Effects of irrigation interval and tillage systems on irrigated cotton and succeeding wheat crop under a heavy clay soil in the Sudan

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Abstract

A water crisis that occurs in Sudan during winter due to the competition for water to irrigate cotton (Gossypium barbadense L.) and wheat (Triticum aestivum L.) and to produce hydroelectric power necessitates a search for efficient means and ways of conserving water. Tillage is one of the methods for soil moisture conservation. Experiments were conducted in Gezira, Sudan on a Vertisol to determine if tillage practices and the lengthening of irrigation interval beyond two weeks during the period October–February would conserve irrigation water and maintain cotton yields. The residual effects of cotton tillage systems on the following wheat were also evaluated. The cotton experiment was conducted in split plot design with three replications. Three irrigation treatments of two-, three- and four-week intervals during the period October–February were used as main plots. Six tillage treatments were used as split plots (combinations of disc ploughing, cultivator and ridging). Treatments were compared by measuring cotton plant height and yields. Significant decreases in cotton yield were found between the four-week, and the two- and three-week irrigation intervals. However, no significant differences in cotton yields between the two- and the three-week irrigation intervals were detected. The lengthening of irrigation interval from two to three weeks during the period of irrigation water crisis (October–February) would result in conservation of about 3000 m$^3$ ha$^{-1}$ of irrigation water. This corresponds to about 600 000 000 m$^3$ of water for the cotton irrigated area in the Sudan. Therefore, the three-week irrigation interval during the period October–February has the potential for water conservation for cotton production in Gezira Vertisols, with the use of economical shallow tillage. The tested deep and shallow cotton tillage treatments did not have residual effects on the following wheat crop. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Tillage; Irrigation; Cotton; Wheat; Vertisols; Sudan

1. Introduction

The main rotational crops that are grown in Sudan irrigated central clay schemes are cotton (Gossypium hirsutum L. and G. barbadense L.), wheat (T. aestivum L.), sorghum (Sorghum bicolor L.) and groundnut (Arachis hypogea L.). Cotton is the backbone of Sudanese wealth. It is grown under rain and surface irrigation. In irrigated schemes, it occupies 143 000 ha in the Gezira; 28 000 ha in Rahad; 25 000 ha in New Halfa; 8000 ha in Suki, with a total of about 204 000 ha (Coordination unit for irrigated schemes, 1996). All crops under surface irrigation system are grown on the top of 80 cm spaced ridges to facilitate irrigation and to avoid the risk of water logging.
Research results indicate that disc ploughing followed by harrowing resulted in greater groundnut yield (Ishag et al., 1987) and in greater sorghum yield than ridging only (El-Awad, 1990). Recently, more emphasis has been placed on wheat production as a strategic food crop. In some areas, discing has been adopted as a primary tillage operation for wheat. On Vertisolic soils in Rahad, use of a disc harrow rather than disc plough and ridging after seed broadcasting resulted in significantly greater yields of wheat than broadcasting alone (Dawelbeit and Babiker, 1997).

The primary tillage operation for cotton land preparation in the Gezira scheme up to the late 1980s was conducted using a special adapted blade implement drawn by tracklaying tractors. The blade implement was designed to break the lower layer of soil to a depth of 20–30 cm, in a one-year fallow land, to check the growth of noxious weeds. However, due to the crop intensification and diversification, and machinery costs, the fallow system has now been abandoned along with the use of the blade implement. Farmers and administrators have raised a question as to what are the suitable methods for cotton land preparation. Also, they are of the opinion that deep ploughing for cotton has favourable residual effects on the following wheat yield. A survey of cotton tillage systems under farmers’ fields conditions, in New Halfa Vertisols, indicated no difference in cotton yields between deep and shallow tillage types (El-Awad, 1993). However, there is lack of information to quantify the relationship between tillage systems and cotton yield and also between residual effects of cotton tillage systems and the succeeding wheat crop in the rotation.

Rain water supply to rivers begins to decline in early October. From October to February, the irrigation of July-sown cotton and winter wheat, in addition to hydroelectric power production, are dependent on stored water from dams. During this period, an irrigation water crisis occurs, particularly during the reproductive stage of cotton, as both agriculture and hydroelectric power compete for water. Present recommendations for irrigation on cotton and wheat are of two-week irrigation intervals (Technical packages, 1991). Each irrigation equals about 1000 m³ ha⁻¹. Therefore, methods for field soil moisture conservation to lengthen the irrigation interval beyond two weeks during the irrigation water crisis period are of great economical value.

The objectives of this study were: (1) to determine if the irrigation interval could be lengthened beyond the recommended two weeks, during the period of irrigation water crisis from October to February, without a significant reduction in cotton growth and yield; (2) to evaluate the effects of different deep and shallow tillage systems on cotton growth and yield; (3) to evaluate the residual effects of tested cotton tillage systems on the following wheat crop growth.

2. Materials and methods

2.1. Location, soil and climate

The study involved cotton (G. barbadense L.) local variety (Shambat B) and wheat experiments. The two experiments were carried out at Maatug Research Substation (14°14′N, 32°49′E) in the Gezira scheme. Cotton experiment was conducted in 1987/1988 and 1988/1989. Cotton was followed by wheat on the same cotton area in 1988/1989 and 1989/1990. The climate is semi-arid. According to Gezira meteorological data, in 1987/1988 and 1988/1989 cotton-growing seasons, the total rainfall was 200 and 282 mm, respectively. August rainfall was 111 and 162 mm for the respective seasons. The mean maximum temperature during the period July–September was 37.7 and 35.0°C, while the mean maximum temperature during the period October–February was 33.3 and 35.8°C for the respective seasons.

The experimental site is situated on an aggradational plain deposited by the Blue Nile system. The soil is a Vertisol, which is characterized by swelling when wet and shrinking when dry. The average physical and chemical properties of the soil to a depth of 0–25 cm as reported by Faki et al. (1994) are shown in Table 1.

2.2. Tillage treatments

The experimental design was a split plot with three replications. Plots were established for three irrigation intervals of two-, three- and four-weeks during the period October–February as main plots, and six tillage systems as split plots. Tillage plots were 6.4 m × 12 m (8 row-crop × 12 m) of which 4 m × 10 m (5 row-crop × 10 m) was used as net harvested area. Each
irrigation interval plot and each tillage system plot was spaced from each other by 8 and 1.5 m, respectively. This was done to prevent lateral distribution of soil water among the main plots and from split plot to the adjacent ones. The 8 m distance also served as a road for the tractor passing and turning with different implements.

The evaluated tillage treatments were as follows:
1. Disc ploughing+harrowing+ridging.
2. Disc ploughing+ridging.
3. Scarifying+harrowing+ridging.
4. Scarifying+ridging.
5. Ridging+split ridging.
6. Ridging only.

For the two seasons, the primary ploughing operations were carried in June before the rainy season. The average gravimetric soil moisture content to a depth of 0–20 cm was 0.19 g g⁻¹. The depth of primary ploughing operation (i.e., disc ploughing and scarifying) was 20 cm for the first four treatments and categorized as deep ploughing. While the depth of the last two treatments (i.e., ridging) was 15 cm and categorized as shallow ploughing.

Implements used in the experiment were as follows:
1. Disc plough. A three-furrow disc plough, with discs of 65 cm in diameter. Width of work was 80 cm.
2. Disc harrow. A mounted offset disc harrow, with discs of 56 cm in diameter. The front 10 discs were notched, while the rear 10 discs were plain. Discs were placed 20 cm apart. Width of work was 200 cm.
3. Scarifier. Scarifier with alternated inclined tines on two horizontal bars. Five tines were attached to the front bar and four tines were attached to the rear one. Cutting share was of a duck-foot shape. It was 21 cm in width. The two adjacent tines on each bar were set up 42 cm apart to give a distance of 21 cm between the alternated tines. It cuts and breaks the lower layer of soil without inversion. Width of work was 210 cm.
4. A 4-body ridger. A 4-body ridger with ridger bodies placed 80 cm apart. It was used in ridging treatments. Then it was used in all treatments for the final seedbed preparation.

Before the establishment of tillage plots, a field test for primary tillage implements (disc plough, scarifier and ridger) was carried out in 1987/1988 season to determine some parameters of tractor and implement performance.

2.3. Cotton experiment

2.3.1. Irrigation intervals

For the two seasons, cotton was sown and irrigated on 16 July. It was irrigated biweekly as recommended until 1 October, except in August. Because of high rainfall in August, the crop received one irrigation when necessary. Thus, the crop received in addition to August irrigation, two regular irrigations of two-week interval in July, two in September and one on 1 October. The test for irrigation interval treatments commenced on 14 October and terminated on 3 February. Accordingly, the main plots of two-, three- and four-week irrigation intervals received nine, six and four irrigations, respectively. Water was applied just below the surface of the top of the ridges. Each irrigation equals about 1000 m³ ha⁻¹.

2.3.2. Cotton sowing

Cotton was sown manually on the top of 80 cm spaced ridges and 50 cm between holes. A dibbling method was used for sowing. In this method, a long walking stick, with plain and pointed heart-shape metal attached to the lower end of it, was used for preparing a 7 cm deep hole. Then, 5–7 seeds of cotton were dropped into the hole manually and covered by loose soil. The average vertical ridge height from the bottom of the furrow to the top of the ridge was about 20 cm.
15 cm. After four weeks from sowing, nitrogen at the rate of 143 kg N ha\(^{-1}\) was applied and immediately followed by green ridging. The green ridging is an operation conducted using 4-body ridger (80 cm spaced ridger adjusted on the toolbar to pass in the old furrows). The objectives of the operation were to cover the fertilizer and reshape and maintain the old ridges. After green ridging, the crop was thinned to three plants per hole. The intended plant population was about 78 750 plants per hectare. The experiment was hand-weeded twice. The first weeding was conducted before the second irrigation and the second before the green ridging operation. Cotton pests were kept under control using appropriate pesticides as required.

2.3.3. Cotton measurements

Cotton plant height was determined using a measuring tape for randomly chosen 10 plants per subplot. The measurement was taken at first picking time, from the soil surface up to the highest bud. Cotton was handpicked twice. The first pick was carried on 21 December, and the second and the final picking was done on 15 February after 100% boll opening. The total seed cotton yield is the sum of cotton weight of the two picks.

2.4. Wheat experiment

2.4.1. Experimental location

Wheat experiment was conducted on the same land of cotton experiment. As irrigation interval treatments were omitted in this experiment, the main plots were not considered and consequently the design of the experiment became a randomized complete block design with nine replications. Subplot size was the same as for cotton experiment. The harvestable area used in the analysis was 3×3.5 m\(^2\). For wheat sowing, all subplots were ridged using the 4-body ridger, with 80 cm spaced bodies. Then, all subplots were levelled using tractor-mounted scraper, to break down the top of the ridges. A wheat local variety (Condor) was broadcast manually at a seed rate of 143 kg ha\(^{-1}\), and the 4-body ridger was used again to cover the seeds and to make furrows. The objective of the furrows was to facilitate the irrigation, which was applied at fortnight intervals. The amount and method of irrigation were similar as that for cotton. Nitrogen at the rate of 143 kg N ha\(^{-1}\) was added before the second irrigation.

2.4.2. Wheat measurements

Wheat plant height at maturity was determined by an average measurement of randomly selected 10 plants per subplot from the soil surface to the highest point of the spike. The number of seeds per head were counted for randomly selected 10 heads per subplot. The weight of 1000 seeds per subplot was calculated.

After drying, the crop in the harvestable area was cut using sickles and manually collected in heaps for threshing using wooden sticks, and finally, cleaned and weighed to measure crop grain yield.

For the two experiments, data were analysed using the analysis of variance technique. When the F-test indicated statistical significance, Duncan’s multiple range test or least significant difference (LSD) test at 5% significance level (LeClerg et al., 1962) was used to indicate which differences were significant.

3. Results and discussion

3.1. Cotton experiment

Statistical analysis showed that there were no significant differences between irrigation intervals, tillage systems and their interactions on cotton plant height for the two seasons (Table 2).

Comparison of cotton yields in the two seasons (Tables 3 and 4) showed no significant differences between tillage systems or between the interactions of tillage systems×irrigation intervals. The effects of tillage could probably be masked by swelling and shrinking phenomenon that occurs in heavy clay soils. Tillage results agree with Wolf et al. (1984) who found that there were no differences in cotton yield between precision-minimum tillage and conventional tillage under different soils, including Vertisols, and different

Table 2
The means±SE for cotton height (cm) for irrigation interval and tillage in the two growing seasons

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation interval</td>
<td>72.7±3.3</td>
<td>86.7±3.5</td>
</tr>
<tr>
<td>Tillage system</td>
<td>72.5±1.4</td>
<td>86.5±1.6</td>
</tr>
</tbody>
</table>
climatic conditions throughout Israel. However, although primary tillage operations did not influence crop yield, it was found that deep ploughing (disc ploughing and scarifying) consumed more fuel, had a low work rate and was more expensive than shallow ploughing (ridging) (Table 5). Therefore, it could be recommended that shallow ploughing is more economical than deep ploughing (El-Awad, 1998).

The irrigation interval treatments were found to result in high significant difference ($P<0.01$) in cotton yields in the first season (Table 3) and in significant difference ($P<0.05$) in the second season (Table 4).

### Table 3
Effects of irrigation interval and tillage on seed cotton yield (kg ha$^{-1}$) in the first growing season (1987/1988)

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Irrigation intervals (weeks)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Means$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc ploughing + harrowing + ridging</td>
<td>1554 A</td>
<td>1523 A</td>
<td>952 B</td>
<td>1343 a</td>
<td></td>
</tr>
<tr>
<td>Disc ploughing + ridging</td>
<td>1575 A</td>
<td>1624 A</td>
<td>1117 B</td>
<td>1439 a</td>
<td></td>
</tr>
<tr>
<td>Scarifying + harrowing + ridging</td>
<td>1469 A</td>
<td>1381 A</td>
<td>901 B</td>
<td>1250 a</td>
<td></td>
</tr>
<tr>
<td>Scarifying + ridging</td>
<td>1600 A</td>
<td>1479 A</td>
<td>950 B</td>
<td>1343 a</td>
<td></td>
</tr>
<tr>
<td>Ridging + split ridging</td>
<td>1650 A</td>
<td>1401 A</td>
<td>912 B</td>
<td>1321 a</td>
<td></td>
</tr>
<tr>
<td>Ridging only</td>
<td>1542 A</td>
<td>1339 A</td>
<td>1058 B</td>
<td>1313 a</td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td>1565 a</td>
<td>1458 a</td>
<td>982 b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD ($P=0.05$)

| Irrigation intervals | 156.3 (kg ha$^{-1}$) |
| Tillage systems | NS$^b$ |
| Irrigation intervals $\times$ tillage systems | NS$^b$ |

*a* Means with the same letter are not significantly different at $P=0.05$ according to Duncan’s multiple range test.

*b* Not significant.

### Table 4
Effects of irrigation interval and tillage on seed cotton yield (kg ha$^{-1}$) in the second growing season (1988/1989)

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Irrigation intervals (weeks)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Means$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc ploughing + harrowing + ridging</td>
<td>1670 A</td>
<td>1359 AB</td>
<td>1136 B</td>
<td>1388 a</td>
<td></td>
</tr>
<tr>
<td>Disc ploughing + ridging</td>
<td>1603 A</td>
<td>1440 AB</td>
<td>1175 B</td>
<td>1406 a</td>
<td></td>
</tr>
<tr>
<td>Scarifying + harrowing + ridging</td>
<td>1633 A</td>
<td>1288 AB</td>
<td>1185 B</td>
<td>1369 a</td>
<td></td>
</tr>
<tr>
<td>Scarifying + ridging</td>
<td>1365 A</td>
<td>1264 AB</td>
<td>1115 B</td>
<td>1248 a</td>
<td></td>
</tr>
<tr>
<td>Ridging + split ridging</td>
<td>1646 A</td>
<td>1359 AB</td>
<td>1169 B</td>
<td>1391 a</td>
<td></td>
</tr>
<tr>
<td>Ridging only</td>
<td>1491 A</td>
<td>1289 AB</td>
<td>1031 B</td>
<td>1270 a</td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td>1568 a</td>
<td>1333 ab</td>
<td>1135 b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD ($P=0.05$)

| Irrigation intervals | 268.6 (kg ha$^{-1}$) |
| Tillage systems | NS$^b$ |
| Irrigation intervals $\times$ tillage systems | NS$^b$ |

*a* Means with the same letter are not significantly different at $P=0.05$ according to Duncan’s multiple range test.

*b* Not significant.

### Table 5
Operational data of deep and shallow ploughing and cost of primary tillage for cotton production

<table>
<thead>
<tr>
<th>Ploughing depth (cm)</th>
<th>Disc ploughing</th>
<th>Scarifying</th>
<th>Ridging</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Tillage type</td>
<td>Deep</td>
<td>Deep</td>
<td>Shallow</td>
</tr>
<tr>
<td>Fuel consumption (l ha$^{-1}$)</td>
<td>15.2</td>
<td>7.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Work rate (ha h$^{-1}$)</td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Cost (US$ ha$^{-1}$)</td>
<td>138</td>
<td>83</td>
<td>50</td>
</tr>
</tbody>
</table>
The four-week irrigation interval treatment resulted in significant reduction (37 and 28% for first and second season) in cotton yield compared to the two-week interval for the two seasons (Tables 3 and 4). Compared to the three-week interval, the four-week treatment significantly reduced cotton yield by 33% in the first season only. These results agree with Wolf et al. (1984) who found that water application through precipitation and irrigation were found to have a greater effect on cotton yield than tillage type. However, there were no significant differences in cotton yields between the two- and the three-week irrigation intervals for the two seasons (Tables 3 and 4). The mean cotton yield of the two-week interval for the two seasons was similar (1565 and 1568 kg ha$^{-1}$). The results agree with Lazim (1987) who found that with the two- and three-week irrigation intervals except during flowering stage (mid-September–late-October), in which the irrigation intervals were changed to 10, 14 and 21 days, no significant differences in cotton yields were detected.

The two-, three- and four-week irrigation interval plots received about 9000, 6000 and 4000 m$^3$ ha$^{-1}$ of water, respectively, during the differential irrigation period from 14 October to 3 February. Therefore, lengthening the irrigation interval from the recommended two-week to a three-week interval would conserve about one third of irrigation water per each cultivated hectare of cotton. This is equal to about 3000 m$^3$ of water. Therefore, for all cotton cultivated area in the Sudan irrigated schemes (204 000 ha), the conserved amount of dam water would be equal to about 600 000 000 m$^3$. This amount of water would help to mitigate the irrigation water crisis that occurs in winter season.

3.2. Wheat experiment

For the two seasons, the growth parameters (plant height, number of seeds per head, weight of 1000 seeds and crop grain yield) of the following wheat crop were not significantly affected ($P<0.05$) by the preceding cotton tillage treatments (Table 6). These results were expected, because all plots were uniformly tilled, fertilized, planted and irrigated. These results agree with Unger (1984) who reported that deep tillage effects on heavy clay soils are usually temporary and often disappear within the first year.

4. Conclusions

1. No differences in cotton growth and yields were evident between the recommended two-week and three-week irrigation intervals. Therefore, for irrigation water conservation, cotton irrigation interval could be lengthened to three weeks during the period of irrigation water crisis from October to February.
2. Although no differences in cotton growth and yields were detected between deep and shallow tillage, the fast and more economic shallow tillage could replace the expensive and time-consuming deep tillage in Gezira Vertisols.
3. The evaluated deep and shallow cotton tillage treatments have no residual effects on the following wheat growth in Gezira heavy clay soils.

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References


