a variable in this economy study.

5. This function represents the Acala-44 variety, under the climate and soil conditions of the Salt River Valley, and the agrotechnic conditions of this area. It will be subject to change if any of these conditions change.

6. Timing of irrigation is an important factor. However, as yet it is not known which method of timing is better--by dates or by moisture

tension (the per cent of available water) in the soil. These data used herein are from experiments in which the recommended schedule of irrigations by dates for the Salt River Valley was utilized.

7. This study assumes higher levels of fertilizer for higher levels of irrigation but does not specify the amounts. It is assumed that this will not affect the production function.

8. The yields used here may be considered higher than those obtained by farmers because the experimental plots receive treatments that a large field usually cannot be given. However, in such case, still the same shape of curve is assumed. Hence, it does not affect the analysis at all. It would affect only budget considerations.

9. Consumptive use and K values vary for different levels of irrigation and yields. With three irrigations, consumptive use equals 33 inches or less (28 inches), K = .59-.74. With six irrigations, consumptive use equals 42-47 inches, K = .86-.94.

10. Consumptive use varies among areas; K is similar. In Arizona, consumptive use equals 33 inches, K = .67. In New Mexico consumptive use equals 29 inches, K = .65.

11. To determine the actual quantity of water applied, the irrigation efficiency must be considered. In this study irrigation efficiency is assumed to be 67 per cent.

12. The yields and consumptive use have increased considerably during the last decade.

13. These figures are directly applicable (after consideration of the limitations) to a large cotton production area in the Salt River Valley (125,000 acres). For other areas, only a rough interpretation can be made especially by the use of the Blaney-Criddle formula.

CHAPTER III

ANALYSIS OF THE FUNCTION

Units for the Independent Variable (Water)

There are two sets of the independent variable: number of irrigations and consumptive use figures.

Since it is not known as yet if the timing by dates, i. e., number of irrigations, influences the yield, it is not known which of the figures are to be preferred--the number of irrigations or the consumptive use figures. It would seem that the consumptive use figures should be used, since these are the true figures of the quantity of water which has been used by the plant. (The data of 1958 supports this assumption). On the other hand, the number of irrigations provide only an estimate of the quantity of water used, but it conforms with the farmer's procedure to apply the water according to number of irrigations. (This procedure should be changed, and water should be applied according to the moisture tention -- the level of available water -- in the soil, and may be with modifications according to the timing by dates.) Should consumptive use figures be used, a way would have to be found to interpret them to number of irrigations when recommending to farmers.

A further complication arises from the fact that the number of irrigations and consumptive use figures are not always related directly as mentioned above. Also, the quantity of water applied in one irrigation varies with different irrigation schedules. In a 3-irrigation schedule more water is absorbed by the soil in each irrigation, say 7-8 inches per irrigation. The reason is that more water is absorbed by plants between irrigations, so refilling the reservoir requires more total water. In a 6-irrigation schedule, less water is absorbed in each irrigation, say 5-6 inches.

The production function was derived from data given as yields per irrigation and it is treated as such. Hence, a noncontinuous linear curve emerges (it will be discussed in a later chapter). It has the advantage that recommendations to farmers can be derived directly from this function. Since the analysis must consider also the amount of water applied, it is estimated for the analysis at 30 and 45 inches of water for 3- and 6-irrigation schedules, respectively.

By interpolating, 35 and 40 inches of water are found for 4- and 5-irrigation schedules, respectively. (This is done for the analysis purposes.)

Since the 3-irrigation schedule, or 30 inches of water, is the minimum level of irrigation considered, and the possibilities of applying 3-, 4-, 5-, and 6-irrigation schedules is analyzed, it is necessary to know how much water is added to the total quantity of water by moving from one irrigation schedule to another. Each change from 3- to 4- to 5- to 6-irrigation schedule requires an additional 5-6 inches of water, or roughly .5 foot. Hence, these figures will be used for the analysis to follow, and it should not be confused with the fact that the water applied per irrigation in the different irrigation schedules is not the same amount. The coincidence arises in the following manner. In each irrigation schedule one foot of water is applied as a preplanting irrigation of which it is estimated that roughly nine inches is retained for consumptive use. Then, each post-planting irrigation in each schedule uses a different quantity of water (most in the 3-irrigation schedule and least in the 6-irrigation schedule). By coincidence, the net effect of these variations is an additional five inches of water as one shifts from a 3- to a 4- to a 5- to a 6-irrigation schedule. It may be shown for illustration purposes only as follows:

Total Effective water inches	Pre-Planting Irrigations inches	Post-Planting Irrigations inches	Number Post-plant. Irrigations	Amt. per Post-plant. Irrigations inches
30	9	21	3	7
35	9	26	4	7-
40	9	31	5	6+
45	9	36	6	6

Range of Applications

The lowest application of water is considered as 3 irrigations. Practically no farmer applies less than 3 irrigations and it is doubtful if there is any economic yield below 3 irrigations, which conform with about 28-33 inches consumptive use.

This study assumes 6 irrigations as the highest level of application, the 6-irrigation schedule conforming with about 42-47 inches consumptive use. It is questionable whether a seventh irrigation would increase yield.

Generally, negative returns as a consequence of irrigations appear more quickly in seed production than in forage production, i. e., a certain quantity of water will cause negative returns in a seed crop, while still increasing a forage crop.

The additional irrigation water applied to cotton does not harm the plants by surplus of moisture as such, but may cause vegetative growth in place of fruiting.

As a practical matter to us, it makes no difference whether there are negative returns or yield remains constant when more than 6 irrigations are applied. In both cases there is no increase in yield and the additional irrigations do not pay. Therefore, for this analysis only part of the function is considered; that part between 3 and 6 irrigations. In summary, the range of 3-6 irrigations are considered which are estimated at 30 and

45 inches consumptive use, respectively. Translation of these figures into quantity of water required for irrigation on the farm gives roughly 3.7 and 5.5 acre-feet of water, respectively, when the irrigation efficiency is 67 per cent.

More experiments are required to supply information on the consumptive use requirements and to enable one to compute the production function for yield versus consumptive use more accurately.

Reliability of the Function

The data used for calculating this production function have several limitations as mentioned before. Moreover, in the original data the variations among the years are larger than the variations among the treatments. There are also only a few treatments of the 4- and 5-irrigation schedules. Hence, the function cannot be considered as reliable.

By using all the data available for the years 1954-1958[1], the following second degree polynomial function is derived: $Y = 897.06 + 148.59X - 9.27X^2$, where Y is the estimated yield per acre and X is the number of irrigations. It is represented graphically in Figure 3.

This is the best estimate the data affords, but still it is only a tentative production function. It is called so because (a) the limitations

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[1] For the data, see Appendix.

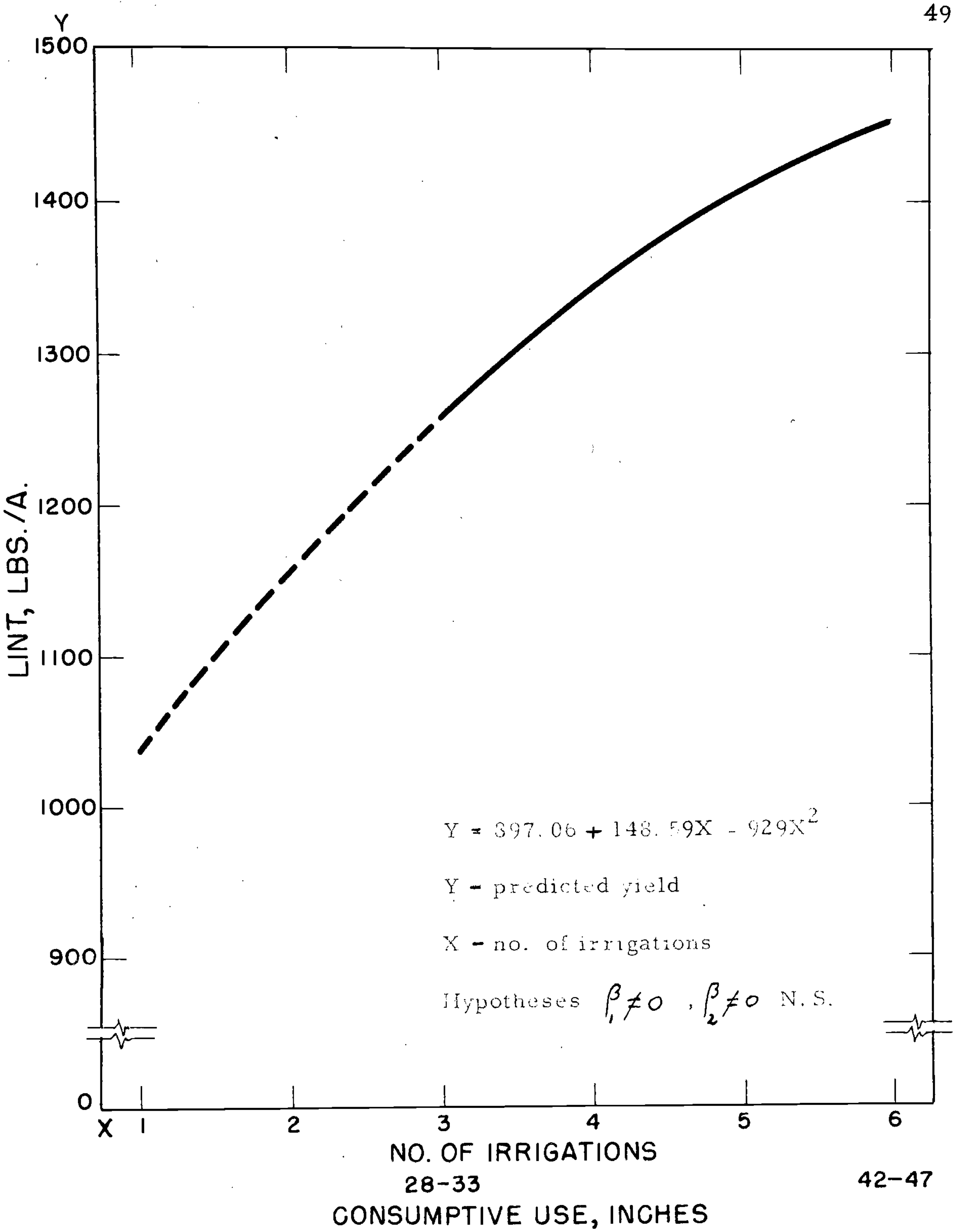

Figure 3. Cotton yield versus water (land fixed at 1 acre).

of the data mentioned, and (b) the function is not statistically significant.[1] More experiments will have to be done to supply more information in order to overcome the limitations mentioned.

Since there are but few treatments for irrigation levels between 3 and 6 irrigations, one cannot know for sure what is the nature of the curve for this range. It may be concave, straight, or convex. However, the general theory which is built on empirical experiments indicates that it is convex, i.e., decreasing marginal returns (as this function shows). If the curve is linear or concave, there is no need for any economic analysis. In these cases the most efficient use of water is when it is applied at the highest level, i.e., six applications (and may be more, since if the curve is concave, increasing marginal returns exist). If the curve is convex, there is need for an economic analysis. The following analysis is founded on this "if", i.e., the assumption of a convex curve. More experiments are required for the 4- and 5-irrigation schedules for increasing the reliability of the nature of the function in this range.

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[1] The hypotheses $\beta_1 \neq 0$; $\beta_2 \neq 0$ are not accepted, i.e., β's do not differ significantly from zero. The reason lies in the large variations in yield among the years (due to weather) for which no adjustments have been made. The yields for 3- and 6-irrigation schedules, respectively, differ significantly in most of the years. r - .11; coefficient of variations - 18 per cent.

This curve is partially confirmed by evidence from New Mexico experiments (23).[1] The yield versus water figures derived from these experiments support the lower part of the curve (shown by the broken line), since the yields and the consumptive use in New Mexico are lower than in Arizona.

Good and Poor Year

It is well-known that under favorable conditions (especially weather) it is possible for plants to take advantage of the different growth and yield factors and so respond with higher yield. It seems that the same relates to cotton, but from the limited data one cannot derive a positive conclusion. However, there are hints that in a "good year" (mainly: long growing season, warm spring, and late fall frost and no hail) the production function is high and steep. In a "poor year" the production function is low and flat.

In the case of cotton, the outcome due to weather is partly known during or even ahead of the irrigating season (temperature of spring, hail storms, etc.). Hence, there exists the possibility that the level of irrigation can be adjusted accordingly.

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[1] Average yield of A--1,517 grown on deep fine textured soil, for 1951-1955 given for inches of water. We adapted it to the estimated figures of consumptive use for the data from Arizona.

If the cotton response is as mentioned above (more data are needed for confirmation), then a flexible model can be adopted concerning the level of irrigation. In the case of a cold spring, it seems that the probability of getting high yield response to irrigation is low. Presumably, the farmer will be better off not to apply the maximum level of water. Moreover, the probability of achieving negative returns by higher levels of irrigation increases. The opposite is true for good weather in the early season.

Mean or Mode as Average for the Function

Since the variations in yields among the years are large, and also because it seems that there are differences in the shape of the curve according to the weather, the problem of which average of annual yields per irrigation schedule to use arises--whether to use the mean or the mode.

Hypothetically, it seems that the use of the mode would give better results for maximizing income over years than the mean. The reason is that the weather is partly known. This is in contrast to the conditions in Oregon, where a study (12) shows that the mean average curve gives highest net income over the years in the use of fertilizer on wheat, where the weather conditions are unpredictable. However, more data and economic analysis of the future data are required for determining which average should be used.[1]

The probability of occurrence of certain weather conditions which influence cotton yields such as hail, early fall frost, etc., need to be determined also. It may be that data from a particular year in which the probability of occurrence of such weather is very low should be dropped from the calculations of the average.

The data for this function covers a period too short for any reliable conclusion concerning which average (mean or mode) to use for construction of the yield response curve. Practically, the only possibility is to use the mean curve. Out of five years, three years had exceptional weather conditions. In 1954 the yield was pulled up; in 1956 it was pulled down, but it is not possible to weight each year according to the probability of occurrence of such exceptional weather.

Elasticity of Production

One study (22) shows that most of the experimental data for cotton yield response to water has an elasticity larger than one. It found that all points fell between two free-hand drawn curves of the shape.

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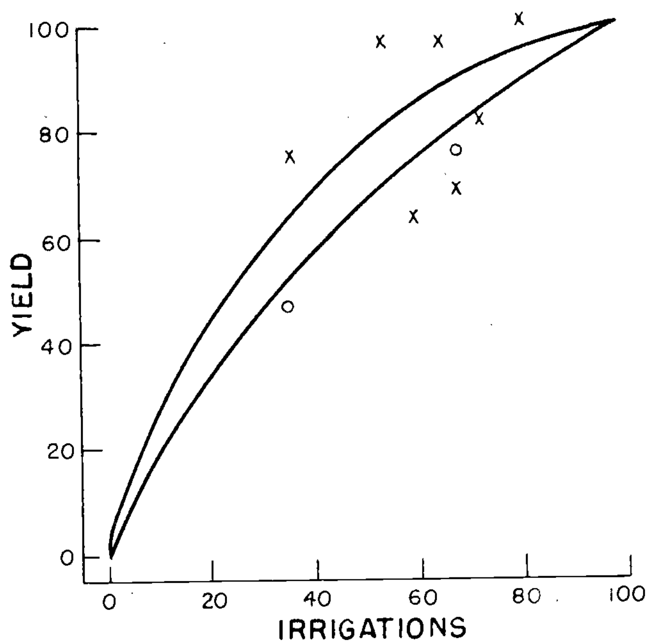
[1] For elaboration, see (12, 27 - p. 486-489, 28 - p. 8).



However, later experimental data and the particular data used in this study do not follow this shape. The points fall outside and to both sides as indicated. Points from the function derived in this study are below the lower curve as indicated by circles.

Conclusions and Summary

1. The production function is a result of data from five years which were averaged to a mean (see Appendix).

2. The function is $Y = 897.06 + 148.59\ X - 9.27\ X^2$.

3. This is a tentative function. Because large variations in yields among the years (due to weather) and other limitations that the

data exhibit, the function, statistically speaking, is not significant. However, this is the best possible estimate of such function for Arizona.

4. More experiments with the 4- and 5-irrigation schedules must be undertaken for evidence on the nature of this portion of the function.

5. The units of the independent variable are numbers of irrigations.

6. The rational range of water applications is 3-, 4-, 5-, and 6-irrigations, which are estimated at 30, 35, 40, 45 inches of water, respectively,

7. A change in the irrigation schedule from 3 to 6 irrigations (an addition of roughly 15 inches of water, i.e., 50 per cent) causes an increase of 15 per cent in yield.

8. In a warm spring a frequent irrigation schedule seems to be economical. In a cool spring, or if other retarding factors occur (as hail), an infrequent irrigation schedule seems to be more economical.

9. More experiments are required for (a) a more reliable function, (b) evidence on the nature of the function (point 4 above), (c) determination of the nature of the independent variable, i.e., the relations of number of irrigations, consumptive use, and timing, (d) evidence on the effects of weather and determination of what constitutes a good or poor year, and (e) decision whether the mean or mode should be utilized as the average.

CHAPTER IV

COSTS OF PRODUCTION AND PRICES OF THE PRODUCTS

Costs of Production

For economic analysis it is necessary to incorporate the money costs of production and the price of the product into the production function.

This study applies (in Chapter V) the marginal analysis to determine the optimum level of production in a marginal analysis, only the additions to variable costs associated with the input being analyzed and only the additions to revenue received need to be considered. However, each cost item may be considered one at a time, as fixed or as variable, according to the situation being analyzed. If land is considered as a fixed factor, its costs are ignored in the analysis. If land is considered as a variable input, its costs must be considered, but some items of land costs may be considered as fixed costs and need not be included in the analysis.

In this chapter cost items of cotton production, which is required in Chapter V, is discussed and estimated. No distinction of fixed or variable cost items is made here; this will be considered in the cost section of the next chapter.

Large differences in the costs of production create a special problem. The costs differ among areas (climate, soils, distance from markets, etc.), among farms in an area (soils, level of management, etc.), and among years (weather, insect attack, change in technology and general upward trend in price level). Different costs may be accompanied by different yields. The yields in some circumstances are low as in a certain area or on poor land or with poor management, etc., while the inputs (quantities and costs) may be low, too. However, the costs per unit of lint generally will be higher when the yield is low (36). The costs, at least part of them, may differ as between cases in which the same yield is obtained due to differences among farmers and among estimates.

A detailed investigation of the costs of production is outside the scope of this study; therefore, it has been decided to rely on existing material.

The best procedure for a cost study is to consider only a limited group of farms of specific size, management level, soil, location, etc. However, this problem will not be treated in such a precise way in this thesis. Since reference is mainly to the Salt River Valley in Arizona, it is assumed that farm conditions in this area are similar enough for a single set of cost estimates. This assumption is supported by the fact that the variations in the estimates of the costs are at least as large as the variations among the farms in the Salt River Valley. This also is consistent with the earlier assumption that only the prevailing practices which are widespread among farmers will be considered.

Since there isn't a detailed study of costs of production of cotton in Arizona, costs for this study are based on the following estimates and statistical data from Arizona and California (14, 15, 50);estimates by farm advisors, California Agricultural Extension Service, Imperial County 1956; Fresno County 1953; Kern County 1957; estimates by Soil Conservation Service (Portland, Oregon) for Duncan, Arizona 1957. Some other studies were used as a source of data on specific items, which will be mentioned in connection with the discussion. An attempt is made to analyze and explain the source and development of the final figures, which will be used in the economic analysis that follows. The cost items will be partitioned and grouped to fit the specific needs of the economic analysis.

Numbers will be averaged and rounded. Sometimes a final figure will be chosen which is (to some extent) an arbitrary figure, because not enough data are available for a more reliable figure.

As was mentioned, the cost figures in the original data vary over a comparatively wide range. These are objective (real) variations of costs on the farm (caused by climate, soil, level of management, etc.) and subjective (opinion estimate) variations in costs brought about by the nature of the items included and differences in the evaluation of the different items. Among the many different cost estimates examined, almost each one fails to include some one of the following items: (a) charge for land, (b) interest on operating capital, (c) general management, and (d) miscellaneous expenses. In the items included there are large variations in subitems which are included and in their evaluation.

Charge for land

The charge made for land includes all the expenses (cash and non-cash) which the owner incurs for control of his land such as (a) interest on the value of the land, (b) real estate taxes, (c) interest, depreciation, maintenance, insurance, etc., on the improvements, or (d) the rent charged.

The land value, and therefore the land costs, exhibit large variations according to location, yielding possibilities, and many other reasons. Some of these variations are directly related to other cost items such as type of soil which determines the needs for cultivation, irrigation, fertilization, etc., or area which determines the insect and disease control on one hand and overhead costs on the other hand. The land value is closely tied to water costs. The more expensive the water, the lower is the land value. A study (37) shows that the total costs of water and land tend to be constant in three pump lift areas in Arizona, since the 1940's, for the various field crops and especially for cotton (based on a yield of 500 pounds per acre), i. e., the high costs of water are compensated by the low costs of land, and vice versa. Also, if water is scarce, the land value is low. This introduces one important reason for this analysis, since, if the land-water value ratio is low, or if water is scarce, there is a possibility that applying less water per acre and so irrigating more acres will make for more economical use of these resources.

Consequently, one must get the land-water costs in three contexts--with water fixed and land varying, with land varying and water fixed, and with both land and water varying.

The difficultires of land evaluation are well-known. In addition to the regular appraisal problems, the cotton allotments further complicate it. For this reason many estimates of costs do not include this land cost item, or only a rough figure is given.

In this study emphasis is given to cotton production in the Salt River Valley in Arizona. If renting in the Salt River Valley were common, the common rent charge could be used. But in the Salt River Valley most of the farms are not rented. The rent paid for "allotted acres" with a surface water allotment of cotton land is in general \$50-\$100 and as high as \$90-\$110 (4).[1] Costs of renting an acre will be considered to be \$100.

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[1] One procedure to determine rent in Arizona is according to the yielding potential of the field, as a rent of \$25-\$35 per bale.

The land value is estimated (3, 14) at $500 per acre, but land is sold for prices above $1,000 per acre (50).

These high rents for "additional" acres and the high land values, in part, result from the capitalization of the income from additional tracts thus secured plus the income secured from the land which the farmer already has, but which is used more efficiently through the larger unit. The high land values result also from nonland income capitalization considerations as speculation, income tax benefits, etc.

It is necessary that some land cost figure be established. Therefore, it was decided to use the arbitrary rounded value of $50 per acre in the Salt River Valley as cost of land. This value is the rent estimate in the Imperial Valley, California. It is 10 per cent on the average $500 land value, which may be divided into 5 per cent interest and 5 per cent for all the other land cost items.

In areas where water is pumped, the charge for land must be lower. The higher the water must be lifted, i. e., the higher the costs of water--the lower is the price of land. The arbitrary rental values of $40 per acre for 200 foot lift and $20 per acre for 300 foot lift will be used in this study.

Operating costs

These include all preharvest costs except costs of land, water, and irrigation.

1. Machine operation costs vary widely. Cotton machinery custom rates are usually higher than the cost of operation of owned machinery. The costs of operation are higher on a small farm than on a large farm. In addition, the small farmer has to hire more custom machinery.
2. Land preparation, cultivation, weed control, and other practice costs vary (in amount and prices) according to soil type, area, size of farm, level of management, etc.
3. Fertilizer costs vary for the same reasons as do cultivation costs. In addition, as a conclusion of Chapter II, when a higher level of irrigation is applied, the farmer increases the level of fertilizer, say 50 pounds per acre valued at $7. (There is no additional application costs for fertilizer, since it is done with the cultivation).
4. Insect and disease control varies among areas and years.

It is hard to evaluate the preharvest operating costs in dollars per acre. It was decided to evaluate such costs at $100 per acre, a round figure which is the average of the two main estimates in Arizona (14, 50).[1] In California, the average of the operating costs in the estimates checked was about $125 per acre at a yield of 1.5 bales per acre.

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[1] (50) evaluates it at $80 per acre without overhead and management expenses and yield of two bales per acre. (14) evaluates it at $120 per acre (but there is an opinion that these costs are on the high side) at a yield of 2.5 bales per acre.

In general, a farmer who is a good manager, or has a good soil and has enough capital, will strive to get the highest possible yield by applying more water and more of the rest of the preharvest operation practices. Hence, his preharvest costs will increase and usually his yield will increase also. This situation exists especially as a result of acreage allotments and the high constant price for cotton lint.

In practice, if a farmer changes the level of irrigations he will also change the level of other practices. In this study, interest centers more on this aspect than on any fixed total of operating costs. There are two possibilities to consider in this connection (1) the changes in costs due to changes in the level of the practices which accompany the change in irrigation level are in different directions and in total cancel out, or (2) the more realistic assumption that as the irrigation level increases, the other practices such as fertilizer, cultivation, etc., are also applied more intensively with consequent increase in preharvest costs. There is also the probability that more diseases and insects will infect the field, therefore, causing an increase in control costs. There is also a chance for lower efficiency in picking through lodging.

Some of the preharvest operating costs vary with the level of irrigation. Hence, these costs must be considered as variable costs which must be added to the variable costs of water, whereas those preharvest operating costs included in the $100 per acre estimated above must be considered as fixed costs, when figuring the economic use of water.

Arbitrarily, it is estimated that the change in preharvest operating costs will approximate $15 per acre comparing practices used with 3- and 6-irrigation schedules. Since there are three additional irrigations, $5 per acre of variable operating costs per irrigation are assumed.

Water and irrigation costs

These costs vary mainly according to the source of water--whether it is surface water or pumped water (and, for the latter, according to the depth of pumping). There are many other reasons for cost variations of water and its application to the crop. For the costs of surface water, this study uses the price for water charged by the Salt River Valley Water Users Association.[1]

The maximum quantity of surface water (priced at $2 per acre foot) which is available to farmers who are members of the Salt River Valley Water Users Association is three acre feet, but usually the quantity is lower. The rest of the water which the farmers need is pumped

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[1] For 1959 the Association estimates that the water charge will be $2 per acre foot for the first three acre feet. For additional water over three acre feet, the estimate is $7. 50 per acre foot (51). However, the true water costs are higher (about $6 per acre foot), the difference (about 60%) being paid by the power plant revenue (17).

by the association or by the farmers with costs of $7. 50 per acre foot and more.

There is a detailed study of the costs of pumping water in Arizona (48). However, since there is criticism that some of the items are charged too high (particularly depreciation) corrected figures have been used in this study, which are $8 and $12 per acre foot lift to 200 feet and 300 feet, respectively.[1] (3)

The costs for labor and equipment for applying the water also vary among the several estimates. When water costs more, it is reasonable to expect that the irrigation efficiency will be higher. However, in this case, it is not the water but labor that costs more. An estimated cost of $2 per irrigation (14) is used herein to cover the costs of applying the water to the field. Some fixed costs as equipment, maintaining the ditches, etc., are not included.

Harvesting costs

Picking costs -- These costs vary mainly with the number of pickings (2 or 3) and with the practice (hand or machine). The harvest practice also determines the grade of the lint, so that lower costs may partially be offset by lower grade and value of the lint.

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[1] Two cents for electricity and two cents for all the other costs per acre foot per foot lift. Costs of gas operated wells are somewhat lower.

Although these costs vary less than any other cost item, (there are common rates for hand picking and custom machine picking[1]; and there are several studies of machine harvesting costs, e. g., in Arizona (59)), still there are variations in the costs. However, the picking costs (first pick by hand, later by machine) and the additional harvesting costs are similar in most of the estimates. The most common estimates of harvesting costs are about $40 per bale.

Ginning costs -- These vary slightly, mainly according to the moisture and trash content (mainly determined by picking practices), and other regular variations.

Ginning costs, including all the services at the gine, are about $15 per bale (15, 50).[2]

The total harvesting and ginning costs thus come to $55 per bale. Since a bale weighs 500 pounds, these costs are eleven cents per pound of lint. These costs are figured per bale and per pound, for they will be subtracted from the price of the lint in order to determine a price for lint "in the field" before picking.

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[1] Hand picking at $3.00-$3.75 per hundredweight of seed cotton; machine picking at $1.25-$2.00 per hundredweight of seed cotton.

[2] It is a practice to consider that the income from the seed offsets the ginning costs (14). But the seed value fluctuates and usuall exceeds the total ginning costs.

Prices of the Products

The price of the cotton lint varies mainly by grade and staple length. Many factors influence the grade, but this study does not deal with these problems. It is assumed for this study that the level of irrigation does not influence the quality of the lint and hence does not influence the price. Variations of the prices among the years have been comparatively small because of the price support program.

The price of lint for 1958 was 34 cents per pound and for the period 1948-1957 it was 34.43 cents per pound (51).

The price of seed for 1958 was $43 per ton, which makes 3.4 cents per pound of lint.[1]

The price for the period 1953-1958[2] was $51.60 per ton, which makes four cents per pound of lint.

The total price for lint and seed computed per pound lint is 37.4 cents for 1958. The total of these two prices, as an average for the periods mentioned, is 38.4 cents per pound lint. It was decided to use the more conservative price of 37.4 cents per pound lint in this study. The harvesting plus the ginning costs are eleven cents per pound of lint. Hence, the value of the lint in the field, before harvesting, is 37.4 cents minus eleven cents equals 26.4 cents per pound.

[1] For each pound lint there are 1.6 pounds of seeds, or for each 500-pound bale, 800 pounds of seeds.

[2] Since the trend of the price of seed is downward, it was decided to use a shorter period to figure an average value of seed.

Conclusions and Summary

1. Each cost item required in Chapter V is discussed and estimated in this chapter.
2. Large differences in costs of production exist among areas, farmers, and years.
3. No detailed study on costs of production of cotton exists in Arizona.
4. The costs considered in this chapter are based on several estimates.
5. The final figures are rounded and in some cases are arbitrary to some extent.
6. The final figures are as follow:

Charge for land:	(Salt River Valley) rented	$ 100 per acre
	owned	$ 50 per acre
	200 foot lift	$ 40 per acre
	300 foot lift	$ 20 per acre
Operating costs:	fixed	$ 100 per acre
	variable with irrigation	$ 15 per acre
Water costs:	(Salt River Valley) 1st 3 A-F	$ 2 per A-F
	additional water	$ 7.50 per A-F
	200 foot lift	$ 8 per A-F
	300 foot lift	$ 12 per A-F
	costs of application	$ 2 per irriga.
Harvesting costs:	picking	$ 40 per bale
	ginning	$ 15 per bale
	total of	$ .11 per lb. lint

Price of lint		$ .34 per lb. lint
seed	$43 per ton	$ .034 per lb. lint
total price for seed cotton		$ .374 per lb. lint
harvest costs		$ .11 per lb. lint
Net price of lint in field		$ .264 per lb. lint

CHAPTER V

THE ECONOMIC ANALYSIS

For estimating the optimum level of production, the costs of the factor inputs and prices of the product must be incorporated into the production function. Optimum level of production means that the two scarce resources--water and land--will be combined in proportions that will maximize the net income. These proportions will change according to changes in costs of the resources or price of the product or both. (A change in technology of production--assumed to be constant in this study--is also a possible cause of change in the proportion of the scarce input factors).

There are three different Cases or possibilities for the combination of water and land, each of which will be discussed in later sections:

A. Land is fixed and water varies (limited land and unlimited quantity of water).

B. Water is fixed and land varies (limited quantity of water and unlimited land).

C. Both water and land vary (both are unlimited, or both may be limited but within these limits they are considered as subject to variations), and they can be substituted for one another.

Application of these cases to actual situations may differ according to the conditions, the unit under consideration, or for other reasons. For example, Case (A) is the usual situation which the individual farmer confronts. An area as a whole may also confront this situation. Case (B) is a situation which an area or a state confronts more than individual farmers, although farmers in certain areas or situations confront it also. Case(C) is the usual situation which an area or a state confronts. Sometimes individual farmers confront it also. In many situations an area confronts Case (B), while the individual farmer in the area confronts Case (A).

Studying the ways to solve these inconsistencies is an important subject, but it is beyond the scope of this thesis. An attempt has been made to apply to each case examples of actual situations.

This study assumes that acreage allotments for cotton do not exist. However, at the present time, acreage allotments limit the land planted to cotton in Arizona. Hence, most of the farmers may analyze their situations under Case (A), i.e., land fixed by the allotments. On the other hand, for Cases(B) and (C) the analysis assumes that acreage allotments do not exist. If this assumption were true, most farmers would analyze their situation under Case (C).

Before analyzing each case, some general considerations will be discussed.

Discontinuous Linear Function

In the regular system of irrigation, when each irrigation refills the root zone, the amount of water applied is divided into a number of irrigations and cannot be completely or almost completely divisible as for example is the case with fertilizer application.

Only if the consumptive use figures are considered, i.e., the service that the irrigation provides to the plant, can the water input be considered as highly divisible, and the function a continuous one, as shown in Figure 3.

As mentioned earlier, the data in this thesis are given as number of irrigations and the consumptive use figures are estimated. Also, at present, recommendations to farmers are given mainly in terms of "number of irrigations" rather than in inches of water. The irrigation is applied in "lumps" (5-6 inches of water at a time), therefore, the yield is measured only for a given number of irrigations, i.e., a certain yield for 3, 4, 5, or 6 irrigations, respectively.

By connecting the four different yields on the graph in Figure 5, one can get a noncontinuous linear function. Noncontinuous--because one considers only the points on the curve; linear--because one assumes constant relations when moving from one level of irrigation to the other.

Figures 3 and 5 are computed by the same second degree polynomial function. But for Figure 5 only four points were computed--for the 4-irrigation schedules, while for Figure 3 points in between also were computed.

The economic analysis is based on the noncontinuous function. Hence, the considerations and conclusions are in terms of number of irrigations.

Inches of water is too small a unit to use as a yardstick for irrigation in Arizona. The payments for water are for acre feet of water which are measured in many areas only by approximation. This condition results from the low and changing efficiency in conveyance and application of the water, and the fact that part of the runoff water (surpluses) are reused. The farmer confronts special problems such as variation in fields, size of stream of water, interference of other operations, etc., which hinder the application of accurate quantities of water. Recommendations in inches would not serve the farmer's purposes.

Costs and prices cannot be estimated in any accurate way. By using the discontinuous production function or production contours, some protection against this inaccuracy is provided. When the optimum level of production is estimated according to a noncontinuous production function, the price ratio may swing over a comparatively wide arc before causing a change in the optimum level of irrigation. When using a continuous production function, each small change in price ratio, i.e., a real change or a change in the estimate, will cause a change in the optimum level of water application. In actual life, small changes in costs cannot be detected.

How to Divide the Water Between the Fields

Because the production function is in the range of diminishing returns, it provides guidance for division of the water, given as post-planting irrigation, between fields.

If a farmer has a limited quantity of water, he will maximize cotton production and his income by allocating the same or about the same quantity of water, i.e., number of irrigations, to all his fields, providing that all his fields are of the same soil type and not less than three irrigations are applied.[1]

It is a common practice among farmers to solve such cases by "taking good care" of part of the fields by applying maximum water and getting the best yield possible on that part, while the rest of the fields will be given only the minimum quantity of irrigation or left idle. In cases where the production function has the nature described, this attitude is erroneous.

Costs and Prices Under Consideration

In a marginal analysis, only the variable costs associated with the input being analyzed and the additions to revenue received need to be considered. The farmer must know what are his additional (marginal) costs and additional (marginal) revenue when an additional unit of input is

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[1] The basis for this conclusion can be found in (27, p. 120).

added to production. The units of the inputs under consideration in this study are one irrigation or one acre of land.

The optimum level of production--that level which provides the highest net income to the producer--is reached when the marginal income equals the marginal costs. Hence, with the production function given, the optimum level of production is determined by the price ratio of the input and output. The following items must be included in the cost and revenue analysis:

A. Marginal costs of irrigation.

1. Costs of the additional one-half acre foot of effective water--On the average, the amount of water per irrigation for the fourth, fifth, and sixth irrigation is estimated to be about one-half acre foot. By "effective water" is meant the water which is available for consumptive use by the plants. Since the irrigation efficiency is less than 100 per cent, only part of the water is "effective." The production function and the economic analysis are built on this portion of the water. To figure the costs of the effective water, one must add to the price of an acre foot of water the costs of that portion which is not used (the inefficient portion). This can be done by simple arithmetic. However, a simple tool is available in Figure 4 for assisting in this calculation. For example, when the price of water is $8 per acre foot and the irrigation efficiency is 67 per cent, the cost of the effective acre foot is $12. The horizontal line for $8 and

Figure 4. Costs of effective water (i. e., the water which is available for consumptive use by plants) for different water prices and irrigation efficiencies.

and the vertical line for 67 per cent intersect on the diagonal line labeled $12, which shows the costs of the effective water to be that amount.

The price and costs of water have a wide range from $2-$15 per acre foot and more. The range of costs of the effective water is still greater.

If water costs differ according to the amount used, not the average price of the water but the actual price of the additional water applied by the additional irrigation must be included in the costs calculations. For example, the first three acre feet of water to members of the Salt River Valley Water Users Association are cheap ($2 per acre foot in 1959). This water is used for the preplanting and first three post-planting irrigations. Because it is assumed herein that application of less than three post-planting irrigations are not profitable, this low price for the first three acre feet cannot be considered in the marginal costs. The additional water which is used for the fourth, fifth, and sixth irrigations costs $7.50 per acre foot. Hence, this price is the one that must be considered in computing marginal costs of irrigation. Under conditions where costs decrease by using an additional quantity, then the lower costs resulting therefrom must be considered in computing the marginal costs of water.

2. Labor costs of applying the one-half acre foot of water--On the average this cost is estimated to be $2 per irrigation and is assumed to be this amount for this study.

If an individual farmer has the labor for irrigation on the farm and the costs incurred exist whether the labor is used or not, i. e., the labor is a fixed cost, then he should not include this item in his calculations of marginal costs.

3. Additional operating costs associated with additional irrigation.--According to the discussion in Chapter IV, when a higher level of irrigation is applied, there are usually some increases in operating practices and costs. It was estimated that the increase in these costs is $15 when comparing operating costs for a 3- and a 6-irrigation schedule, respectively. Since this represents a change of three irrigations, it was estimated that this cost is $5 per irrigation.

If an individual farmer does not change his operating practices when he changes the level of irrigation, he should not include this item in his calculations.

B. Marginal costs of land.

Only the variable costs associated with land use need to be considered, i. e., the land costs which the farmer incurs by adding an acre to the production of cotton.

Usually, in a marginal analysis, the land is considered as a fixed input and, therefore, there is no need to decide whether the item of land costs is variable or fixed as well as no need for estimating the level of land costs. For the following analysis this decision is crucial because land is the variable input, but sometimes it is not self-evident which items of land costs must be considered as fixed and which items as variable. Moreover, it is hard to decide which items are relevant to the case and what is their magnitude. Some illustrations are given herein as a guide for typical situations.

1. Charge for land--The items to be included as marginal costs of land vary according to the situation. (a) Additional land is acquired for cotton production. In this case either the rent (e.g., $100 per acre) or the annual costs incurred by purchasing the land (e.g., $50 per acre) must be considered as variable costs. If a profitable crop can be planted on acquired land, the opportunity costs, i.e., the profit (net income) which this crop may provide, must be added to the rent or to the annual costs of the purchased land. (b) Owner operator land. In this case, only the opportunity costs must be considered as variable costs. If a profitable alternative crop exists on the farm, the opportunity costs include the returns from this crop to land, i.e., the imputed returns to the charge for land, e.g. $50 per acre, and the profit, e.g., $20 per acre. If the farmer does not realize profit from the alternative crop, the opportunity costs include only that portion of returns to land which this crop provides.

Determination of the opportunity costs can be complicated. Suppose the water supply is limited and the alternative crop requires less water per acre than 30 inches consumptive use--the lowest level of irrigation of cotton. Then, for adding one acre to cotton production, more than one acre (say, 1.2 acres) of the alternative crop should be taken out of production. The opportunity costs for the additional acre planted to cotton are that income earned by the 1.2 acres of the alternative crop. If cotton would provide income above these opportunity costs, one additional acre would be planted to cotton and .2 acre would remain idle. The optimum level of cotton irrigation determines the acres of the alternative crop to be given up for each acre of cotton. This determination is done by regular budgeting procedure, to be explained later.

If the land is idle, no opportunity costs exist, hence, in this case the marginal costs of land are zero.

If the farmer considers the possibility of disposing of his land as an alternative to cotton production then (a) if he can sell it, the calculated income from the sum which the sale of one acre will provide, must be considered as opportunity costs, or (b) if he can rent it out, the rate of rent minus the current expenses of ownership per acre must be considered as opportunity costs.

2. Marginal operating costs associated with use of additional land--When a farmer adds an acre to production, this acre must be cultivated and operated so in addition to the charge for the additional land itself, the additional operating costs must be considered as costs of the land

in this case. These costs are estimated at $100 per acre and they must be added to the costs of land as described above. Usually, when the farmer extends his operation, the operating costs per additional acre may be reduced if increasing returns to scale emerge. These reduced costs per acre must be considered. If decreasing returns to scale emerge, the increased costs per acre must be considered.

C. Price of additional lint produced.

Since the harvesting and ginning costs are calculated per pound of seed cotton rather than per acre, and since the gross price of lint is a composite of the seed and lint price before deduction of harvest and ginning costs, it is necessary to determine the net price of lint before harvest as it hangs in the field. This price is the composite price per pound of lint (calculated as the price of lint plus the price of that amount of seeds normally associated with a pound of lint). minus harvesting and ginning costs calculated per pound of lint. Again, only the marginal costs of harvesting need to be considered. Harvesting costs are mainly variable costs, but if there are some fixed costs such as the fixed costs on a self-owned cotton picker, they are relatively small. Hence, no further effort is made to distinguish these costs and the harvesting costs are estimated to be $.11 per pound. Since the total lint price for purposes of this study is estimated to be $.374 per pound of lint, the net price of lint hanging in the field is $.264 per pound.

Calculation of costs and returns by the individual farmer

It is up to the individual farmer who wishes to budget, i. e. to determine that combination of land and water which is optimum for his conditions to determine, first, which of his costs are variable and which are fixed; second, to estimate the variable costs on the one hand and the price of the product on the other hand. Having these costs and prices, it will be possible for him to determine the optimum level of production for his conditions with the assistance of charts (Figures 6, 8, and 10) which are presented later in this study.

However, a complication emerges in this budgeting by the impact of the consequences of the budget on the marginal costs considered. For example, if operating costs are estimated at $100 per acre and the budget determines a low irrigation schedule, more acres would be planted to cotton. If increasing returns to scale emerge, the marginal operating costs may be reduced. A new budget, with the changed marginal costs, must be set. This is a regular procedure in budgeting, to proceed by trial and error, until a final plan emerges. Similar complications may emerge in different situations, e. g., in the determination of the opportunity costs, discussed above.

Case A -- Land Fixed, Water Variable

For the first condition to be analyzed, a fixed unit of land of one acre is assumed to which water can be applied at varying schedules of 3, 4, 5, or 6 irrigations. For each irrigation schedule a certain yield is predicted by the mathematical function assumed here to be the noncontinuous production function presented in Figure 5. The respective predicted yields are: 1,259, 1,343, 1,408, and 1,454 pounds of lint per acre.

The decision as to which irrigation level is optimum depends on the price relationships of lint and water.

As mentioned earlier, the optimum level of production is that combination of inputs where marginal income equals marginal costs, i. e., where the value of the additional lint (Δ lint) produced by one additional irrigation (Δ irrigation) is equal to the cost of this additional irrigation which is the value of the additional variable costs incurred by one additional irrigation. It is expressed in equation (1).

$$\Delta \text{ Lint x Price/lb. of lint} = \Delta \text{ Irrigation x Price/Irrigation} \qquad (1)$$

This equation may be transformed to equation (2).[1]

$$\frac{\Delta \text{ Lint}}{\Delta \text{ Irrigation}} = \frac{\text{Price/Irrigation}}{\text{Price/lb. of lint}} \qquad (2)$$

Equation (2) is used for finding the optimum level of irrigation at different price combinations. It is used to construct Figure 6, which is a tool enabling one to find easily the estimated optimum level of irrigation for different price combinations of lint and water.

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[1] Detailed explanation can be found in (27, Ch. 4).

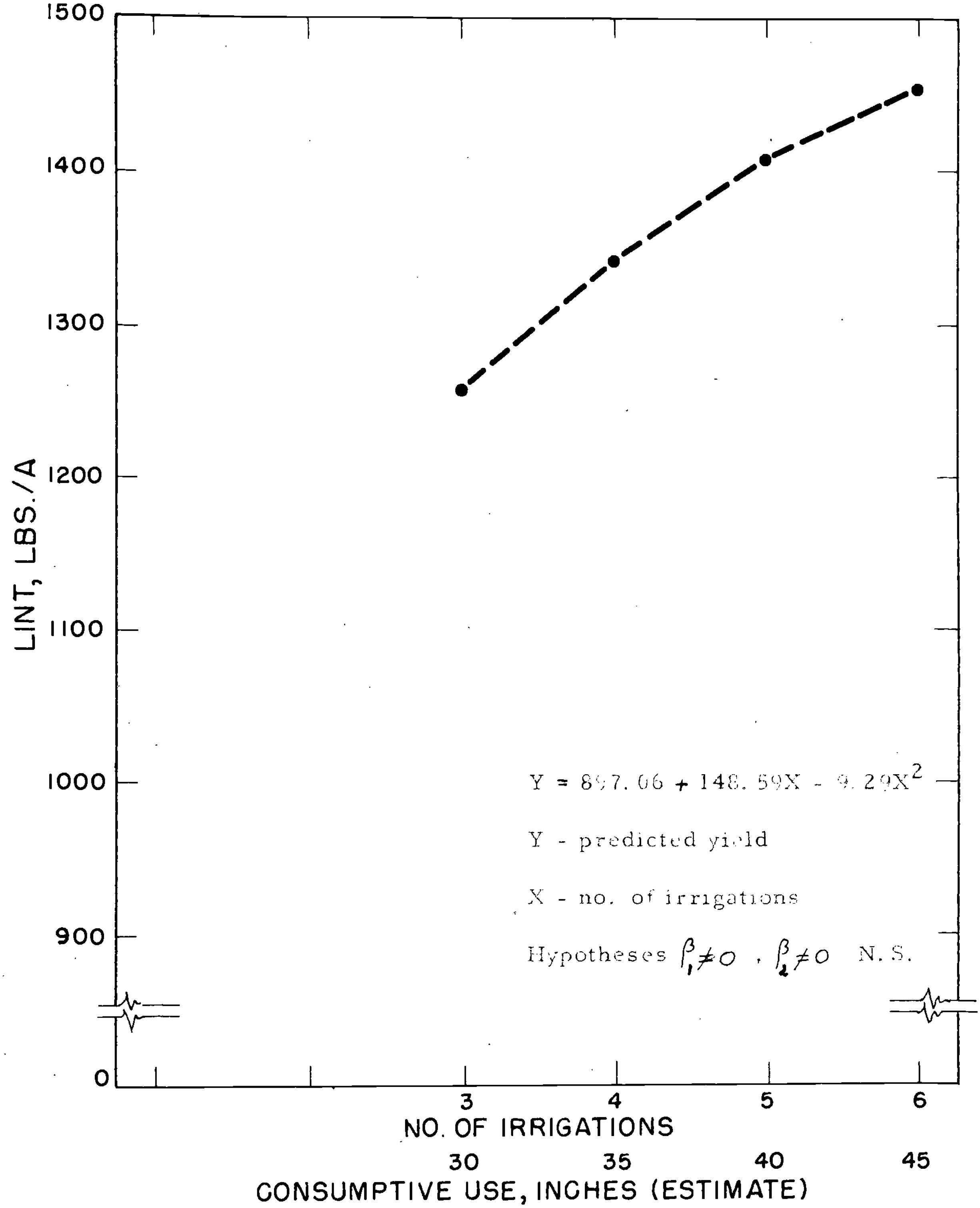

Figure 5. Cotton yield versus irrigations (land fixed at 1 acre).

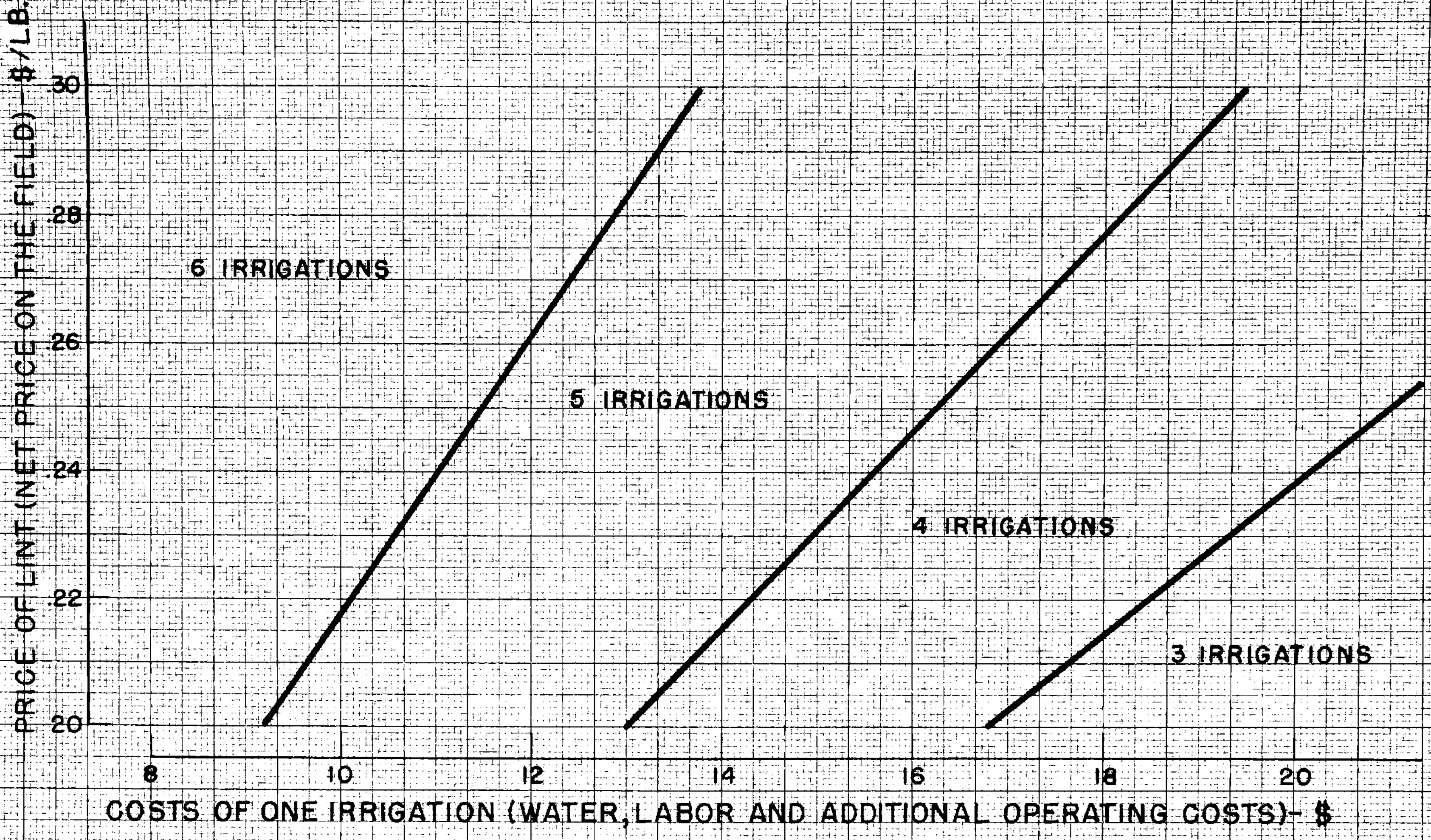

Figure 6. Estimates of the optimum level of irrigation for a fixed supply of land and unlimited supply of water for different price combinations of lint and water.

Figure 6 is constructed in the following manner:

(a) Find the ratio in the left hand part of equation (2), i.e., additional yield to additional irrigation.

Example: for the sixth irrigation relative to the fifth one:

$$\frac{1{,}453 \quad - \quad 1{,}408}{6 \quad - \quad 5} = \frac{46}{1}$$

(b) Set the above ratio equal to the right hand part of equation (2), i.e., to the reciprocal price ratio for two levels of lint prices.

Example:

Lint at \$.30 $\frac{46}{1} = \frac{\text{P./Irr.}}{.30}$; P./Irr. $= \frac{46(.30)}{1} = \$13.80$

Lint at \$.20 $\frac{46}{1} = \frac{\text{P./Irr.}}{.20}$; P./Irr. $= \frac{46(.20)}{1} = \$\ 9.20$

(c) Plot the two points and connect them by a straight line. (The same ratio determines all points between these two points. Hence, the relation is linear and is expressed by a straight line.)

(d) Repeat the same procedure from "a" to "c" above for the fifth and fourth irrigation schedules. (The ratios for the left side of equation (2) for the calculations are $\frac{65}{1}$ and $\frac{84}{1}$, respectively.)

The three lines divide the space into four areas. Each area provides an estimate of the optimum level of irrigation for a considerable range of price ratios of lint and water. The optimum for each level of irrigation falls in a range of prices of lint and cost of irrigation because of the discontinuous production function described earlier. The ratio of prices must change from one schedule to another. To find the optimum level of irrigation under conditions where land is fixed but water variable, one must determine his net price of lint and determine the addition to his costs by adding one additional irrigation. If the additional cost of one additional irrigation is $12.14, with a price of lint of $.264 per pound or more, a 6-irrigation schedule is the optimum level of irrigation, i.e., at the costs and prices specified, a 6-irrigation schedule will bring the highest net income per acre--the fixed input unit. If the price of one additional irrigation is more than $12.14 per acre with the price of lint constant at $.264 per pound, or if the net price of lint is lower than $.264 per pound with the cost of an additional irrigation constant at $12.14 per acre, a lower irrigation schedule will be more efficient. Thus, each line in Figure 6 defines the limit of the optimum between one irrigation schedule and the next higher or lower schedule.

The lowest level of irrigation that may be profitable at the various prices for lint and costs of additional irrigations cannot be determined from Figure 6. By budget analysis, the "break-even point" can be determined for each combination of price of lint and additional irrigation and the "outside" limits of profitableness thus determined. These limits have not been calculated in this study and are not shown on Figure 6. Hence, any optimum combination of irrigations found in Figure 6 for any chosen level of lint price and cost of an additional irrigation should be recognized as indicating the optimum combination for highest profit or least loss per acre. Whether it is profitable or not depends upon an additional calculation not here performed.

Examples

(a) In the Salt River Valley, to members of the Water Users Association, the price of water for each additional acre foot over three is $7.50 per acre foot. If the irrigation efficiency is 67 per cent, with the assistance of Figure 4, it is found that the costs of an effective acre foot are $11.25. Since one irrigation requires one-half foot of water, it costs one-half of $11.25 or $5.62. With $2.00 for labor and $5.00 for operating costs, the additional cost of an additional irrigation is $12.62. By referring to Figure 6, it is apparent that at these prices and with lint priced at $.264 per pound, a 5-irrigation schedule is optimum.

However, if the farmer has a high irrigation efficiency (73 per cent and more), or if he has no additional operating costs associated with applying an additional irrigation, or if his net price of lint is higher than $. .274 per pound, his optimum irrigation schedule will consist of six irrigations.

(b) In an area where water must be pumped 200 feet, the cost of the pumped water is about $8 per acre foot. By applying the same computations procedure that was used in example (a) one arrives at costs of $13 per irrigation, and still the 5-irrigation schedule is optimum.

(c) In areas of higher pump lift for water, the additional costs per additional irrigation are higher, so a lower irrigation schedule may be optimum. For example, for a 300 foot lift, water costs about $12 per acre foot. With a 67 per cent irrigation efficiency, its full cost is found to be $18, which for one-half acre foot will cost $9. Adding $2 for irrigation labor and $5 for additional operating costs connected with the irrigation results in a price for an irrigation of $16. Hence, Figure 6 shows that with lint priced at $. 264, a 5-irrigation schedule is optimum. At any price below $. 246 per pound, a 4-irrigation schedule will be optimum.

Case B-- Water Fixed, Land Variable

For the second condition to be analyzed, a fixed quantity of water is assumed which may be applied to varying quantities of land in schedules of 3, 4, 5, or 6 irrigations. When there is a limited quantity of water, it can be applied to plots of different sizes with the outcome of different yields per acre. Although there is a diminishing marginal productivity of land when land is added to a stock of water, a greater total product, nevertheless, results when the water is spread over more acres, provided that the water is not spread over more acres than will permit a minimum 3-irrigation schedule.

When a farmer, an area, or a country has only a limited quantity of water, i. e., only a fraction of the quantity which might otherwise be used profitably, the problem arises how to distribute this limited quantity of water relative to land on which it might be used.

It is assumed that 45 acre inches of effective water are available as a fixed quantity. For actual field consideration, a larger quantity must be considered to offset the losses of inefficient irrigation. If the irrigation efficiency is 67 per cent, the fixed quantity of water must be considered to be about 5. 5 acre feet, of which only 67 per cent (or 3. 75 acre feet or 45 inches) is available for consumptive use.

When the fixed quantity of water is applied to plots of land of different sizes, a new production function will emerge showing yield response of these plots when irrigated by the fixed quantity of water.

Since only the 3-, 4-, 5-, or 6-irrigation schedules can be utilized, water can be applied only in the quantities of 30, 35, 40, or 45 inches per acre, respectively. These quantities of water are the quantities used for each of the four irrigation schedules, respectively, i. e., each irrigation schedule requires five acre inches of water more than the next lower one beginning with a minimum of 30 acre inches for a 3-irrigation schedule. (For the details see first section, Chapter III). For this phase of the analysis the computations cannot be based on the number of irrigations but only on the "acre inches" of water used.

The fixed amount of available water (45 acre inches) can be applied to one acre as a 6-irrigation schedule. But if less water must be applied, the 5-irrigation schedule must be utilized. This schedule requires only 40 acre inches per acre. Hence, the 45 acre inches will suffice for more than one acre. The plot which can be irrigated by the 45 acre inches utilizing a 5-irrigation schedule is $\frac{45}{40} = 1.125$ acres. The same conditions pertain to the 4- and 3-irrigation schedules. Hence, the available 45 acre inches of water can be applied as:

a 6-irrigation schedule on one acre, or

a 5-irrigation schedule on 1.125 acres, or

a 4-irrigation schedule on 1.286 acres, or

a 3-irrigation schedule on 1.500 acres.

From the original production function (Figure 5), the yield per acre for each of the four irrigation schedules can be obtained and by multiplying the yield per acre for each irrigation schedule by the acreage irrigated by it, as shown above, the following yields for the 45 inches of water are predicted: 1,454, 1,584, 1,727, and 1,889 pounds of lint on the respective acreages shown above. A new production function is thus derived which is plotted in Figure 7.

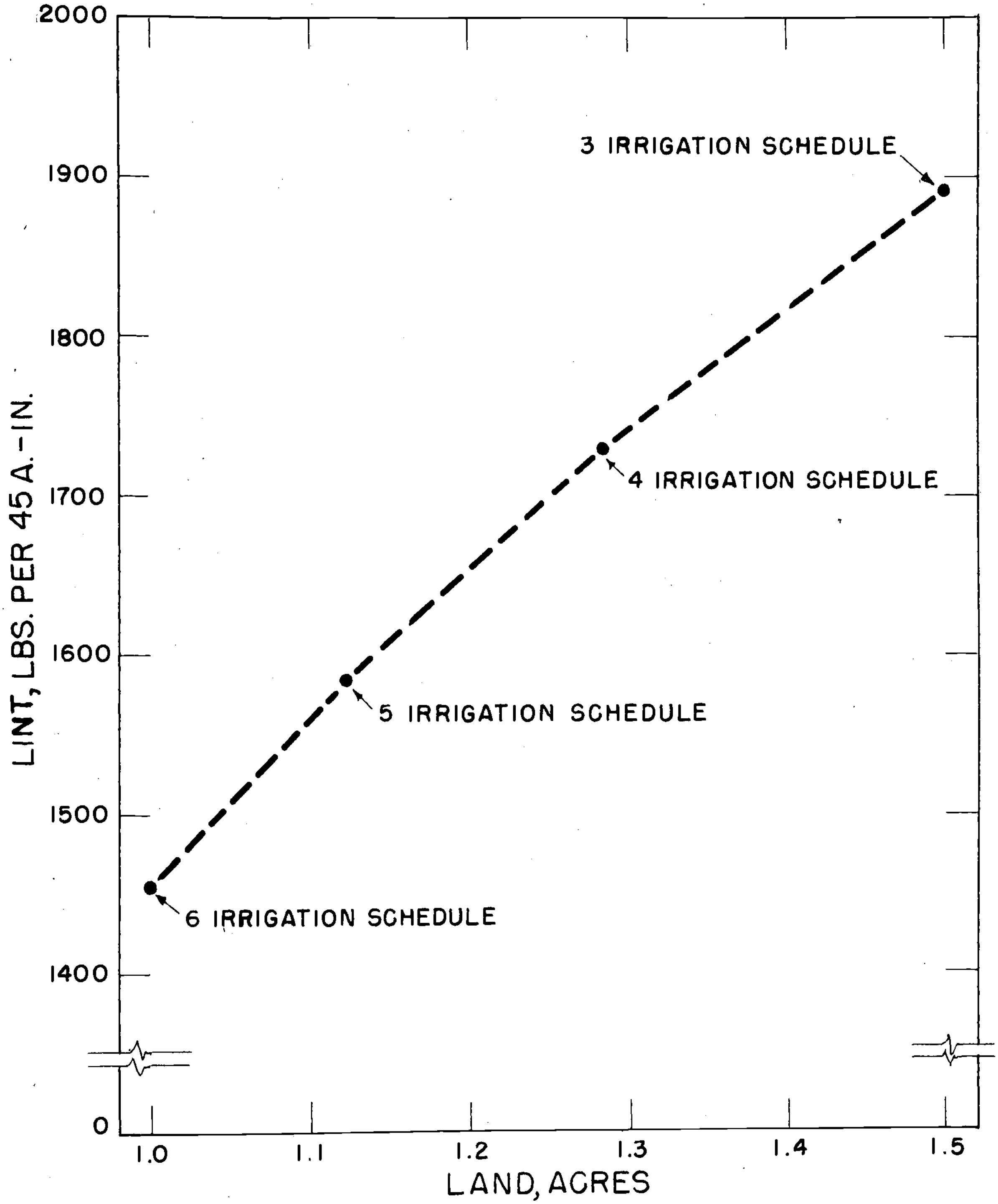

Figure 7. Cotton yield versus land[1] (water fixed at 45 A-in.), showing yields for the four irrigation schedules.

[1] Derived from the function given in Figure 5.

By applying the field price of lint and the additional costs of additional land to this production function, it is possible to calculate the optimum level of production, i.e., the optimum acreage to be planted and irrigated by the fixed quantity of water.

Conclusions can be derived in terms of irrigation schedules as well as in acreages, i.e., in plots of different sizes. Only plots--"lumps of land"--can be added to production because of the fact that the plots must be irrigated by one of the four irrigation schedules. Hence, instead of concluding that one acre or 1.125 acres, etc., is the optimum level of production for certain price ratios, it is possible to conclude that a 6- or 5-, etc., irrigation schedule is optimum. The conclusion then could be: Apply your fixed quantity of water at this schedule on all the acreage for which the water will suffice.

The conclusion is stated as an irrigation schedule, so the farmer knows which irrigation schedule is optimum. From this he can calculate the acreage to plant in the following way. The total quantity of water in acre feet available to him for cotton will be divided by the quantity of water that he usually applies per acre for the recommended irrigation schedule. The outcome will be the acreage to plant. This takes the irrigation efficiency into consideration. If the irrigation efficiency is 100, and the 3-irrigation schedule is recommended, then if the farmer has 300 acre feet of water available, the acreage to plant will be $\frac{300 \times 12}{30} = 120$ acres.

If his irrigation efficiency is 67 per cent, then he will plant only $\frac{300 \times 12}{45}$ = 80 acres. (For the variation in the denomination--water per acre--due to differing irrigation efficiencies, see Figure 4).

Calculating the optimum level of production for different price ratios and constructing Figure 8 have followed the same procedures that were used and explained in the section "Case A - Land Fixed, Water Variable." Therefore, the explanation will not be repeated here. Figure 8 is a tool which enables one to find easily the estimated optimum level of irrigation and, hence, to estimate the acreage to be irrigated for different price combinations of lint and land.

To find the optimum level of irrigation, one must determine his net field price of lint (which was on the average $.264 per pound in Arizona in 1958) and determine his additional costs for adding one acre. Figure 8 reveals that if the additional costs of adding one acre are any amount up to $200, and if the price of lint is $.264 per pound or more, a 3-irrigation schedule is the optimum level of irrigation, i.e., with these two prices, a 3-irrigation schedule utilized on the farm will bring the highest income that can be achieved by the limited quantity of water.

If the costs of an acre are higher, or the price of lint is lower, a higher irrigation schedule will be more efficient.

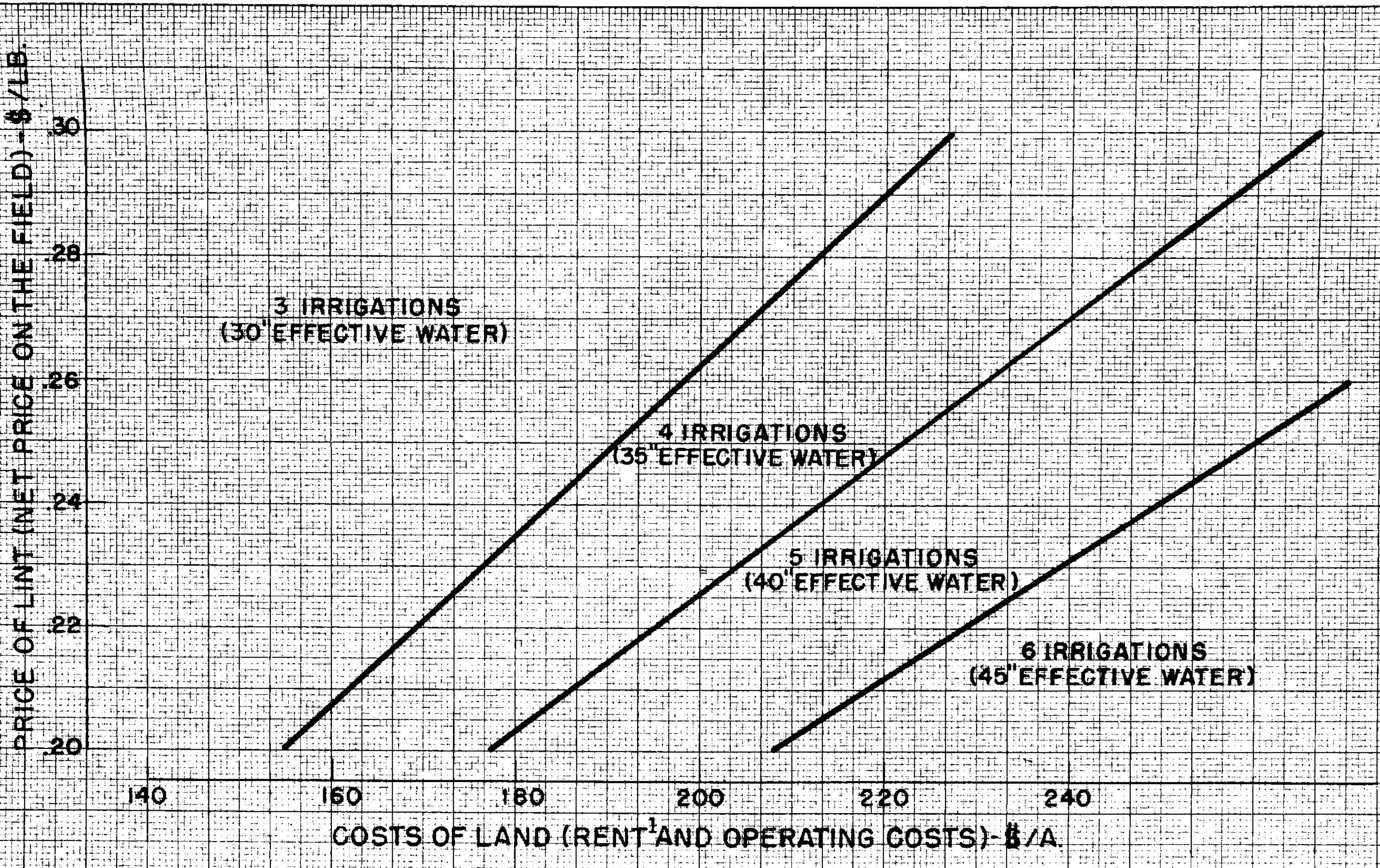

Figure 8. Estimates of the optimum level of irrigation for a fixed supply of water and unlimited supply of land for different price combinations of lint and land.

1 Rent or charge for land where applicable and opportunity costs.

Examples

In these examples it is assumed that acreage allotments for cotton do not exist.

(a) In the Salt River Valley these conditions usually do not exist, since the land is fixed for the farmer, and if the land varies, the water varies also. However, this situation may exist when there is an inadequate water supply, but only if the water supply is limited to such extent that it barely suffices to irrigate all the farmer's land at a minimum level of irrigation. When a profitable alternative crop exists, then the costs for each additional acre planted to cotton must include the opportunity costs as well as operating costs. This amount may approximate $170 per acre (opportunity costs: charge for land--$50 per acre, profit--$20 per acre plus $100 per acre operating costs). With net price of lint at $.264 the 3-irrigation schedule is optimum.

When a farmer can rent land without acquiring additional water, then his costs for each additional acre must include the cost of renting the additional land as well as operating it. This amount may approximate $200 per acre (rent--$100 plus operating costs of $100). With net price of lint at $.264 either the 3- or 4-irrigation schedules are optimum.

(b) In areas where water must be pumped 200 feet, the charge for land is considered to be $40 per acre. If alternative crop pays this sum, or if a farmer considers buying land and the annual charge for land is $40 per acre, the costs of additional acre may approximate $140 per acre (opportunity costs or charge for land $40, operating costs $100). The 3-irrigation schedule is optimum.

(c) In areas of higher pump lift for water these conditions arise in many ways. The land is cheaper in these areas, and in many cases no opportunity costs exist since the water is too expensive to use on other crops. Hence, on owner-operator land only the opportunity costs of $100 per acre are considered, and the 3-irrigation schedule is optimum. In most of these areas, if the water is limited and land unlimited, the farmer will be better off if he applies water at the minimum level to the maximum acreage.

(d) In a new area in the desert, where a certain quantity of water exists, this analysis must be applied to decide the most efficient number of acres to reclaim and to irrigate. The rate of investment per acre (price of land, reclamation, leveling, installment of ditches, etc.) must be figured. The annual costs of land will be (1) the interest on the investment, (2) other expected expenses as taxes, etc., (3) opportunity costs, and (4) operating costs. By incorporating the expected net lint price, the optimum irrigation schedule can be estimated with Figure 8. The number of acres to be improved will be determined by the total quantity of water available and can be calculated from Figure 8 as explained above.

(Additional acreages will be required to meet requirements for rotation crops and supplementary enterprises, but this matter is not pursued in this study.)

Case C.--Water and Land Variable

For the last condition to be analyzed, both water and land are considered as variable resources. This is a combination of the two former Cases in which water or land, respectively, was considered as the variable. When both resources are variable, the substitution of one for the other is considered, hence, water may be substituted for land and vice versa. In the former Cases the production function for each input was expressed by a curved line with two dimensions--yield versus one varying input--as one sees in Figures 5 and 7. Now, the new production function is expressed as a surface with three dimensions--yield versus two different varying inputs: land and water. The three dimensions are not shown, but the consequences of this surface as a contour map is shown in Figure 9.[1] This map is not required for the analysis, just as the graph of the production functions in Figures 5 and 7 were not necessary, but they provide a convenient way to illustrate the basic agronomic relationships upon which this economic analysis rests.

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[1] Detailed explanation can be found in (27, Ch. 5).

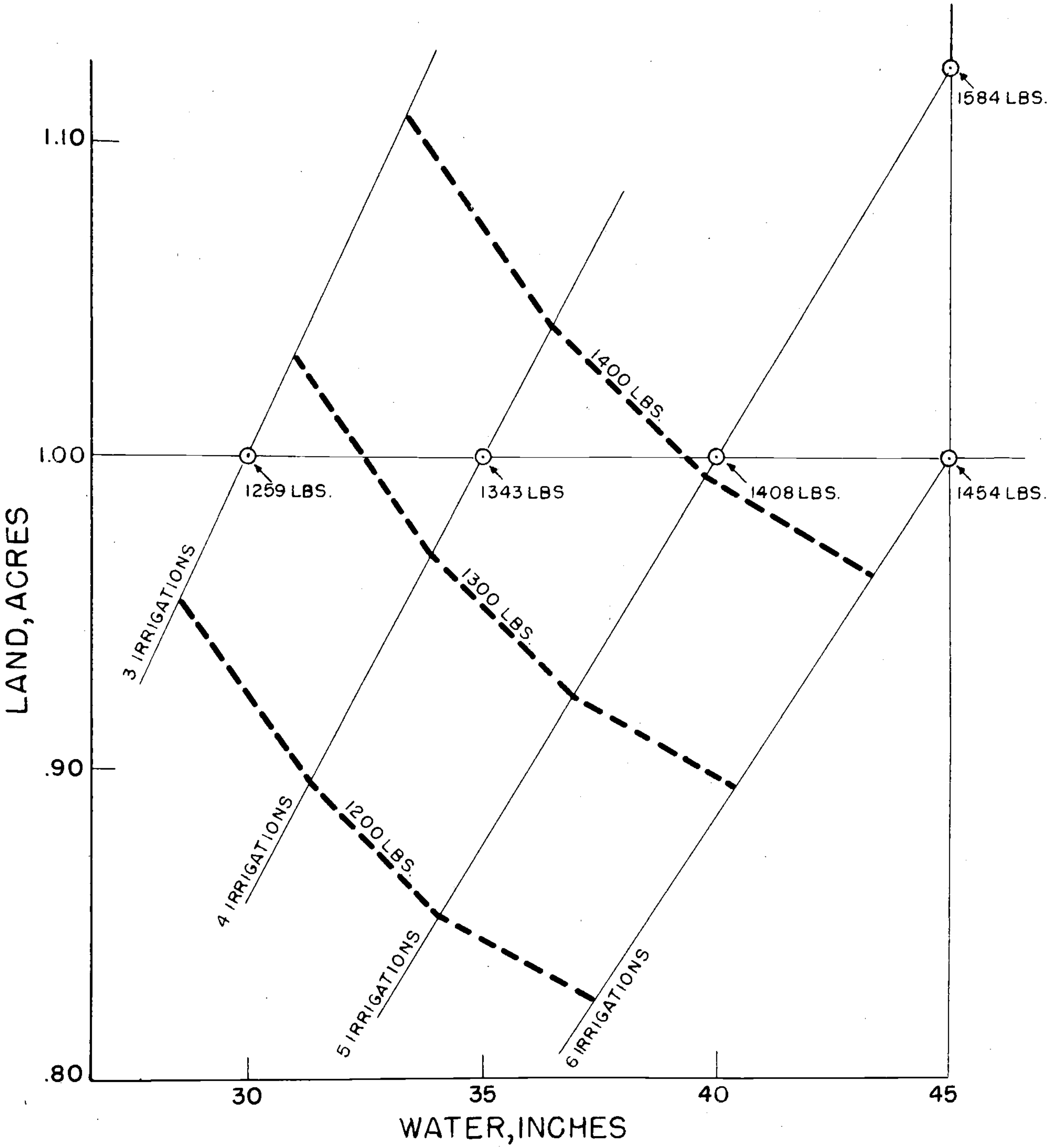

Figure 9. Cotton yield versus water and land[1] (both varying). (iso-product contour map)

[1] Derived from Figures 5 and 7.

Explanation of Figure 9

Each of the heavy (broken) lines, called "iso-product contour," represents a certain yield (1,200, 1,300, and 1,400 pounds of lint) obtained from different combinations of water and land inputs. Since these inputs can be combined only in definite "step" proportions because of the limitations imposed by conforming to definite irrigation schedules, the non-continuous linear curves described earlier in this chapter again emerge. Thus, 1,200 pounds of lint can be produced on .953 acres with a 3-irrigation schedule for which a total of 28.6 acre inches of water are needed. (Three irrigations are equivalent to 30 acre inches per acre; hence, .95 acre requires only 28.6 acre inches.) The same yield--1,200 pounds--can be produced also in any one of the following combinations:

On .89 acre with 31.3 acre inches in a 4-irrigation schedule, or

On .85 acre with 34.1 acre inches in a 5-irrigation schedule, or

On .825 acre with 37.1 acre inches in a 6-irrigation schedule.

By using the same procedure, the iso-product contour for 1,300 and 1,400 pounds of lint are derived. In the same way it is possible to calculate the contours for any other level of production within the constraints of 3-, 4-, 5-, or 6-irrigation schedules and for any other multiples of the data in Figure 9, provided that (a) the inputs remain in the same proportional combinations, and (b) that returns to scale are constant, i.e., assuming the same yield per acre for each irrigation schedule regardless of whether the scale of production is large or small.

One can see the two former production functions (Figures 5 and 7) in the production surface or contour map. The projection of the production function from Figure 5 can be seen in Figure 9 as the horizontal line for one acre. Along this line, the yield obtained on one acre with each of the irrigation schedules is shown and the amount indicated. The yields shown are the same as the yields indicated in Figure 5.

The projection of the production function from Figure 7 can be found along the 45 inches vertical line, starting at one acre and extending upwards, and by extending the irrigation schedule lines until they intersect. The yields shown at these points of intersection are the same as the yields indicated in Figure 7.

For finding the optimum combination of water and land, the prices of these inputs must be incorporated. This optimum is found by setting the marginal rate of substitution of the inputs equal to the reciprocal of their price ratio.

The following equation expresses the relation:

$$\frac{\Delta \text{ water}}{\Delta \text{ land}} = \frac{\text{price of land}}{\text{price of water}} \qquad (3)$$

The marginal rate of substitution is expressed by the left hand side of equation (3). This ratio expresses the amount by which one resource input is decreased as the input of the other resource is increased by one unit, providing the differing combinations of resource inputs produce the same level of output, i,e., move along the same iso-product contour.[1]

Equation (3) is used for finding the optimum level of combinations of inputs at different prices for both inputs. It was used for constructing Figure 10. Figure 10 is a tool which enables one to find easily the estimated optimum level of irrigation for different price combinations of water and land when both inputs are variable.

Figure 10 is constructed in the following way:

(a) Find the marginal rate of substitution, i. e., the left hand part of equation (3), for each change in irrigation schedule from 3 to 4, 4 to 5, 5 to 6 at the 1,200 pound yield level. For producing 1,200 pounds of lint, by adding one irrigation--say, from 3 to 4 irrigations--the water used was increased from 28.6 acre inches to 31.3 acre inches, while at the same time, the land used decreased from .95 acre to .89 acre. Hence, the marginal rate of substitution is:

$$\frac{31.3 - 28.6}{.89 - .95} = -45$$

This ratio is expressed in inches per acre. The minus sign is not significant in the analysis, hence, it is ignored.

[1] Detailed explanation can be found in (27, Ch. 6).

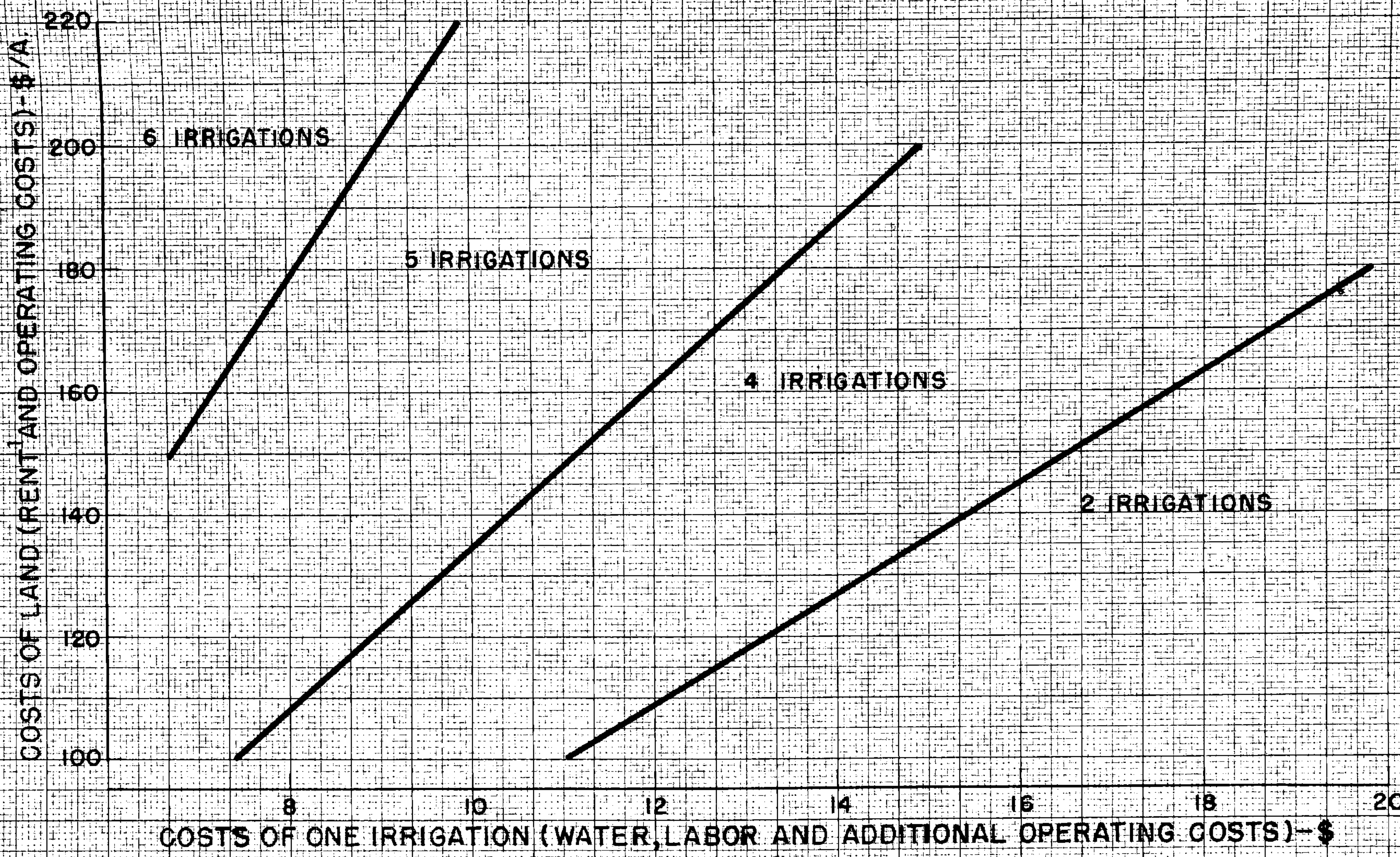

Figure 10. Estimates of the optimum level of irrigation for different cost combinations of land and water.

[1] Rent or charge for land where applicable and opportunity costs.

Since the findings in this study are expressed in irrigation schedules, it is necessary to change this ratio to one of the number of irrigations per acre. Since each additional irrigation is considered in the computations to add five inches to the total water requirement, the ratio of 45 is divided by five and a ratio of irrigations per acre of 9 is derived. Theoretically, the same ratio will be found for each of the different levels of production (so long as the two inputs are held in combinations of the same proportions). However, since there are small variations due to rounding, etc., the average for several ratios computed is found to be 9.06 and is used here.

(b) Set "a" equal to the right hand side of equation (3), i.e., to the reciprocal price ratio. This is done for two levels of land cost:

With land costs at \$100; $9.06 = \frac{100}{P./Irr.}$; $P/Irr. = \frac{100}{9.06} = 11.04$

With land costs at \$180; $9.06 = \frac{180}{P./Irr.}$; $P/Irr. = \frac{180}{9.06} = 19.89$

(c) Plot the two points and connect them by a straight line.

(d) Repeat the same procedure "a" to "c" above for each increase in irrigation schedule from 4 to 5 and from 5 to 6. (The marginal rate of substitution for these cases is 13.46 and 22.28, respectively.)

To find the optimum level of combination of the two resources of land and water, one must know his additional costs for adding one irrigation or one acre. Knowing them and using the marginal rates of substitution given here which are derived from the production functions shown in Figures 5 and 7, one can calculate his optimum combination of land and water. Figure 10 is provided so one can do this without the need of going through the calculations.

In contrast to Cases A and B, the price of lint is not incorporated since the price of lint does not affect the optimum rate of combination of two inputs. The price of lint determines: (a) the scale of production in case of diminishing returns to scale (constant returns to scale are assumed in this study), (b) the limits of profitable production. These limits can be found by budgeting alternative production combinations at various prices in such a way as to determine "break-even" prices. The budget must consider the level of yield, the profit, and the net price of lint in addition to the variable costs of the land and water which enter into production. It is possible to incorporate the consequences of such budgets into Figure 10. The outcome will appear as a series of iso-price lines, each line representing a price of lint which will connect the vertical axis with the horizontal axis and will intersect the border lines indicating the optimum levels of irrigation. For each net price of lint and for each level of irrigation, it is necessary to compute a budget for two price combinations of inputs. These lines will indicate the limit of profitable production at each of the assumed prices of lint at the yields resulting from each of the indicated combinations of land and water. Since many factors enter into these budgets, and they vary so widely from farm to farm, they have not been computed and plotted here.

As in Cases A and B, the information in Figure 10 shows areas of highest profit, or of least loss, at the various combinations of land and water costs shown. It does not show the limits of profitable production.

Looking at Figure 10, one sees that when costs of land are high and costs of water are low, a high irrigation schedule is optimum, i. e., water substitutes for land. On the other hand, when the costs of water are high and costs of land are low, a low irrigation schedule is optimum, i. e., land substitutes for water.

Similar consequences arise in the two former Cases. In Case A, in which land is fixed, a low irrigation schedule is optimum for high costs of water. In Case B, in which water is fixed, a high irrigation schedule is optimum for high costs of land.

Examples

Assuming that acreage allotments for cotton do not exist, this case is relevant to a wide range of conditions.

(a) In the Salt River Valley, this situation exists when the water supply is limited, but still the supply suffices to irrigate all the farmer's land with more than the minimum level of irrigation, and a profitable alternative crop exists. The land costs amount to $170 per acre (see Case B), and when one irrigation costs $12.62 (see Case A), the 5-irrigation schedule is optimum.

(b) In areas where water must be pumped 200 feet, the cost of one irrigation amounts to $13 and when the land costs amount to $140 per acre, the 4-irrigation schedule is optimum.

(c) In areas where water must be pumped 300 feet, the costs of one irrigation are $16 and when the land costs amount to $120 per acre (opportunity costs $20 and operating costs $100) the 3-irrigation schedule is optimum.

Comparing the estimates for Case C in Figure 10, with the estimates for the same prices of inputs in Case A in Figure 6, on one hand, or for Case B in Figure 8 on the other hand, one will find differences in the solution provided as may be seen in the following examples:

Example			Optimum irrigation schedule		
Area	Irrigation cost, $	Land cost, $/A	Case A	Case B	Case C
Salt River Valley	12.62	170	5	3	5
Water pumped 200 feet	13.00	140	5	3	4
Water pumped 300 feet	16.00	120	5	3	3

The differences result from the fact that different factors are considered. Whereas in Case A, costs of land are ignored because land is fixed, and whereas Case B, costs of water are ignored because water is fixed, in Case C the costs of both inputs are considered because both are varying and substitute for one another.

The decision as to which case is relevant and which figure to use depends only on the specific conditions of the individual farmer. If his land is fixed, and he strives to maximize the income per acre, Case A is relevant. Case B will be relevant when water is limited and the farmer strives to maximize income per unit of water. However, if both resources are considered to be variable, Case C is relevant for maximizing income to the farm.

Source of the Analytical Tools

The derivation of the second degree polynominal function has been performed in the standard manner.

The analytical tools which are used in this chapter are based mainly on tools that are illustrated and explained by E. O. Heady (27). Several times this source has been cited for detailed explanation.

Since the nature of the input is discontinuous, all the production functions are discontinuous also. Although the discontinuous nature of such a function is illustrated by Heady (27), no study was found in which a production function of this nature had been applied.

The analysis deals mainly with one resource--water. But it is handled in a unique way, in three different situations concerning its relations to land. No study was found in which one resource had been analyzed in this way. However, there are many studies on output versus variable resource--one or more--in which the regular continuous production function or surface is applied,e. g. ,(11, 29, 30, 43).

For estimating the optimum level of irrigation in the three situations which have been analyzed, price ratios must be equalized to physical production ratios. A tool has been used to enable one to find the optimum level of irrigation for any price ratio (Figures 6, 8, and 10). This tool is illustrated by Heady and Jensen (31) for estimating the optimum level of combination of two inputs. This tool has also been used in some studies. E. Heady et al. (29) used it to estimate the optimum level of combination of two inputs on one hand, and to estimate the optimum level of production according to the prices of the input and the output on the other hand. However, in these cases, the production function or surface is of the continuous nature. Therefore, there are an infinite number of possibilities for physical ratios and only certain ratios are picked out for equalizing to price ratios. In this study, where the discontinuous function is in use, the potential production is only at certain levels (four levels of irrigation). Therefore, there are only certain ratios to which price ratios must be equalized, and between them the price ratio can swing over considerable variation without change in the recommendations.

In summary, for two phases of the analysis, tools have been used which were not found in any former studies; the discontinuous function and the analysis of one resource (water) in its three different relations to land.

Conclusions and Summary

The general conclusions and implications of this chapter will be discussed in the concluding chapter.

1. The production function is of the discontinuous linear nature. All the analysis is founded on it, i.e., on the four levels of irrigations and four levels of output, only.

2. Allocating equal, or about equal, amounts of water between all his cotton fields will maximize the farmer's production and income.

3. Only marginal costs must be considered in estimating the optimum level of irrigation. Sometimes, especially for land, it is hard to determine these costs.

4. The marginal costs which have to be considered are:

(a) For one irrigation: (1) costs of one-half acre foot of effective water.

(2) costs of application

(3) additional (variable) operating costs

(b) For one acre of land: (1) rent or charge for land where applicable and opportunity costs.

(2) operating costs.

(c) Lint - net price of one pound in field.

5. Three situations of land-water relations are considered. Each case is illustrated by a production function and pictured by a chart (Figures 6, 8, and 10) for estimating the optimum level of production.

6. The examples show that all four irrigation schedules are optimum at the prices assumed, each for definite set of conditions considered in Arizona. For the optimum irrigation schedule for average conditions in 3 typical areas in Arizona see p. 107.

7. Production economics analytical tools have been used in the analysis. However, the author did not find some of them to have been applied in any former study.

CHAPTER VI

CONCLUSIONS AND APPRAISAL

Each of the former four chapters end with conclusions and summary; they will not be repeated here. The function of this chapter is to record general conclusions and interpretations of the study as a whole.

Yield per acre of land or per unit of water:

The usual yardstick for resource efficiency in agriculture is the yield per acre, since land is normally considered as a fixed resource. In the case of water, a different approach can be taken. As long as water is unlimited and additional water can be obtained (with additional costs), water is considered as any other variable resource. When water becomes limited, as the situation exists for example in Arizona and Israel, the yardstick must be changed. The yardstick of yield per unit of water then becomes meaningful, especially in areas where an unlimited supply of land exists, i. e., where additional areas of desert land can be brought under irrigation and put to production. In other words, water, not land, is here the limiting factor and, hence, must play the central role in planning for resource efficiency.

The concept of yield per unit of water must be considered and it must be brought to the attention of the agronomists, engineers, economists, and other scientists who concern themselves with resource efficiency questions. The ordinary way of thinking as well as the approach to and management of experiments concerned with water-land relationships in production must be adjusted by the adoption of this concept of yield per unit of water. After this concept has been adopted by the scientists, the people in charge of public administration and politics will adopt it. Existing social institutions will have to be adjusted accordingly.

This study is an experiment in manipulating this concept. The unit of measurement used is yield per acre, but still the approach is to find the optimum level of irrigation when water rather than land is the limiting factor. The consequences prove that this concept and attitude is also practical and economically feasible in certain conditions.[1]

This study is only one step in analyzing the economical optimum level of irrigation. A further step is required to analyze a farm or an area in which the different crops, in a crop-rotation, are considered as

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[1] C. O. Stanberry (54) refers to the physical factors--climate, plant, soil, and water--affecting the "moisture utilization efficiency", which is the expression of units of marketable crops produced per unit of water used in evapotranspiration (consumptive use). W. L. Parks (44) refers to some of these factors also. However, the economical optimum level of water application when water is the variable resource, may not coincide with the level of irrigation providing the highest moisture utilization efficiency.

a composite. Hence, no consideration is given to crop rotation in this study. Moreover, the prevailing practice by many farmers in Arizona is to ignore crop rotation in planning cotton production.

Scarcity of experimental data:

The number of studies of yield response to water in general, and especially in cotton production, are limited. The author did not find any economic studies of the production function of irrigation. Such studies are important and the need for them increases.

The unit of the variable input of water:

The data for this study are given as yield response to numbers of irrigations. The whole study is based on these units, which are also the appropriate units for making recommendations to farmers. However, the interrelations among consumptive use, number of irrigations, and timing of irrigations must be further investigated to make this unit more meaningful and to measure adequately its economic significance.

Uncertainty concerning the shape of the production function:

For the specific case of the production function for cotton in Arizona, more experiments are required to determine a more reliable function as well as for other reasons listed in the conclusions of Chapter III. The experiments which provided the data used in this study were not planned so as to provide the specific data required for a study of this nature. Only part of the experimental data were used for deriving the function and mainly the data for 3- and 6-irrigation schedules were available. A serious limitation in the data is the lack of information as to the output consequences of the 4- and 5-irrigation schedules, i. e., the intermediate levels of irrigation on one hand, and the lack of the extreme irrigation schedules, i. e., less than 3- and more than 6-irrigation schedules, on the other hand. The nature of the function was assumed to be convex, i. e., diminishing marginal returns. If this be true, then the 4- and 5-irrigation schedules are the optimum levels of irrigation for a wide range of economic conditions.

A definite and firm conclusion of this study is that the researchers must emphasize the 4- and 5-irrigation schedules, i. e., the intermediate levels of irrigation, in their future experiments in cotton irrigation in Arizona.

For the analysis in this study, two aspects of the nature of the function are important: (a) the difference between the yields for the 3- and the 6-irrigation schedule, and (b) the curvature of the function. The data provide evidence for point "a" (in most of the years the difference is statistically significant), but not so for point "b". Hence, no effort was made to derive a function which exhibits a statistically significant difference for point "a". It is believed that if the replications were used as observations rather than the averages of the replications, for deriving the function, the differences between the yields for the 3- and 6-irrigation schedules would be statistically significant ($\beta_1 \neq 0$), but the curvature of the function would still be statistically insignificant ($\beta_2 = 0$).

Value of this study is not dependent on the validity of the production function:

Because of the limitations of the data for deriving the function, the production function on which this study rests is a tentative one. This is a serious limitation to the validity of predictive conclusions reached in this study, especially because inferences from this function rest on shaky ground, hence, no reasonably valid recommendation to farmers can be derived from it. However, the importance of this study is not in its power to predict yield response to water, but is (a) the development of the economical approach to water as a limited resource, (b) the analysis of the relations of water to land in the three possible situations, and (c) the application of the analytical tools and procedures developed in this study. The procedure and tools are applicable to any data on yield response to water, for any crop, and for a wide range of production and economic conditions.

The discontinuous production function on one hand and the use of simple tools on the other hand enable one, given the relevant input-output data, to find directly the estimated optimum level of irrigation for any price conditions (Figures 6, 8, and 10). To use the tool provided, the relations of water to land in the farm or area must be determined first, i.e., whether water or land is the limiting factor. Accordingly, one of the figures (charts) will be applicable to the given circumstances. To use a figure for estimation, one must decide which of the relevant costs are variable and which of them are fixed. Next, the variable costs--the marginal costs--for water or/and land on the one hand and the net price of the product on the other hand must be estimated. With this information at hand, one can estimate directly the optimum level of production, i.e., the optimum combination of water and land for the specified conditions. However, since the estimate determines the level of irrigation and, consequently, determines the scale of operation, it may have an impact on the marginal costs considered and a new set of costs may emerge. In such a case, the optimum level of production and the relevant marginal costs must be coordinated by trial and error. (Examples of the use of these figures are given in the text.)

Simplicity of tools and recommendations to farmers:

The analysis of each water-land Case ends with a simple tool which enables one to estimate "easily" the optimum level of irrigation. Each of these tools rests on a shaky production function and this tool cannot be better than is the underlying function. However, a question arises--suppose the production function were statistically reliable, does it apply to the specific conditions that each farmer confronts? Probably not. Furthermore, to use these tools, the farmer must determine which of his costs is variable (marginal) and relevant to the case at hand and also must estimate the magnitude of each. (The net price of lint is estimated by subtracting the estimated harvesting costs--again, the marginal costs of harvesting, only--from the net market price). Another question arises--does the farmer or extension worker have the required records and knowledge to identify and estimate the regular and marginal costs in any specific farm situation?

These questions arise frequently when production economics or farm management research is applied by farmers or extension workers. When economic recommendations of feed or fertilizer, for example, are made, mainly the first question arises. When, for example, water, or even more so when land is considered, both questions arise because each of these inputs consists of a complex mixture of cost items.

This study assumes that the production function and the consequences of the tools, when applied to a specific case, are a general guide rather than a definite prediction. On the other hand, an attempt is made (a) to specify explicitly and by examples, as illustrations for typical situations, the main cost items which are relevant to each case (in Chapter V), and (b) to explain and estimate each cost item (Chapter IV).

The production function is the best estimate for Arizona:

The production function presented herein with all its shortcomings is still the best estimate available of cotton yield response to water in Arizona. If this function represents the true relations of cotton yield to water, the function and the whole study is applicable directly to many areas in Arizona and to other areas with some interpretations and adjustments to slightly altered conditions. (See the conclusions of Chapter II).

The examples given in the study of the use of the figures for estimating the optimum level of irrigation for average conditions in areas in Arizona suggest the following recommendations at the prices assumed. With an unlimited quantity of water, high irrigation schedules are optimum for maximizing income per unit of land. With a fixed quantity of water, low irrigation schedules are optimum for maximizing income per unit of water. If both resources are limited or unlimited, i. e., the substitution of one resource by another is considered, for maximizing income to the farm, a low irrigation schedule is optimum when water is expensive compared to land, and a high irrigation schedule is optimum when water is inexpensive compared to land (see p. 107).

Water use efficiency as goal of society and individual:

The consequences of this study show that not only can land be substituted for water, but it is economically feasible for the farmer to do so under certain conditions. Since the over-all quantity of water is limited in certain areas, the goal of the society is to maximize income and product from this limited resource. Here is a case where, under a wide range of conditions, the goal of the individual matches the goal of the society. (These goals are pointed out in the Introduction). However, adjustments of the existing situation and social institutions to fit the required change are difficult. Inconsistency in these goals may occur when, for example, water is limited in an area as a whole, whereas for the individual farmer the water supply is unlimited, as conditions are in the Salt River Valley. Finding the proper way to reconcile goals under conditions such as these is a special and important subject to be studied.

The inefficiency of acreage allotments when applied to irrigated cotton production under Arizona conditions emerges also as a conclusion from this study. The level of cotton irrigation in practice under many of the conditions in Arizona is not at the level of maximum economic efficiency. Farmers under these conditions could increase their incomes and increase the efficiency of use of scarce water by reducing the level of irrigation with consequent lowering of yield per acre and by planting and applying their limited water to more acres. Hence, efficiency of cotton production would be increased if allotments of cotton were placed on the amount of lint produced rather than on acreage.

The consequence of studies of this kind toward increasing effective use of Arizona's scarce agricultural resources, particularly water, suggests the importance of continuous research along the lines explored in this study.

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APPENDIX

Table 1.

Experimental Details

Table 1. Yields of cotton lint for different irrigation schedules, 1954-1958, at the University of Arizona Mesa Farm and Cotton Research Center.[1]

Year	Exper.	Treat. no.	Recom. sch.	No. of irr.	c. u. (inches)	Irrigation dates							Yield, lint lbs./A.
1954	Ph_2	3	+	3	32.7	6/17	7/14	8/19					1,539
		7		5		5/25	6/22	7/8	7/29	9/1			1,810
		6	+	6	47 est.	"	"	"	"	8/19	9/9		1,981
		5		7	54.3	"	"	"	"	"	"	9/27	1,896
1955	Ph_2	3	+	3		6/15	7/15	8/15					1,398
		8		4		"	"	8/11	9/7				1,432
		6	+	6		5/26	6/23	7/8	7/21	8/16	9/17		1,439
		5		7		"	"	"	"	"	9/7	9/29	1,251
1955	Ph_4	3		3		5/24	6/28	7/12	8/3	8/15	9/3		1,209
		7		5		"	"	"	"	--	"		1,365
		1	+	6	32.8	"	"	"	"	"	"		1,415
1956	Ph_4	3		3		5/29	6/21	7/10	7/26	8/15	9/7		940
		1	+	6	42.1	"	"	"	"	"	"		1,130
1958	Ph_2	2	+	3	32.2		6/16	7/15	8/13				1,117
		3		4	38.7		"	"	"	9/9			1,040
		5		5	35.9	5/22	6/23	"	8/11	"			1,118
		1	+	6	41.6	"	"	7/9	7/29	8/13	9/9		1,289
		4		7	49.0	"	6/16	7/2	7/15	7/29	8/11	9/3	1,464

[1] Source of data: unpublished reports (18, 1954-1958). For details see next page.

EXPERIMENTAL DETAILS

The experiments 1954 Ph_2, 1955 Ph_2 were conducted at the University of Arizona Mesa Farm. The other experiments were conducted at the University of Arizona Cotton Research Center, Phoenix.

Each treatment was replicated four times, except that 1955 Ph_2 was replicated three times and 1958 Ph_2 five times.

All the yields for the tabulated treatments were included when deriving the mathematical function, except for the seven irrigation treatments.

Variety: Acala-44.

Soil: deep, fine texture

Water: 700-800 ppm salt

Irrigation: basin and furrow methods were used; in this soil both methods give the same results. All treatments were given approximately one foot preplanting irrigation. All post-planting irrigations were approximately six inches each. Only the post-planting irrigations are considered in Table 1.

Planting date was: approximately April 5.

Number of cultivations: 3 -- No serious weed problems.

Planting space: 40 inches between rows, 8 inches in row,

20,000 plants per acre.

Insect control: regular practice.

Fertilizer: 1954 -- 60 pounds nitrogen

1955 -- 100 pounds nitrogen

1956 -- planted after alfalfa without fertilizer

July 25 -- 120 pounds nitrogen

1958 -- 100 pounds nitrogen

For treatment 3, 1955 Ph_4 and 1956 Ph_4, water was applied to every other row, alternating with each irrigation. The yields of these two treatments were included as 3-irrigation schedules when deriving the function. The reasons for this are the same as these given later relative to including the 7-irrigation schedule as if they were 6-irrigation schedules.

For 1958, treatment 4 and 5, water was applied when 65 and 80 per cent of the available water in the soil, respectively, had been depleted.

For computing the function, the data in Appendix Table 1 was supplemented by data from "Experiment Ph_1" for cotton tillage at the University of Arizona Mesa Farm for the years 1954-57.[1] Although the

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[1] Source of data, Unpublished Reports (18, 1954-1957).

7-irrigation schedule was used in this experiment, the average yield was not significantly different from that of the 6-irrigation schedule in Table 1. Consequently, these yields for each year (average of 20 replications) were taken to re-enforce the yields for the 6-irrigation schedule. In addition, experiments conducted by K. Harris[1] for many years in the Salt River Valley, show no significant difference in yield for 5, 6, and 7 irrigations.

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[1] Agricultural Research Service, U. S. Department of Agriculture, Phoenix, personal communications.