EFFECT OF WIDE-BED AND ALTERNATE FURROW IRRIGATION ON WATER USE AND YIELD OF COTTON

by

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

The effect of 80- and 90-inch wide-bed cultural practice systems and alternate furrow irrigation on soil moisture distribution, water use and yields of cotton were studied as compared to every furrow irrigation of conventional 40-inch rows.

The every furrow irrigation treatment had the highest soil moisture content throughout the season and received the most water. Alternate furrow irrigation treatments had the lowest soil moisture content and received about 30 percent less water than the every furrow irrigation treatment. There was limited soil water movement from the irrigated furrow to the adjacent non-irrigated furrow. The 90-inch beds had higher soil moisture contents than the 80-inch beds, with about equal depths of water applied. There was considerable lateral movement of water toward the bed center. The wide beds received about the same quantity of water as the alternate furrow irrigation treatment.

No significant difference was found in seed or lint cotton yields due to row spacing or alternate furrow irrigation.

The wide-bed cultural practice and alternate furrow irrigation systems had similar water use efficiencies,

expressed as lint yield per inch of applied water. These systems increased the water use efficiency about 23 percent over the every furrow irrigation system.

INTRODUCTION

This year a serious drought plagued parts of the United States and blighted nearly all of Western Europe. Consequently, a tremendous decrease in crop production occurred resulting in food shortages, and sky-rocketing prices face the whole world.

Investigators have been working to find an answer to the drought problem. Weather modification, including chemical cloud seeding, is said by the meteorologists to be a dangerous and a primitive art. Desalting ocean water, on the other hand, is a costly and energy consuming process.

Water storage, conservation and efficient use remain as the only immediate solution to the water scarcity problem. An average farm irrigation efficiency of 49.6% was reported by Tyler (39) for the Minidoka project in Idaho. Erie (8) reported a farm water use efficiency of 57.9% for 22 selected irrigation projects in the western United States. Water is being needlessly wasted, and crops are irrigated at times when there is still ample water available to the plants in the soil.

Irrigation scheduling practices have not changed significantly from those observed by Israelsen et al. (19) some three decades ago. However, the potential for better irrigation management has increased substantially due to better water control facilities, improved design criteria, more reliable methods for estimating evapo-transpiration, and commercially available soil moisture measurement instrumentation.

Much work has been conducted recently towards reduction of energy use, through better management and improved cultural practices. Trickle and sprinkler irrigations are being widely adopted for more precise control of water.

Different production systems used in growing cotton and associated crops are being evaluated at the University of Arizona Experimental Farm to minimize energy used in machine operations, water needed for irrigation and fertilizer application while maximizing net income.

As part of this work, the purpose of this study is to evaluate wide-bed cultural practice systems and alternate furrow irrigation as compared to every furrow irrigation of conventional 40-inch rows. Water use efficiency, soil moisture distribution and yields of cotton (*Gossypium hirsutum* L. var. Deltapine 16) are the parameters of comparison.

LITERATURE REVIEW

Wide-Bed Cultural System

Wide-bed cultural practice, first given the code "WF" (wide-flange) describes the use of fewer linear feet of row per acre and could result in production savings (12).

Williford, Fulgham and Wooten (40) reported a reduction in the production costs of cotton in the Delta area without a significant reduction in yields through the use of a wide-bed cultural system. One restriction in the early research was the lack of proper power units and adequate wheel spacings to accommodate the wide beds.

Longenecker, Thaxton and Lyerly (24) showed that variable row spacing (V.R.S.) for cotton production, with alternate close and wide row spacing and water applied between the close spaced rows, was effective in reducing production costs by applying less water while still maintaining yields. A sharp increase in water use efficiency was obtained.

Fulgham, Williford and Cooke (12) confirmed the possibility that yields of cotton on wide-beds may equal or exceed those obtained from conventionally planted cotton for a given soil type. A skip-row effect, without skipping any rows, and better weed and traffic control was obtained by the use of wide beds (40). Hawkins and Peacock (16) reported that average lint yields were significantly greater for skip row planting when eight varieties of Upland cotton were planted in regular every row and in 2 x 2 skip-row systems. This was attributed to the increase in yields of the outer rows of the skip row method.

Bruce (6) found that cotton yields per unit length of row from alternating 40- and 80-inch row intervals were 27 to 34 percent higher than that obtained from treatments planted in uniform 40-inch row intervals. He reported that there was more moisture midway between the 80-inch rows than immediately adjacent to the row.

In a study of controlled traffic and reduced inputs for cotton production, Colwick and Barker (7) reported a slight but not significant advantage for 80-inch beds over 40-inch rows. A row configuration of four rows planted 15 inches apart on the 80-inch wide-beds gave the best yield trend. In their preliminary results of wide-bed, narrow-row cotton production, Porish, Brister and Mermond (33) stated that wide-bed, narrow-row system yielded slightly better than the conventional rows. A definite reduction in compaction, excellent soil tilth in the crop area, and better weed control was obtained.

Briggs, Buxton and Patterson (5) found that the greatest advantage of two rows per bed over single rows occurred at the lowest plant population of short season cotton. The average yield increase was 11.1, 7.8 and 5.7% at 30,000, 60,000, and 80,000-90,000 plants per acre respectively, in favor of two rows per bed over one row per bed.

Hawkins and Peacock (17) reported that 10- and 20-inch spaced rows yielded more cotton than the conventional 40-inch rows. However, there was no significant difference in either lint percentage or boll size. Grissom and Spurgeon (15) using 20-, 40-, 60-, and 80-inch rows, noticed that the 20-inch rows were more adversely affected at dry soil moisture conditions. No significant differences were found in cotton yields due to any of the row spacings.

Grimes and Musick (13) found that with limited irrigation, pre-plant only, and low seasonal rainfall, higher yields were obtained when sorghum plants were spaced in wide rows. Moisture was depleted faster in narrow rows and much of the available moisture was used for foliage production prior to grain formation. With wide rows, moisture remaining between rows was used later in plant development resulting in higher grain yields.

Musick and Dusek (28) concluded that two rows per bed produced equivalent or higher grain sorghum yields than single row spacing under limited irrigation, even though plants in double rows used water at a slightly higher rate and incurred moisture stress sooner.

Alternate Furrow Irrigation

Alternate furrow irrigation gives an opportunity for reducing the total quantity of irrigation water applied and permits irrigating a field in a shorter time period with a given water supply (30). This reduction may not reduce yields appreciably and thus increase the water use efficiency.

Grimes, Walhood and Dickenes (14) showed that alternate furrow irrigation gave control over plant water stress during a period when it is necessary to slow vegetative growth and promote flowering. They found that yields of cotton from alternate furrow tests were as good or better than yields from regular furrow irrigation, with considerably less water used.

Jones (22) reported that cotton plants were overstressed during the fruiting period with alternate row watering of 38-inch rows. Satisfactory results were obtained when a 27-53 spacing was used with the narrow middle rows being irrigated. He recommended the use of 30-50 variable row spacing.

New (31) indicated that irrigations should be more frequent when alternate furrows are being irrigated rather than every furrow. A reduction in grain production was obtained with one-third less water applied to alternate furrows; but an increase in production was gained when equal amounts of water were given to both treatments.

Fischback and Mulliner (10) reported lateral movement of water from the irrigated furrow to the adjacent dry furrow to a depth of three feet. No statistical difference was found in corn yields on any soil texture when comparing every furrow versus every other furrow irrigation. Also no significant difference was evident when water was run in the same furrow or alternated between adjacent furrows, with the same amount of water being applied. O'Neill loamy sand which is a course-textured soil, shallow in depth, yielded less than silt loams. The low water holding capacity of O'Neill loamy sand necessitates light frequent irrigation.

Allan and Musick (1) observed that the non-irrigated furrow, in every other furrow irrigation, did not serve a useful purpose when the same furrow was irrigated each time. Box et al. (4) noticed that considerable drying at the surface occurs in irrigated furrows of alternate furrow methods before the recurrence of irrigation water in the furrow. Alternate furrow irrigation did not decrease yields while decreasing water application by 30%.

Musick and Dusek (30) recommended alternate furrow irrigation be practiced for furrows spaced 30 inches or less in slowly permeable soils. Forty-inch row spacings resulted in irrigation furrows being spaced too wide for adequate soil wetting on the lower part of a graded furrow irrigated field. A slight, but not significant, effect of every other furrow irrigation on water intake and yields was obtained on Pullman silty clay loam. A reduction in yields of grain sorghum and water intake was obtained on Pullman clay loam.

Water Requirement of Cotton

The water requirement of cotton, also expressed as "evapo-transpiration" or "consumptive use" or in "water use efficiency" units, depends on many factors such as climate, variety, soil type, length of growing season, etc., together with the efficiency of scheduling and applying irrigation water (23). Franzoy (11) stated that frequent monitoring of moisture disappearance and replenishment is an essential process for determining variations in actual evapotranspiration and correcting and maintaining predictions.

Taylor (38) indicated that instruments for measuring soil moisture potential greatly simplified obtaining knowledge of when and how much irrigation water to apply. They eliminated the need for detailed determination of soil moisture content, climatic data records, and use of complicated empirical equations for determination of evapo-transpiration.

Estimated consumptive use rates coupled with gravimetric determinations of soil moisture provide an excellent basis for predicting irrigation need (11). Consumptive use requirements by crops, both daily and annually, have been studied for several years by Erie, French and Harris (9). They reported a mean of 41.2 inches of water consumptively used by cotton in Arizona. About 60% was extracted from the top two feet of soil, 75% from the top three feet, and small amounts were used from the fourth, fifth and sixth foot depths.

The predicted pattern of cotton water use is always characterized by a very marked mid-season peak. The average consumptive use of water by cotton ranges from 20 inches to 42 inches depending on variety and climatic conditions (23). Irrigation timing has a great effect on crop yield and quality (21). Both delayed and/or inadequate irrigation, and excessive application invariably reduce yields.

Marani and Fuchs (25) reported in Israel that the amount of water applied as a single irrigation to cotton ("Pima 32" variety) was that needed to wet the soil to the depth of three feet at the beginning of flowering. Higher amounts of water, than the six inches applied, did not give significantly different results.

Marani and Horwitz (26) observed that a single irrigation applied at the beginning of flowering improved the lint yield of cotton by increasing both the number and size of bolls. About 1.2 inches of water was sprinkled after planting to initiate germination. Spooner, Caviniss and Spurgeon (35) found that water applied before blooming had no beneficial effect on yields of Upland Cotton.

Schneider, Musick and Dusek (34) concluded that one well timed spring irrigation increased yields more than two poorly timed applications, and two well timed applications increased wheat yields more than three poorly timed irrigations. Musick and Dusek (29) reported that reducing size of seasonal irrigations slightly reduced grain yields, but irrigation efficiencies were significantly increased. They confirmed the practical use of limited irrigation water to obtaining good yields and efficient use of irrigation water, while reducing the irrigation water requirement.

Soil Moisture Determination

Numerous techniques have been developed to measure the quantity of moisture in the soil and/or its availability to plants. Some of the methods used are moisture budgets, oven drying, carbide, gypsum blocks, tensiometers and neutron moisture meters.

Allamaras and Gardner (2) reported that the greatest source of variation in soil sampling is attributed to the random variability among sampling locations. The number of samples or measurements required to produce a desired degree of accuracy is highly variable and depends on the uniformity of soil, water application and sampling technique used (20). Large numbers of samples can be handled by the oven drying method. It is the most accurate, but requires much time and effort. A disadvantage of this method in determining soil

soil moisture content is the fact that a specific location cannot be measured more than once.

Taylor (37) reported that a large number of samples must be taken to determine accuracy of the water content. Holmes et al. (18) justified the need for large numbers of samples because of uneven application of water due to local undulations, cracks, changes in soil structure and pore size distribution. Plants also remove water from the soil in an uneven way.

Soil moisture determination is becoming less tedious by the techniques developed using soil moisture potential measuring instrumentation. It is gaining more importance for irrigation research and irrigation farm management practices.

MATERIALS AND METHODS

Soil moisture distribution, water use efficiency and yields of cotton (*Gossypium hirsutum* L. var. Deltapine 16) under wide bed cultural practice systems and alternate furrow irrigation were studied during the 1976 growing season. Experiments were conducted at the University of Arizona Experimental Farm at Marana.

Experimental Layout

Four treatments were used in the experiment: three row spacings and alternate furrow irrigation. The row spacings were 80-inch wide beds with two rows of plants per bed spaced 40 inches apart (Figure 1c),90-inch wide beds with 50 inches between the two plant rows per bed (Figure 1d) and conventional 40-inch rows (Figure 1a), with every furrow being irrigated. Alternate furrow irrigation was practiced on 40-inch rows with water being applied in every other furrow and in the same furrow each time (Figure 1b).

The four treatments were completely randomized in a 10-acre field with each treatment being replicated four times. The plots were 600 feet long and 40 feet wide except for the 90-inch wide beds which were 45 feet wide.

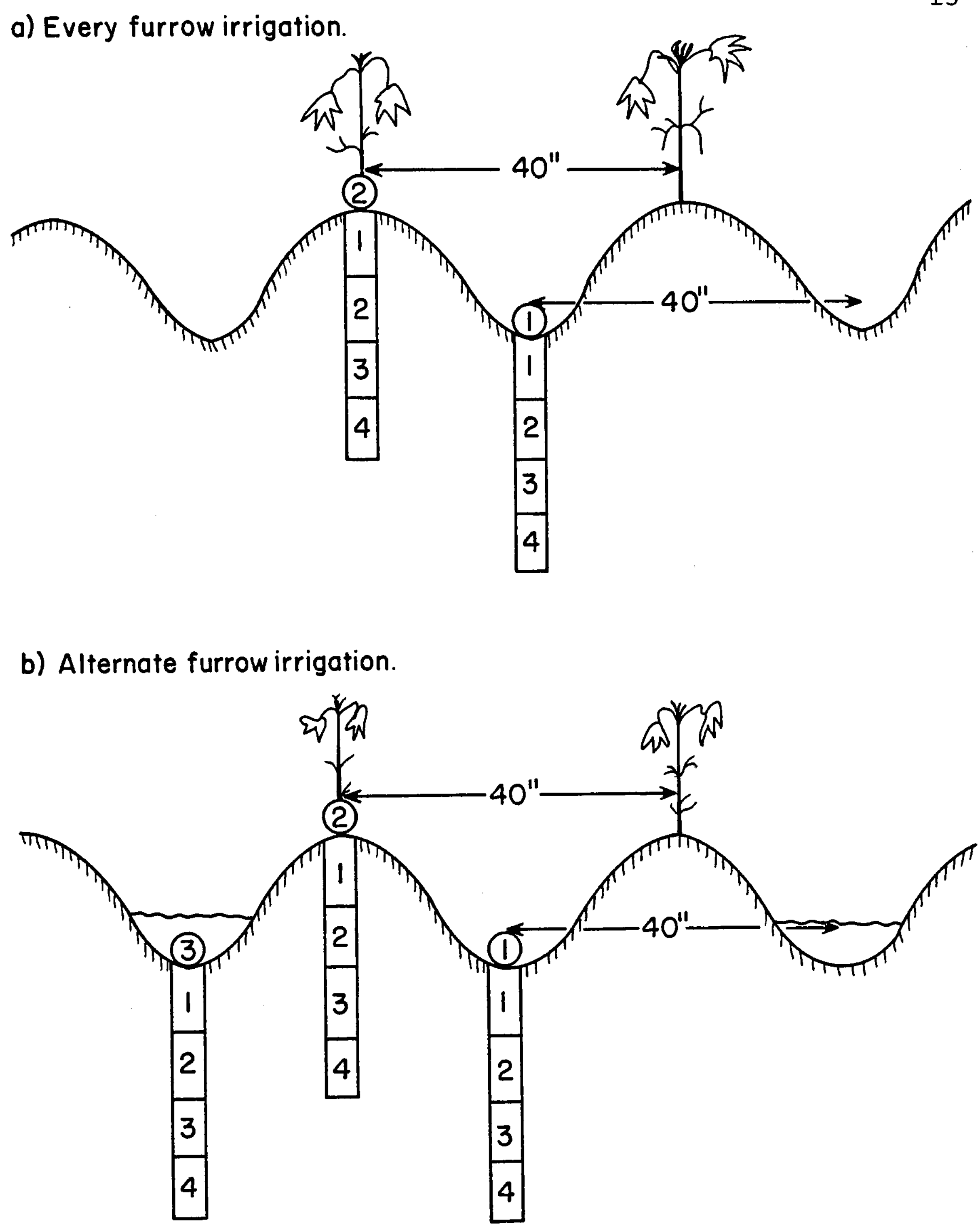
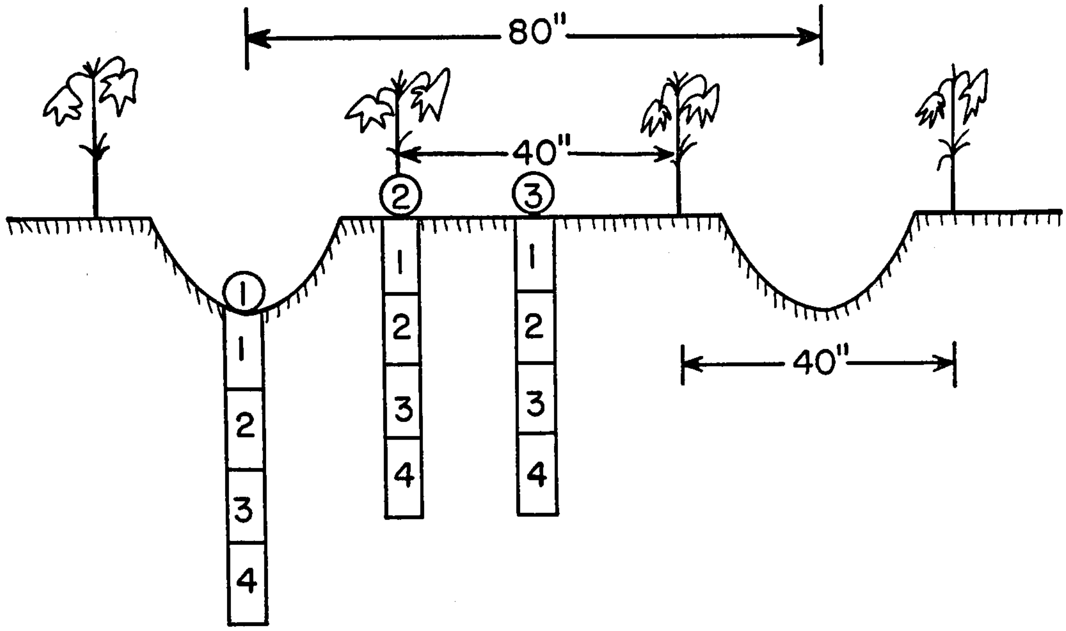


Figure 1. Soil sampling positions and row spacings.

c) 80-inch wide-beds.



d) 90-inch wide-beds.

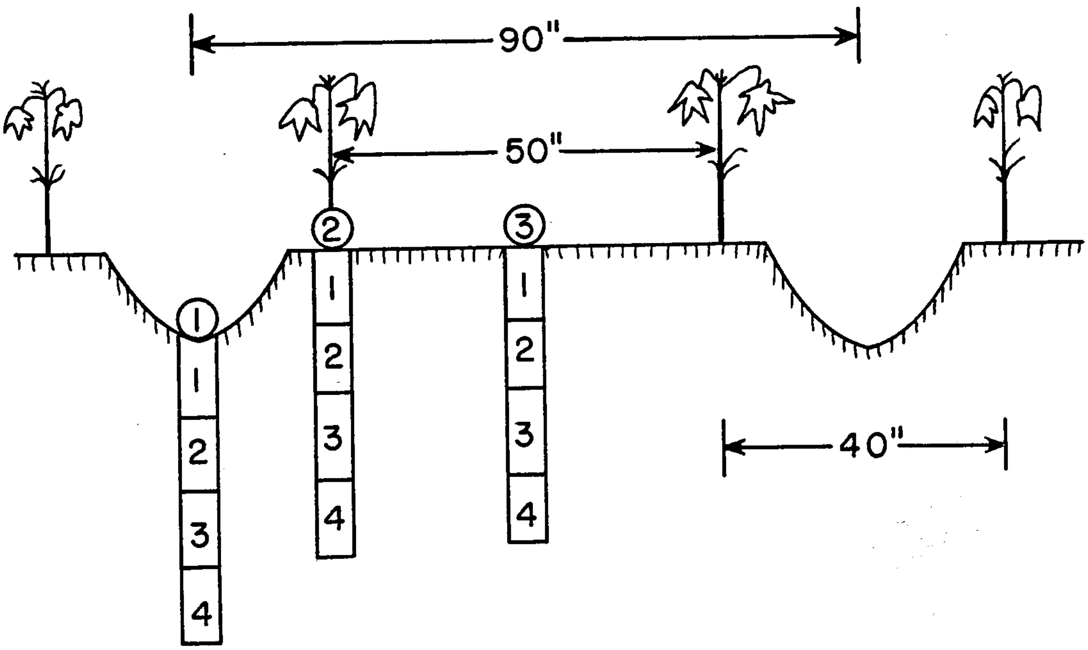


Figure 1. -- continued.

The wide beds were listed with all subsequent wheel traffic in the center of the beds. Conventional 40-inch rows were plowed, disked and planed.

Water Management

Irrigation water was supplied from a well located on the southeast corner of the farm. Irrigation water is classified as medium salinity-low sodium water (27).

The quantity of water applied to each treatment was measured by a critical depth flume, with a 60-degree triangular throat and constructed of galvanized sheet metal (Figure 2). The flume was installed in the irrigation lateral and the depth or head of water on the flume was measured. A calibration chart was then used to convert the head into flow in cubic feet per second. The flow rate in cubic feet per second was multiplied by the time of application and divided by the area to obtain the depth of water applied in inches.

Gravimetric determination of soil moisture content and soil moisture deficiency estimations by the feel and appearance method coupled with the crop behavior were used to assess when and how much water to apply. The skill of the irrigator also determined the depth applied.

Water was delivered to the furrows by siphon tubes from a concrete-lined irrigation ditch. Late in the season,

Figure 2. The critical depth flume used to measure the flow rate.

earth dikes and plastic checks were made in some of the furrows where water penetration was a problem.

The 80- and 90-inch wide beds were irrigated together each irrigation. Water application to the every- and alternate-furrow irrigation systems was measured separately. All treatments were irrigated together twice during the season. All furrows of the alternate furrow irrigation treatments were irrigated, by error, in the post-planting irrigation.

All treatments were pre-irrigated from March 15-20 and replanted on April 21. Each treatment received six irrigations during the periods April 22-24, June 15-17, July 19-21, August 3-5 and 16023, and September 7-9.

Soil Sampling

The soil on the farm is alluvial in origin and classified as Pima clay loam (32). The upper foot of profile has a soil moisture capacity of about 1.8 inches of available water. A plow pan 12-18 inches below the soil surface restricts the water movement through this region. The soil becomes sandy loam below the 36-inch depth.

The gravimetric method for soil moisture determination was used during the study. Soil samples were taken and oven dried for 24 hours at 105^{o}C. An Oakfield probe and a King tube were used for taking soil samples. Soil samples were taken from three positions in the wide beds; in the furrow, in the plant row and in the center of the bed (Figures 1c and 1d). Two sampling positions were used for every furrow irrigation treatment; in the furrow and in the plant row (Figure 1a). Three sampling positions were also used for alternate furrows; in the non-irrigated furrow, plant row and the irrigated furrow (Figure 1b).

Soil samples were taken at increments of one foot from the surface to the four-foot depth. Sampling was done about 250 feet from the irrigation ditch (the field was 600 feet long) and replicated twice, in east and west sides of the field. Hence a total of 88 samples were taken each time.

Yield Data Collection

Defoliant was applied on September 26 and the plots were picked on October 13 using a two row cotton picker. The entire field was divided into two parts; north and south so that the difference in yields due to the restricted water penetration in the southeast and northwest corners of the field could be obtained.

The four center rows of each treatment (12 rows) were picked and weighed to get the seed cotton yields in pounds per four rows and then converted to seed cotton yield in pounds per acre.

RESULTS AND DISCUSSION

Wide-bed cultural practice systems and alternate furrow irrigation for cotton production were evaluated as compared to every furrow irrigation of conventional 40-inch rows with respect to soil moisture distribution, water use and yields. The three parameters are interrelated, but each of these will be discussed separately and their combined effect will then be integrated by means of water use efficiency.

Water Application

Table 1 shows the dates of irrigation and depth of water applied in inches to each of the treatments. The every furrow irrigation treatment received a total of about 37.6 inches of water, about 10.5 inches being applied as pre-irrigation. Alternate furrow irrigation treatments received about 26.6 inches of water with 5.4 inches being applied as pre-irrigation. Wide-bed plots received about 25.6 inches of water; 10.4 inches being applied as pre-irrigation.

All the furrows of the alternate furrow irrigation plots were irrigated, by error, in the post-planting watering. In the two irrigations where the whole field was

Table 1. Dates of irrigation and depths of water applied in inches.

Irrigation Date	Every Furrow	Alternate Furrow	Wide-beds
3/15/76	--	--	10.4
3/18/76	10.5	--	--
3/20/76	--	5.4	--
4/22/76	9.5	--	--
4/23/76	--	9.5	--
4/24/76	--	--	4.9
6/15/76	--	--	2.5
6/16/76	3.5	--	--
6/17/76	--	2.8	--
7/19/76	3.5	--	--
7/20/76	--	--	1.8
7/21/76	--	2.3	--
8/3/76	4.7	--	--
8/4/76	--	--	2.4
8/5/76	--	2.4	--
8/16/76	--	--	1.7
8/19/76	--	2.2	--
8/23/76	2.9	--	--
9/7/76	--	2.0	--
9/8/76	--	--	1.9
9/9/76	* 3.0	--	--
Totals:	37.6	26.6	25.6

* Total rainfall during the season was 5.9".

irrigated, a 10% higher intake rate of the wide beds was assumed for the purpose of calculating the amount of water applied to each treatment. This was based on an assumed reduction in compaction and better soil tilth in the wide beds, since there was no wheel traffic in the furrows.

The wide bed and alternate furrow irrigation treatments received about the same amount of water, which was about 30% less water than the every furrow irrigation plots.

At the beginning of the season during pre-irrigation, the wide beds received a substantially larger amount of water than the alternate furrows. As the season progressed, alternate furrows received more water than the wide beds (Figure 3), although the difference in amounts applied was not appreciable. This could be explained by the fact that the wide beds had more water in the beginning of the season due to water movement to the bed center. Once moisture was stored in the bed center, it served as a reservoir and smaller water applications sustained plant growth later in the season.

Poor water penetration was a serious problem in the southeast and northwest corners of the field as revealed by moisture determination and crop appearance. Soil moisture measurements also showed that sufficient water might not have been applied.

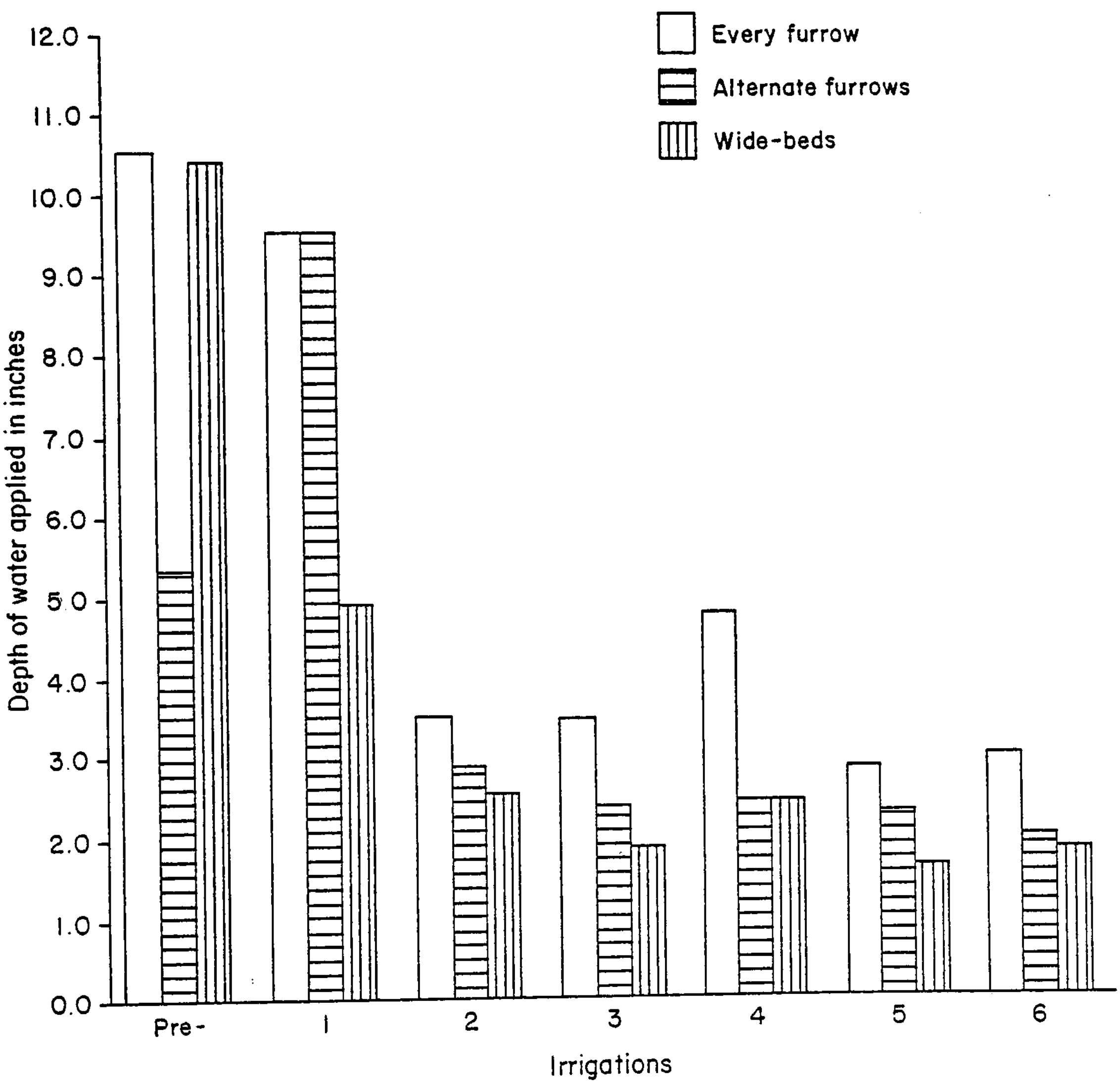


Figure 3. Depth of water applied to each treatment.

To slow the water movement in the furrows to the lower end of the field, in those areas where a water penetration problem was encountered, earth dikes and plastic checks were made in the furrows. Unfortunately this change came too late in the season and plants already showed stunted growth.

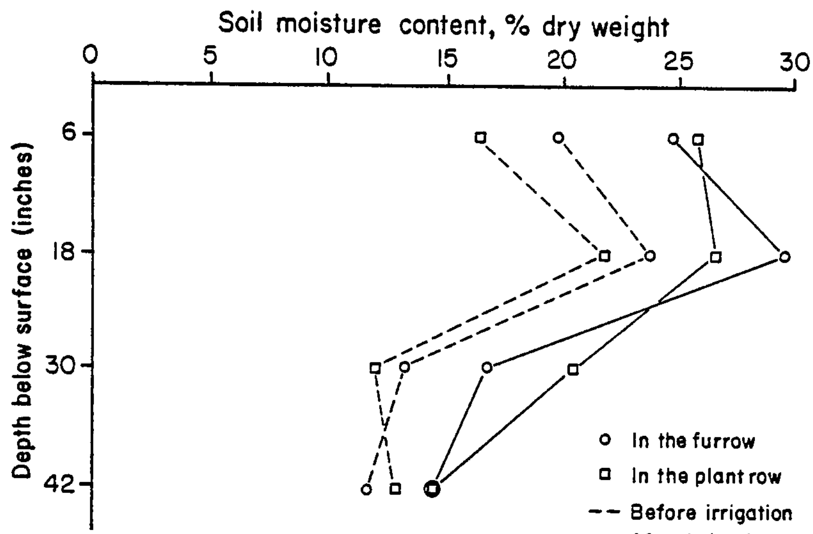
Soil Moisture Distribution

To study the soil moisture distribution under wide beds, and alternate and every furrow irrigation of conventional 40-inch rows, soil moisture determination samples were taken seven times during the growing season. Samplings were taken at increments of one foot from the surface to the four-foot depth. Each foot midpoint was taken to represent the soil moisture content of that foot for the purpose of data presentation, i.e., the six-inch depth for 0-1 foot, etc. Average soil moisture percentage with respect to position and date of sampling is shown in Appendix A for different treatments and dates of sampling.

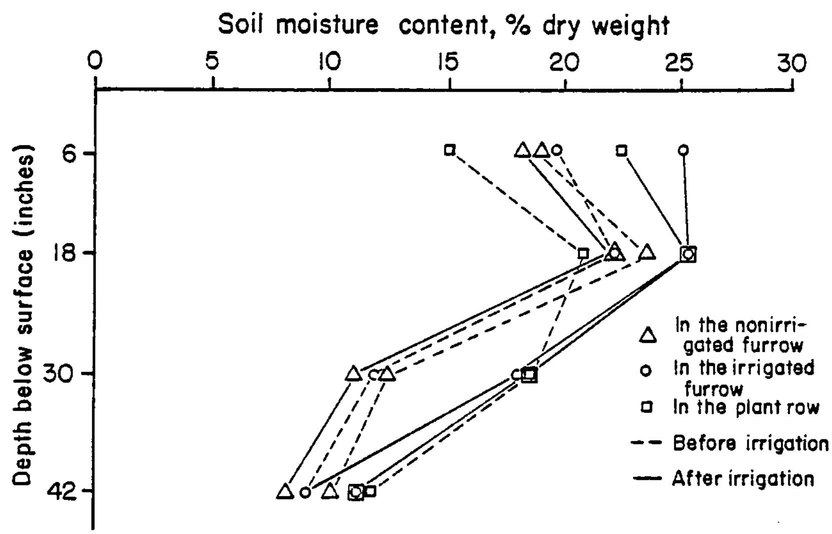
Soil moisture distribution with depth showed a general trend for the second foot to have the highest moisture percentage, on dry weight basis. This might be due to the presence of a plow pan in the second foot which restricted water penetration. It was also noticed that there was only a small change in moisture content in the fourth foot due to irrigation. This indicates that not enough water had been applied and/or water storage was less due to the sandy loam layer which prevails at this depth. Plant rows for all treatments had the lowest soil moisture content in the upper three feet, indicating that most of the moisture needed for growth was depleted from this region.

Figure 4 illustrates the effect of one irrigation on soil moisture change and the distribution with depth. Soil sampling before and after irrigation (June 15-17) shows an increase in the moisture content, under every furrow irrigation, throughout the profile (Figure 4a). The average increase in soil moisture content was about 5 to 10 percent in the upper three feet for both the plant row and in the furrow due to irrigation. The change in the moisture content was relatively small in the fourth foot. About 3.5 inches of water was applied in this irrigation.

Alternate furrow irrigation plots responded to irrigation in the upper three feet with about 5 to 10 percent increase in soil moisture content in the plant row and in the furrow (Figure 4b). In contrast to every furrow irrigation treatment, the plant row of alternate furrows had more moisture than the irrigated furrow before irrigation below the second foot depth. Lateral movement of water occurred from the irrigated furrow to both side beds but not to the non-irrigated furrow as shown by soil moisture determination data of the non-irrigated furrow. There was

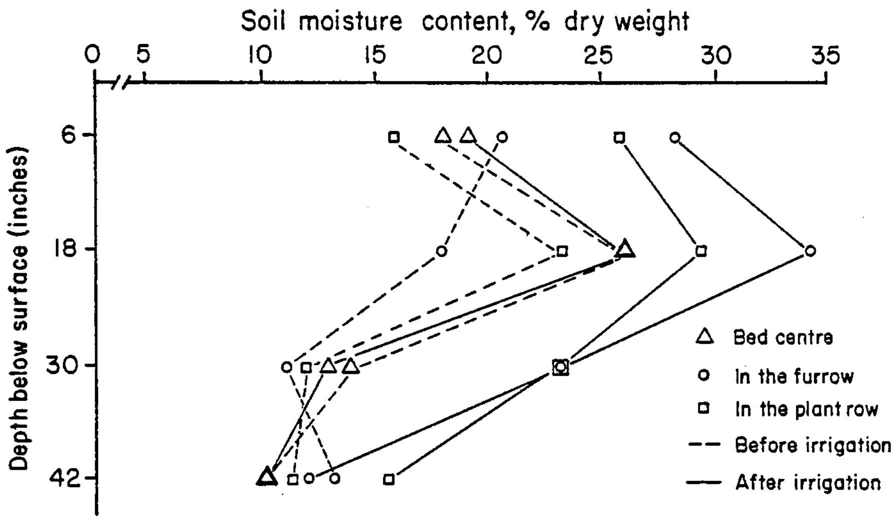


a) Every furrow irrigation.

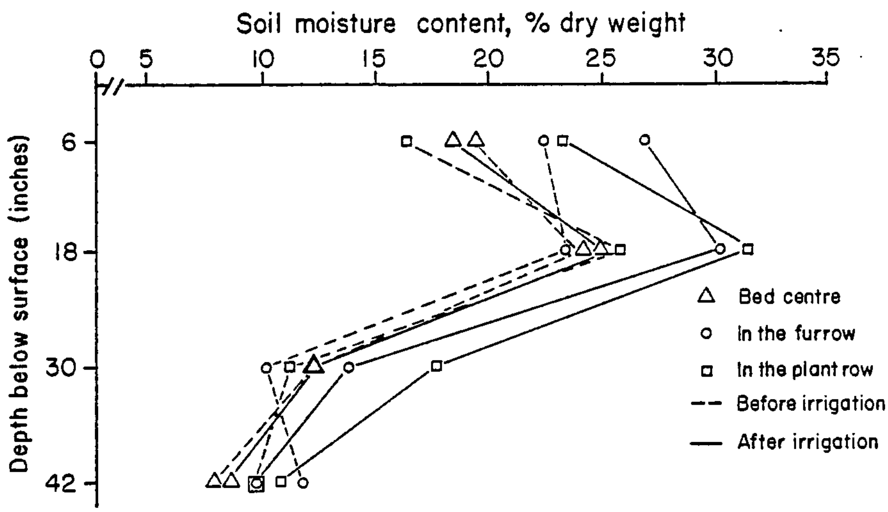


b) Alternate furrow irrigation.

Figure 4. Soil moisture content with depth and sampling location before and after irrigation (June 15-17, 1976).



c) 90-inch beds.



d) 80-inch beds.

Figure 4. -- continued.

no increase in soil moisture content in the non-irrigated furrow throughout the entire depth due to this irrigation, indicating lack of lateral movement of water from the irrigated furrow to the non-irrigated furrow. The two days time after irrigation might not have been enough for water movement to produce a noticeable increase in soil moisture content of the non-irrigated furrow, or the 2.8 inches of water applied to alternate furrow irrigation treatments in this irrigation may not have been enough for adequate wetting. Musick et al. (28) reported that the 40-inch furrows might be too wide for adequate movement of water from the irrigated to the non-irrigated furrow on a slowly permeable soil.

Soil moisture distribution with depth under the wide beds (Figure 4c and 4d) shows a greater increase in the 90-inch bed plant rows and in the furrows. The average increase in the 90-inch beds was about 5 to 15 percent whereas the increase in the 80-inch beds was about 5 to 7 percent. This indicates that the 90-inch beds received a greater volume of water than the 80-inch beds. Both treatments were irrigated together and about 2.4 inches of water was applied in this irrigation. It was noticed that before irrigation the 90-inch beds had less soil moisture in the upper two feet in the furrows. At the same time there was more moisture in the 90-inch bed center in the upper two feet and less in the fourth foot than the 80-inch bed center. The 80-inch beds being narrower probably had more moisture movement from the bed center to the plant row.

Water penetration was restricted to the second foot depth for all treatments in the east side of the field. These consistently had less soil moisture below this zone. Figure 5 represents the average soil moisture distribution with depth for all treatments in the east and west sides of the field before and after irrigation. There was no increase in the soil moisture content on the east side due to irrigation below the two-foot depth, whereas it increased throughout the entire depth on the west side. The higher moisture content of the first foot on the east side probably indicates restricted water penetration, which adversely affected plant growth and yields.

Water penetration was also a problem in the northwest side of the field, where plants showed water stress symptoms particularly on the wide beds. A pit was dug in this area and plant roots were found to be growing horizontally at the two-foot depth. This indicated a compacted layer and that the number of soil samples taken were not enough to represent the whole field. It was previously illustrated that the west side had adequate soil moisture. A larger number of samples should have been taken as suggested by Holmes et al. (18).

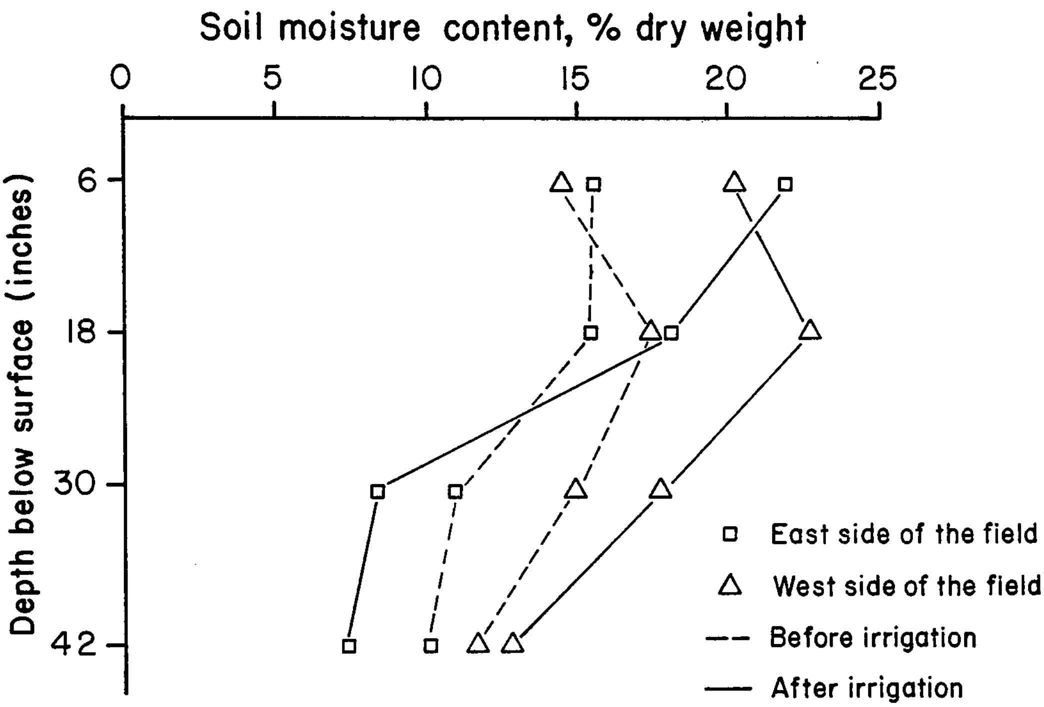


Figure 5. Average soil moisture content of all treatments with depth in the east and west sides of the field before and after irrigation (June 15-17, 1976).

The overall average soil moisture content with time (Figure 6) shows that the every furrow irrigation treatment had the highest moisture content throughout the season. This was expected since it also received the greatest amount of water. The alternate furrow irrigation treatment started with about the same soil moisture content as every furrow irrigation at the beginning of the season. As the season went on it had the lowest soil moisture content, by virtue of the non-irrigated furrow being dry and not replenished by adequate lateral movement from the irrigated furrow. Furthermore the alternate furrow irrigation treatments received lower amounts of water than the every furrow plots.

The 90-inch beds had a higher moisture content than the 80-inch beds which indicates that they received a greater volume of water throughout the season. Just prior to the June 15 and July 19 irrigations, the 90-inch beds had the lowest soil moisture content, when it was expected to have higher moisture content than the 80-inch beds and alternate furrows.

Whereas every furrow irrigation treatments had the highest overall average moisture content, Figure 7 shows that the wide beds and every furrow irrigation plots had nearly the same moisture content in the plant rows with the 90-inch beds having slightly higher moisture content after irrigations. This is probably due to the reduction in

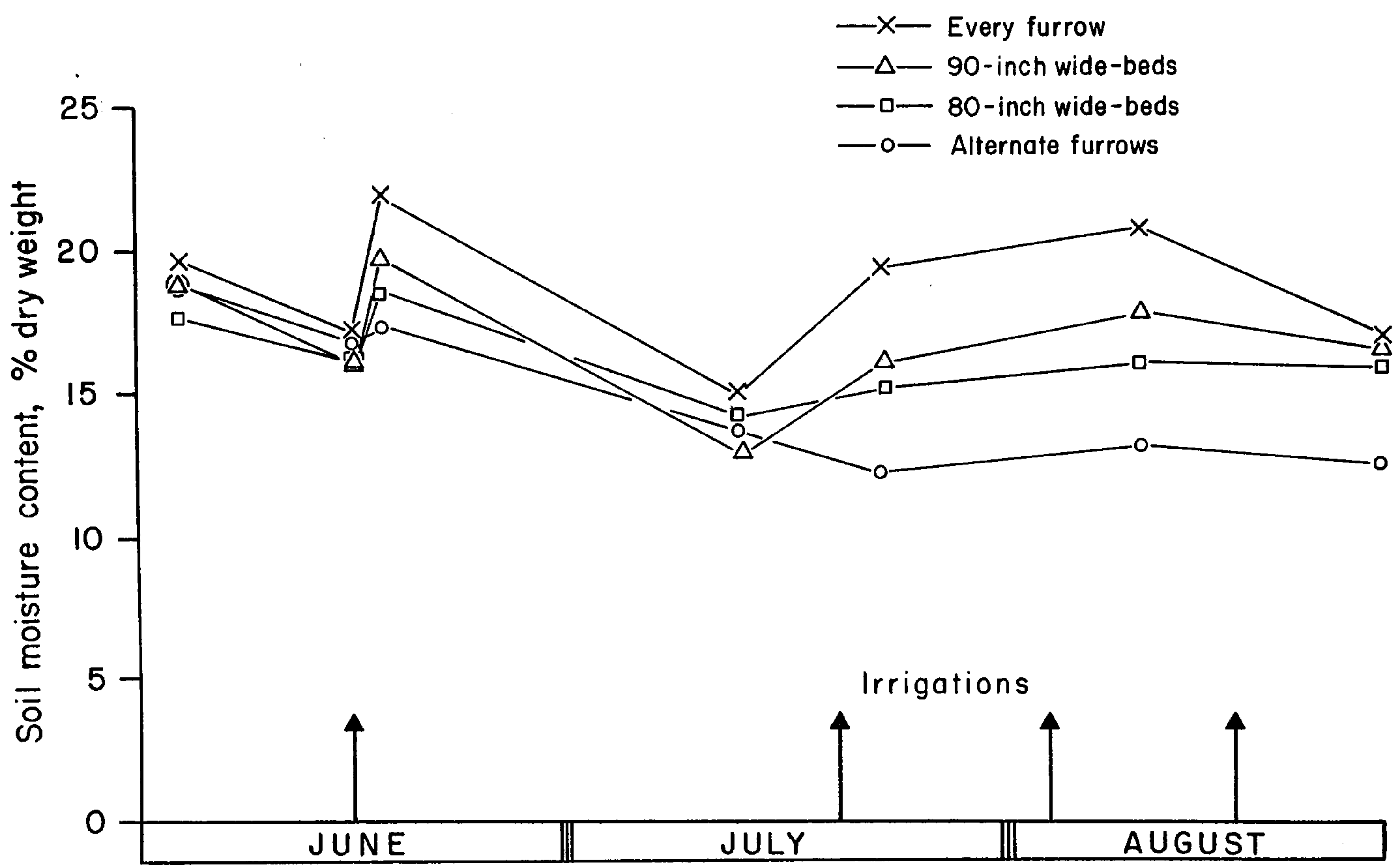


Figure 6. Average soil moisture content with time for the four treatments. -- Every point represents the average of all positions and depths.

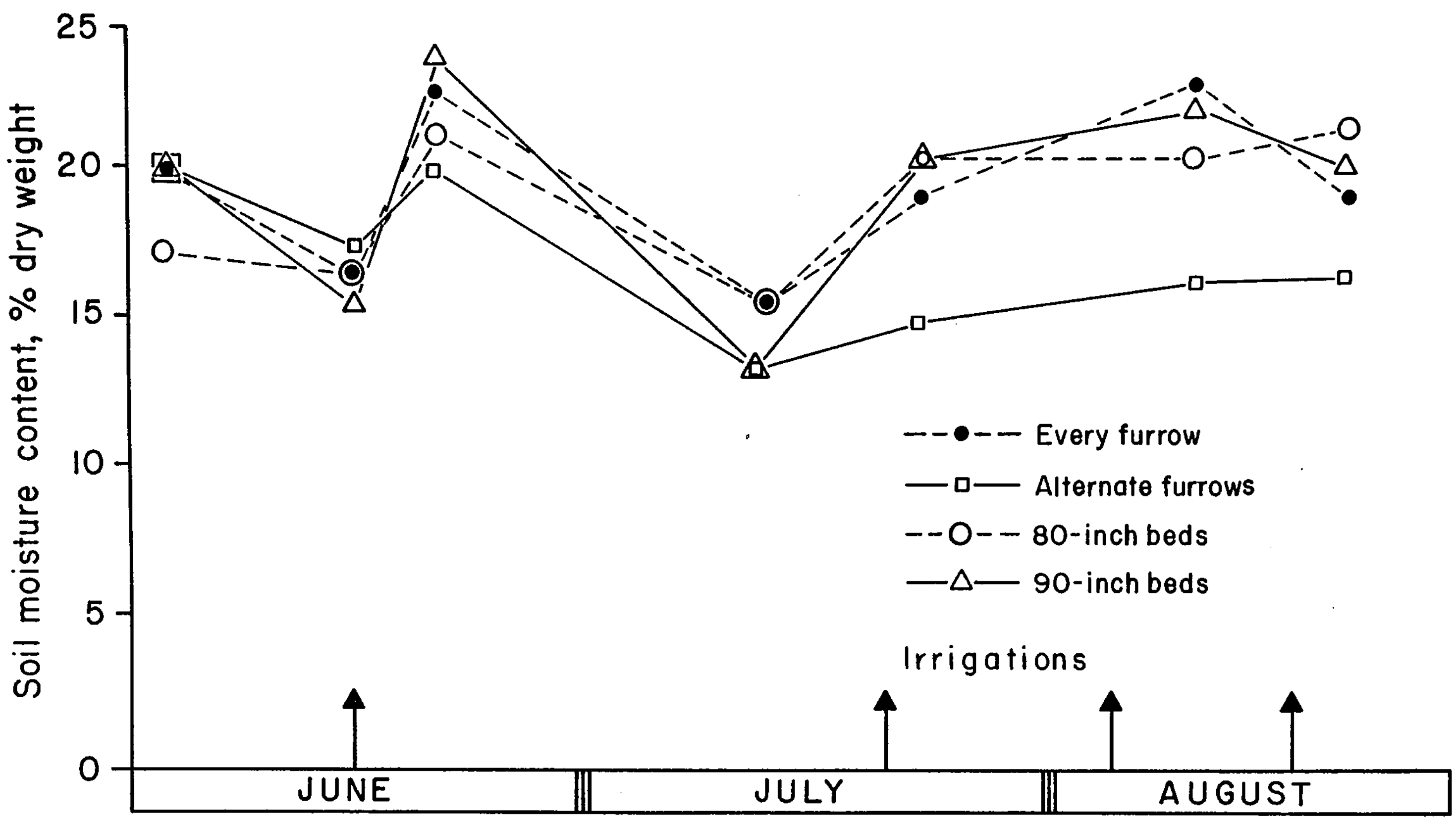


Figure 7 . Average soil moisture content in plant rows during the season.

compaction by using the bed center for wheel traffic, and resulting in better soil tilth in the crop area of the wide beds, supporting the results obtained by Porish et al. (33). This supports the assertion that the wide beds could be utilized for better soil moisture storage for plant growth. Alternate furrow treatment had the lowest soil moisture content, which again indicates insufficient applications of water and reflects low water movement to the non-irrigated furrow.

The non-irrigated furrow of the alternate furrow irrigation system is comparable to the bed center for the wide bed cultural practice system. Water movement from the irrigated furrow to both sites was expected.

Figure 8 illustrates the average soil moisture content in the center of the wide beds and the non-irrigated furrow during the growing season. The 90-inch bed center had higher moisture content than the 80-inch bed center whereas the non-irrigated furrow had the lowest moisture content.

The higher moisture content stored in the 90-inch bed center could be attributed to the fact that there was more volume of soil from the bed center to the plant row, since the distance was 25 inches and only 20 inches in case of the 80-inch beds. Since the 90-inch beds started with more moisture in the bed center than the 80-inch beds, it

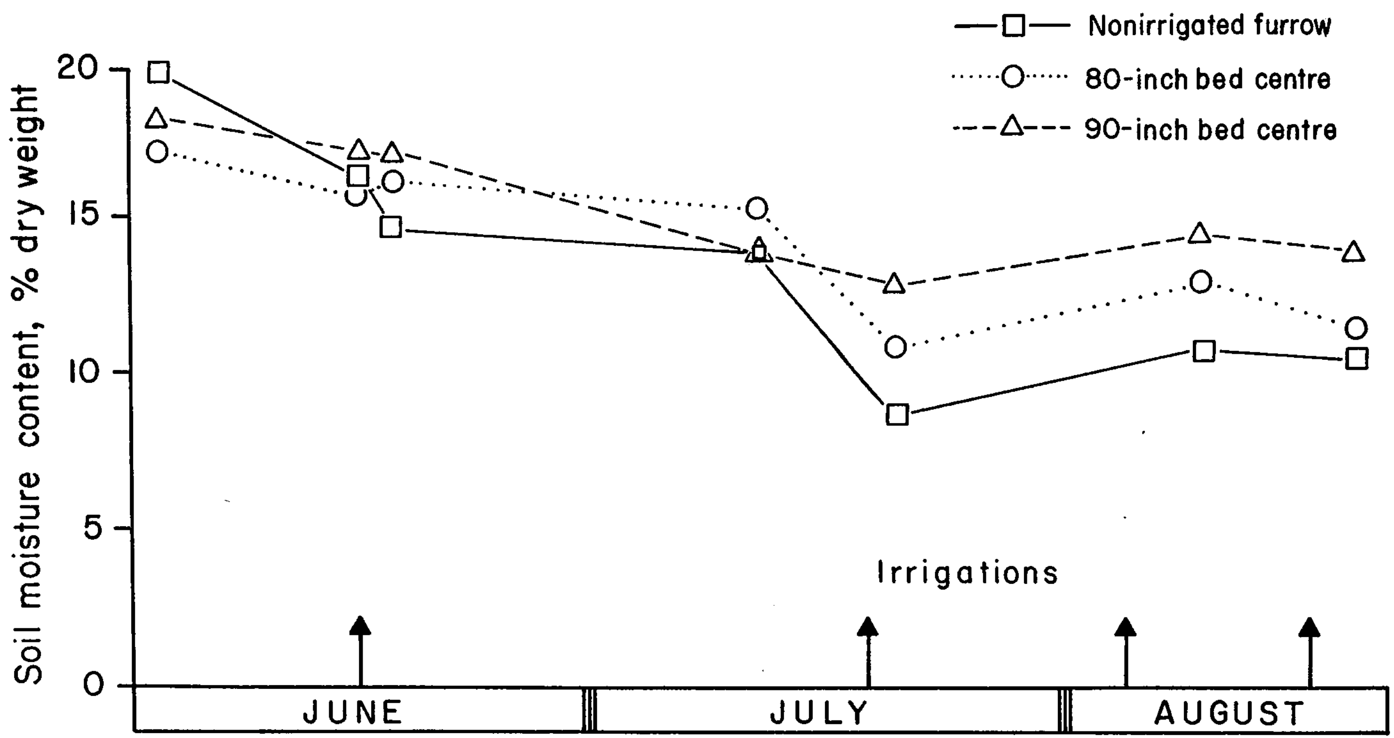


Figure 8. Average soil moisture content in the center of wide beds and in the non-irrigated furrows during the growing season.

was more likely that moisture from the 80-inch bed center would be removed faster by virtue of its distance to the plant row. This supports the reasoning behind the use of wide-bed cultural practice system in using the bed as a reservoir for soil moisture, to be utilized by plants at the time of need.

The moisture content in the non-irrigated furrow was as high as the irrigated furrow early in the season since all furrows were irrigated in the post-planting irrigation. It then steadily dropped throughout the season and three successive irrigations (July 21, August 5 and 19) did not significantly increase the moisture content level. This again indicates a limited lateral movement of moisture from the irrigated furrow to the adjacent non-irrigated furrow, which probably also resulted from insufficient applications of water.

The overall average soil moisture distribution with depth expectedly reveals a higher moisture content in the every furrow treatments (Figure 9). Each point represents the average of all positions for all samples taken at that depth during the season. Every-furrow irrigation plots received a total of 37.6 inches of water. About 30 percent less water was applied to alternate furrow irrigation treatments (26.6 inches of water), which had the lowest overall average soil moisture content throughout the entire

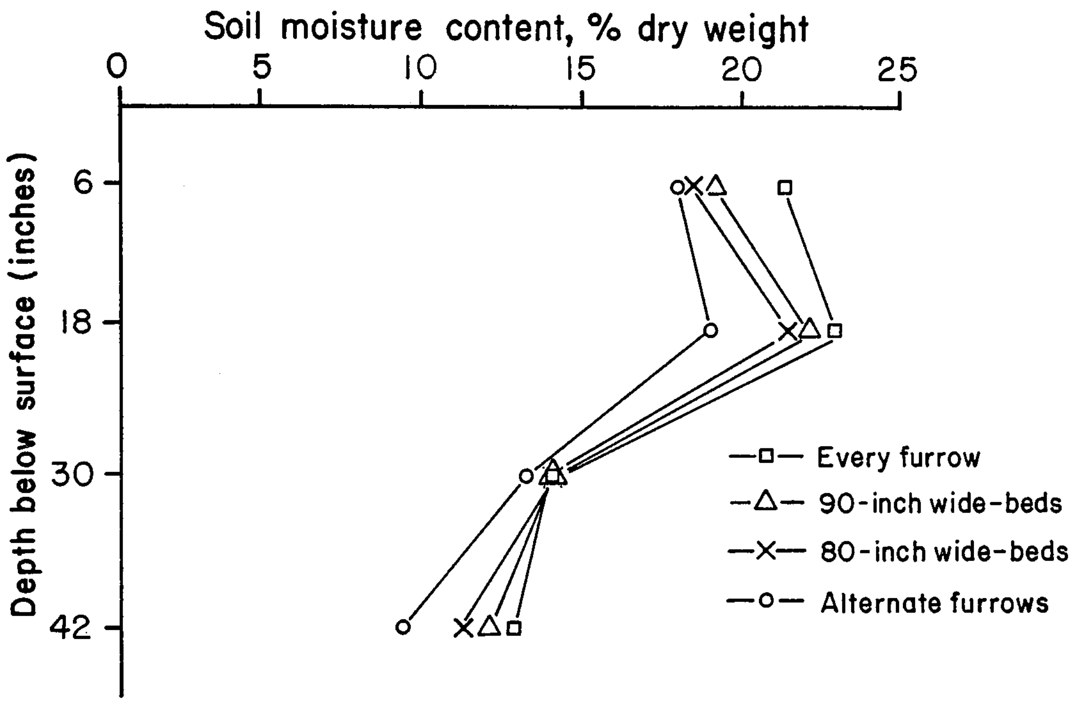


Figure 9. Average soil moisture distribution with depth throughout the season.

profile. The 90-inch bed had a higher moisture content than the 80-inch beds which matches the results from the overall average soil moisture content with time. The wide bed treatments received about the same quantity of water as alternate furrow irrigation plots, but had a higher overall average soil moisture content by virtue of the lateral water movement to the bed center.

Figure 10 shows the percent of moisture depleted from various depths as measured after one irrigation and before the next irrigation. About 73% of the moisture depleted under every furrow irrigation, during this period, was from the top two feet, and 90% from the top three feet. The wide beds had more moisture extracted from the second foot than from the first foot depth. This is probably due to the soil cover in the beds which reduced evaporation from the first foot. Thus drying, due to evaporation, before the recurrence of irrigation could probably be reduced by the use of wide-bed cultural practice system. A soil moisture gain was noticed in the fourth foot under the 80-inch beds. Most of the moisture depleted under alternate furrow irrigation was from the top two feet with little change in the three and four foot depths.

Yield

The center four rows of each plot (12 rows) were picked using a two row cotton picker to obtain the yield

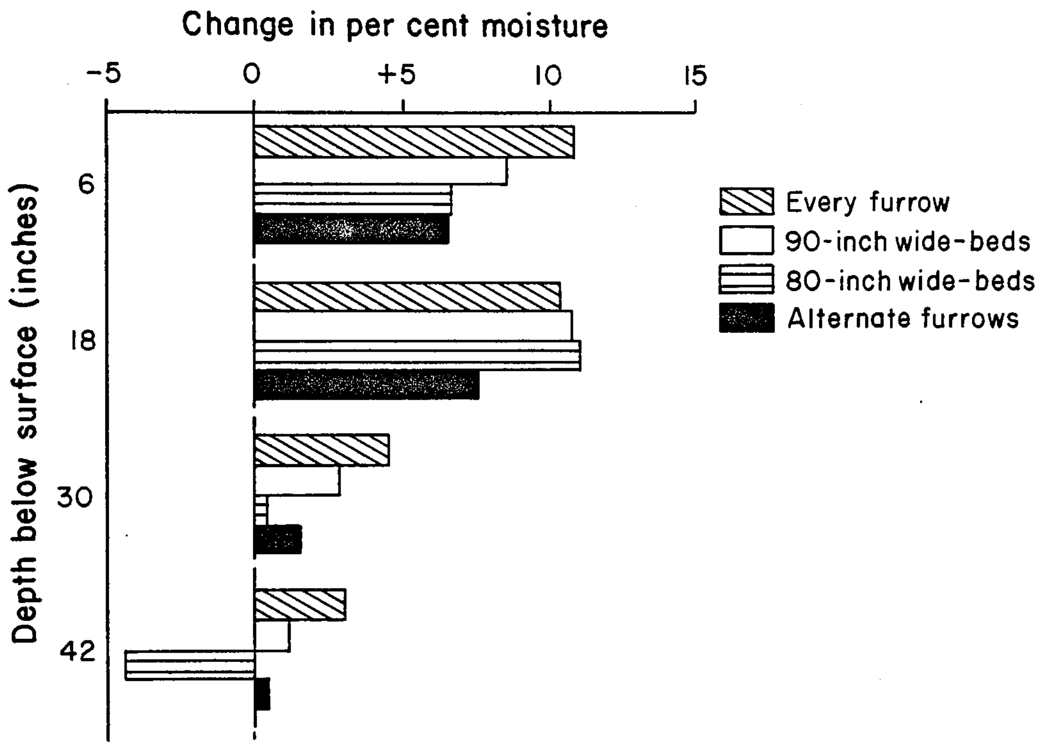


Figure 10. Moisture depleted from various depths as measured after one irrigation and before the next irrigation (June 17-July 12, 1976).

in pounds per subplot. This was then converted into yields in pounds per acre. The field was split into two parts, north and south, to detect the effect of the restricted water penetration in the east and northwest sides of the field on yields.

Table 2 shows the average yield of seed cotton in pounds per subplot (center four rows) and in pounds per acre. Table 3 shows the average yield of seed cotton in pounds per acre in the north and south sides of the field. Table A-1 (Appendix A) shows the plot layout with yields in pounds per subplot and in pounds per acre.

The average yield of seed cotton in pounds per acre on every and alternate furrow irrigation treatments, and the 80- and 90-inch wide beds, were evaluated for significance at the 0.05 level. To test for significant differences between treatment means, the Student-Newman-Keuls' test (SNK), a multiple range test, was used as described by Steel and Torrie (36). A similar test was conducted for the north and south sides of the field.

The statistical analysis did not reveal any significant difference in yields between the means of the four treatments due to any of the row spacings or alternate furrow irrigation. Also, the average yields from the north side of the field were not statistically different than the yields from the south side of the field.

Table 2. Average yield of seed cotton in pounds per sub-plot (4 center rows of each plot) and pounds per acre.

Treatment	Average Yield* lbs/subplot	lbs/acre
Every furrow irrigations	215	2394
Alternate furrow irrigation	184	2046
80-inch wide-beds	179	1997
90-inch wide-beds	201	2006

* No significant difference between the means at the 5% level.

Table 3. Average yield of seed cotton in pounds per acre in the north and south ends of the field.

Treatment	Yield lbs/acre* North	South
Every furrow irrigation	2505	2283
Alternate furrow irrigation	2101	1991
80-inch wide-beds	1948	2046
90-inch wide-beds	1750	2262

* No significant difference between the means at the 5% level.

Every furrow irrigation plots gave slightly higher yields than the other treatments. This might be directly related to the higher overall soil moisture every furrow irrigation treatments had throughout the season. Alternate furrow irrigation treatments yielded better than the wide beds, although they had about the same water application, and the lowest overall average soil moisture during the season. This could be due to plot randomization, only one of the four alternate furrow irrigation replicates was in the east side of the field (Table A-1). This side of the field had a serious water penetration problem (Figure 3), by which the wide beds and alternate furrows were greatly affected. Each of the wide beds were replicated twice in this side, whereas the alternate furrows were only replicated once. In addition to this, the water penetration problem in a spot in the northwest side of the field associated with the wide beds contributed to the lower yields of the 80- and 90-inch beds (Table A-1). A third and important factor is that irrigation of all furrows of the alternate furrow irrigation plots in the first watering after planting might have given the crop a better stand and greater soil moisture storage. Leakage of water from the irrigated furrow to the non-irrigated furrow could have taken place without being detected.

Table A-1 shows that in areas where water penetration was a problem, especially in the east side of the field, the 90-inch beds yielded better than the 80-inch beds. This implies that the 90-inch beds benefited more from the lateral movement of water to the beds, where it had a larger soil volume, hence more moisture storage than the 80-inch beds. This moisture was used by the plants at times of need.

Conventional 40-inch rows did better in the north side of the field (lower end). The wide beds yielded better in the south side of the field (upper end) as shown by Table 3. This is probably due to the fast movement of the water in the furrow to the lower end of the field, in the conventional furrows, where it ponded on further watering. The lateral movement of the water to the beds and possibly better tilth in the crop area, in the wide beds, might have slowed the forward movement of water to the lower end of the field, and further watering was not sufficient for adequate soil moisture distribution in the lower portion of the field.

A salvage count was made after the first pick. Salvage seed cotton was weighed in ounces per 30 foot of row and converted into pounds per acre. Table 4 summarizes the yield of seed cotton including salvage count. There was more salvage from every furrow irrigation plots than from any of the other plots. This indicates late maturity and

Table 4. Summary of seed cotton yield in pounds per acre with salvage count.

Treatment	North Plots		South Plots		Overall Average Yield
	Salvage	Picker+ Salvage	Salvage	Picker+ Salvage	
Every furrow irrigation	339	2846	340	2623	2735
Alternate furrow irrigation	293	2394	292	2283	2339
80-inch wide-beds	327	2275	326	2372	2324
90-inch wide-beds	266	2016	266	2528	2272

boll opening. Alternate furrows and the wide beds had lower salvage indicating early maturity. As reported by many workers (6, 26, 35) soil moisture stress results in early maturity, whereas more water application results in late boll opening and maturity. Longenecker et al. (24) reported an average increase of 15% at first picking due to variable row spacing. There was more salvage from the 80-inch beds than from the 90-inch beds or alternate furrows. A statistical test did not show any significant difference in yields due to any of the treatments after the salvage count was made.

Water Use Efficiency

Water-use efficiency is defined as the yield produced per unit of total water applied. Longenecker and Erie (23:323) stated that "it involves all the water requirement limitations and the yield variability that exists between areas, varieties, years, management, and cultural practices."

The average lint percentage, after ginning, was 35% of the seed cotton yield. To obtain the water use efficiency the average lint yield in pounds per acre was divided by the total amount of water applied in inches. Table 5 (obtained from Table 2) shows the average lint yield in pounds per acre, total amount of water applied in inches, and the

Table 5. Average lint yield in pounds per acre, amount of water applied in inches and average lint yield per inch of applied water in pounds per acre per inch.

Treatment	Lint Yield lbs/acre*	Amount of Water Applied (inches)	Lint Yield per in. of Applied Water lb/ac/in.
Every furrow irrigation	838	37.6	22
Alternate furrow irrigation	716	26.6	27
80-inch wide beds	700	25.6	27
90-inch wide beds	702	25.6	27

* No significant difference at the 5% level. The coefficient of variance was 23%.

water use efficiency expressed as the average lint yield per inch of applied water, in pounds per acre per inch.

The wide-bed and alternate furrow irrigation systems had a water use efficiency of about 27 pounds per acre per inch of applied water, whereas the every furrow irrigation system produced 22 pounds per acre per inch of applied water. Thus the wide-bed cultural practice and alternate furrow irrigation systems increased the water use efficiency by about 23% over the every furrow irrigation treatment.

The current cost of water in the Marana area is 12 dollars per acre-foot and the average selling price of cotton was 78 cents per pound of lint cotton. The additional water applied to every furrow irrigation treatments cost 11 and 12 dollars per acre with 95 and 107 dollars per acre extra return over alternate furrow irrigation and wide-bed practice systems respectively. However, because of the high coefficient of variance between treatments (23%), it cannot be concluded that the additional water applied to every furrow irrigation plots was worthwhile.

The minimum tillage practice used for the land and seed bed preparation of the wide beds saved about 9 dollars per acre in comparison to usual farm practices of land and seed bed preparation of the conventional furrows (3). Additional reductions in the total cost could be obtained by the use of a wide-bed system. Fulgham et al. (12)

reported that the use of minimum or limited tillage with wide beds reduced the total production cost by about 31 dollars per acre compared to conventional furrows and usual farm practices.

SUMMARY AND CONCLUSION

Soil moisture distribution, water use and yields of cotton under wide-bed cultural practice systems, 80- and 90-inch beds, and alternate furrow irrigation were studied as compared to every furrow irrigation of conventional 40-inch rows at Marana, Arizona, during the 1976 growing season.

Soil moisture distribution studies showed that every furrow irrigation treatment had the highest overall average soil moisture content during the season. This was directly related to the amount of water (37.6 inches) received. The alternate furrow irrigation system had about 30% less water applied and the lowest soil moisture content throughout the growing season. There was limited soil water movement from the irrigated furrow to the adjacent non-irrigated furrow. The wide beds received about the same quantity of water as alternate furrow irrigation treatments. The 90-inch beds had higher soil moisture contents than the 80-inch beds. Considerable lateral movement of water toward the bed center was noticed. The soil moisture content in the plant row of the wide beds was higher, though not significantly, than the soil moisture content in the plant row of every furrow irrigation plots. This was probably due to the better tilth in the crop area of the wide beds, and reduced compaction by using the beds for wheel traffic. Most of the soil moisture depleted was from the top three feet for all treatments.

A statistical analysis showed no significant difference between the seed and lint cotton mean yields of the four treatments due to any of the row spacings or alternate furrow irrigation.

Alternate furrow irrigation and the wide bed cultural practice systems had about the same water use efficiency, expressed as lint yield per inch of water applied. They increased the water use efficiency by about 23% over every furrow irrigation treatments.

The wide-beds reduced the production costs by virtue of the minimum tillage operations used and by reducing the total quantity of irrigation water applied.

The use of wide-bed cultural practice and alternate furrow irrigation systems appear to offer an opportunity for reducing production costs without significantly reducing yields. Cost reduction is usually of little value if not justified by a constant or increased net income. With the limited energy resources prevailing and the soaring prices of energy, the adoption of such systems, which save energy and hence production costs, will be justified in the near future.

For a specific and complete evaluation of these systems, an economic study is necessary including production costs and a net income return analysis. More accurate devices should be used for the measurement of input energy. Better water application could have been obtained, in this study, by using such devices as gated pipes and selecting the right pump unit.

At the end the challenge remains--the struggle of mankind for the best, and for perfection, if possible.

APPENDIX A

FIELD DATA

Table A-1. Plot layout with yields in pounds per subplot (center four of the 12 rows) and pounds per acre.

Alt*	80"	90"	80"	Alt.	90"	EV.	Alt.	90"	80"	EV.	EV.	90"	80"	EV.	Alt.
							NORTH								
200**	220	170	165	235	205	210	180	165	165	315	205	160	150	170	140
2227+	2450	1700	1837	2617	2050	2339	2004	1650	1837	3507	2283	1600	1670	1893	1559
= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =	= =
195**	235	240	200	215	240	215	165	200	140	205	195	225	160	205	140
2172+	2617	2400	2227	2394	2400	2394	1837	2000	1559	2283	2172	2250	1782	2283	1559
							SOUTH								

* Alt = Alternate furrow irrigation plots.
EV. = Every furrow irrigation plots.
80" = 80-inch beds.
90" = 90-inch beds.

** Pounds per subplot.

+ Pounds per acre.

Table A-2. Average soil moisture percentage with respect to position of sampling for the every furrow irrigation treatment.

Date	Depth (feet)	Position 1	Position 2
June 3, 1976	0-1	21.7	18.5
	1-2	22.9	28.3
	2-3	14.9	16.7
	3-4	15.4	14.6
June 15, 1976	0-1	19.9	16.4
	1-2	24.0	22.2
	2-3	13.6	12.5
	3-4	12.1	13.3
June 19, 1976	0-1	25.0	26.3
	1-2	30.3	27.2
	2-3	16.8	20.6
	3-4	14.5	14.5
July 12, 1976	0-1	15.0	15.1
	1-2	18.9	18.4
	2-3	14.5	13.9
	3-4	10.2	13.0
July 22, 1976	0-1	25.2	23.5
	1-2	22.7	23.9
	2-3	13.2	18.6
	3-4	14.2	13.5
August 9, 1976	0-1	23.8	22.5
	1-2	23.6	22.7
	2-3	18.1	26.8
	3-4	10.3	16.7
August 26, 1976	0-1	24.4	22.8
	1-2	19.4	20.6
	2-3	11.9	16.5
	3-4	8.3	10.3

Table A-3. Average soil moisture percentage with respect to position of sampling for the alternate furrow irrigation treatment.

Date	Depth (feet)	Position 1	Position 2	Position 3
June 3, 1976	0-1	20.5	17.5	21.6
	1-2	26.7	25.3	25.4
	2-3	15.2	18.3	16.5
	3-4	16.8	17.4	15.8
June 15, 1976	0-1	19.1	15.5	20.2
	1-2	23.8	21.5	22.8
	2-3	12.9	19.2	12.5
	3-4	10.5	11.7	11.8
June 17, 1976	0-1	18.6	22.9	25.4
	1-2	22.7	25.9	25.9
	2-3	12.0	18.7	17.7
	3-4	9.0	11.6	9.5
July 12, 1976	0-1	15.2	14.0	15.7
	1-2	15.1	16.4	17.9
	2-3	13.9	12.3	13.9
	3-4	12.3	8.9	10.0
July 22, 1976	0-1	12.8	20.0	25.1
	1-2	8.9	19.1	22.4
	2-3	8.3	11.4	13.0
	3-4	4.6	7.8	7.3
August 9, 1976	0-1	13.0	18.6	21.0
	1-2	13.4	20.1	22.1
	2-3	10.4	13.4	11.5
	3-4	6.1	10.1	6.8
August 23, 1976	0-1	12.9	21.8	22.3
	1-2	12.5	20.8	16.5
	2-3	10.5	12.7	10.5
	3-4	6.4	7.7	5.8

Table A-4. Average soil moisture percentages with respect to position of sampling for the 80-inch wide-beds.

Date	Depth (feet)	Position 1	2	3
June 3, 1976	0-1	23.4	17.3	19.2
	1-2	26.9	27.6	26.5
	2-3	12.6	13.5	14.3
	3-4	10.8	10.1	10.0
June 15, 1976	0-1	22.6	16.6	19.5
	1-2	23.5	25.9	24.9
	2-3	10.9	11.6	12.2
	3-4	12.0	10.0	8.9
June 17, 1976	0-1	26.8	22.8	18.6
	1-2	30.4	31.5	25.4
	2-3	14.1	17.9	12.0
	3-4	10.2	11.1	9.9
July 12, 1976	0-1	15.8	13.9	15.6
	1-2	17.3	17.7	17.6
	2-3	12.8	13.7	13.6
	3-4	12.6	15.1	14.8
July 22, 1976	0-1	26.0	24.0	14.2
	1-2	25.2	22.3	12.2
	2-3	11.0	16.3	10.2
	3-4	12.1	12.0	7.7
August 9, 1976	0-1	23.1	19.9	11.1
	1-2	24.6	21.9	14.6
	2-3	--	20.4	13.9
	3-4	13.2	16.2	12.0
August 19, 1976	0-1	24.0	22.3	12.7
	1-2	23.9	22.4	13.5
	2-3	16.7	21.8	12.6
	3-4	13.1	16.3	9.9

Table A-5. Average soil moisture percentage with respect to position of sampling for the 90-inch wide-beds.

Date	Depth (feet)	Position 1	2	3
June 3, 1976	0-1	22.9	19.1	20.9
	1-2	25.3	28.9	24.7
	2-3	12.9	16.0	13.2
	3-4	14.5	14.5	14.2
June 15, 1976	0-1	20.0	15.7	18.0
	1-2	18.3	23.3	25.9
	2-3	11.0	11.5	13.0
	3-4	13.4	10.9	10.9
June 17, 1976	0-1	28.0	26.6	19.0
	1-2	34.3	29.0	25.7
	2-3	23.0	23.3	11.8
	3-4	12.1	15.3	10.7
July 12, 1976	0-1	16.2	14.1	14.4
	1-2	18.0	17.3	18.7
	2-3	9.6	10.3	12.0
	3-4	11.1	8.5	10.0
July 22, 1976	0-1	27.4	25.9	12.6
	1-2	25.5	26.3	13.9
	2-3	11.4	16.9	13.7
	3-4	12.1	10.8	10.5
August 9, 1976	0-1	22.6	21.8	15.9
	1-2	26.2	23.7	17.7
	2-3	23.4	22.5	13.2
	3-4	10.6	12.5	11.0
August 19, 1976	0-1	23.1	22.2	13.7
	1-2	24.1	21.6	15.7
	2-3	20.1	20.3	--
	304	10.9	13.8	--

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