Technical Report

Farmers' Practices in On-Farm Irrigation Management in the Gezira Scheme, Central Sudan

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Summary After a general introduction and descriptions of how irrigation water is carried to the fields, we review problems with the management of Nile water for irrigation in the Gezira Scheme, Central Sudan. Subsequently the methodologies used in an on-farm experiment are described. From the results of a questionnaire, the farmers' present irrigation practices are discussed. Field data show that unattended, day and night, continuous flow irrigation of sorghum (dura) and groundnuts uses more water, and particularly so in drier years, than attended daytime watering (and night-time storage). This is mainly due to greater evaporation from water standing on the surface, because percolation is negligible. In this case study, in the order of 20-40% of used water was wasted on-farm. It is deduced that farmers evolved their present practice of watering groundnuts and sorghum out of the sheer necessity of engaging sharecroppers who themselves have to leave irrigation unattended because of their own need for additional off-farm income. Finally, some conclusions and recommendations are derived for a dialogue between authorities and tenants on more efficient water use. The new situation of tenants as “cost-sharing partners” could lead to better watering practices if they would pay for the water they use by volume and if the authorities would carry out maintenance to the full satisfaction of the tenants.

I. Introduction

1.1. General

In Sudan, irrigated agriculture in large schemes, which amounts to only 25% of the annually cropped area, yields about 50% of the total production. However, water has become the major limiting factor for agricultural development.

In the Gezira Scheme (Figure 1), with one annual growing season, a 4-year-course rotation of cotton, wheat, sorghum (dura)/groundnuts, and fallow is practised. It lies roughly between the isohyets of 200 and 400 mm of annual rainfall. It has a hot desert climate, with three months of rainfall above 50 mm, while potential evapotranspiration is about 1,800 mm/year and 160–15 mm/month during the growing season. Soils are Central Clay Plain Vertisol (Black Cotton Soil), an

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expansive heavy clay soil which cracks at a unique water content.

1.2. Water conveyance

The Gezira Main Canal, with a capacity of 365 m³/s, splits into branches with a total length of about 615 km, which themselves branch into about 1,620 km of major canals. The latter discharge into minor canals of about 11,700 km. These minor canals, with an average width of 12 m, are divided into reaches of about 1 to 3 km, depending on their slope. Water slope is in the order of 5 cm/km in daytime and 1 cm/km at the storage level at night.

A minor canal is the starting point in Figure 2; from it a field outlet pipe (FOP), a 35-cm-diameter concrete pipe, supplies water, when fully opened, at a rate of 5,000 m³ per 12 hours (120 l/s), at the design head. It supplies water to 90 feddan (38 ha) of irrigated land along a feeder channel (Abu Ishrin: ABU XX). No canal lining is practised in the Gezira, as in the expansive clay deep percolation is negligible. Perpendicular to the ABU XX, field channels (Abu Sittas: ABU VIIs) mark the boundaries between hawashas with a surface of 5 feddans (2.1 ha), as pictured in Figure 2. Furrows, 80 cm wide and 30 cm deep, and ridges are parallel to ABU VIIs. Actual furrow irrigation takes place from jedwals parallel to the feeder channels. ABU VIIs divide tenancies into two hawashas, each of which is divided into 7 angayas (Figure 2). A jedwal irrigates one angaya,
1.3. Water problems

Sudan is approaching the limit of its quota (18.5 km$^3$) of Nile waters as determined under the *Nile waters Agreement with Egypt in 1959,* with its current consumption of about 15 km$^3$. The Gezira (cum Managil) Scheme, with its 0.9 million ha, is among the largest irrigation schemes in the world and consumes one third of Sudan’s share of Nile waters. The following problems of irrigation water use are observed:

1. difference in access to water between tenants located at different parts of the water lines (tail end problem), both along the minor canals and along the ABU XXs;
2. water logging in (parts of) fields with better access to water and/or breakage induced by these farmers into neighboring fields, and breakage of canals in rainy seasons;
3. as a result of (1) and (2), irrigation that fails to meet crop water requirements in fields with lower access to water, and consequently low yields in many areas.

All together these difficulties result in low overall water application efficiency ($\leq 50\%$).

Tenants are dissatisfied with overall maintenance of the scheme, and authorities are dissatisfied with tenants’ water use. [In this paper the word tenant refers to the person who has the legal right to use the land, while the farmer is the one who actually performs the cultivation activities (this may be the tenant himself, his representative, a sharecropper, or a seasonal renter).]

Authorities running the scheme (Ministry of Irrigation: MOI and Sudan Gezira Board: SGB) are of the opinion that the farmers are wasting water by the unattended continuous (day and night) irrigation method they have evolved, especially for their private crops dura (*Sorghum bicolor*) and

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**Figure 2** The current canalization system in a 5-feddan (2.1 ha) hawasha in the Gezira Scheme, which is half of a tenancy. Arrows show flow direction. FOP = Field Outlet Pipe, ABU XX = Feeder channel, ABU VI = Field channel.
groundnuts (*Arachis hypogaea*). There is a belief that remarkable savings in water would be obtained if the tenants would go back to the traditional night storage (NS) system, in which rather laborious and well-attended daytime application of water is practised.\(^5\)

The tenants have very recently become “cost-sharing partners” by paying the actual costs of water delivery, in which water rates are based on number of irrigation cycles but not yet on the actual volume of water consumed.

1.4. The night storage (NS) system and the present situation

Already around 1930 the NS system was introduced to prevent water waste. The main idea behind this system is to use the minor canals as conveyors during the day and as reservoirs by night.\(^5\) For each irrigation, water through a FOP should flow for 7 to 8 consecutive days (daytime only), and this cycle is basically repeated every two weeks.

Water management in the system is practised according to an intensification and diversification of the scheme introduced in 1975, mainly based on the following two main conditions:

(a) The tenants must irrigate only during daytime (6 a.m. to 6 p.m.). This makes inspection easier and water availability in the minor canals better and fairer. In this attended watering, once an angaya is filled, the farmer moves the flow to the next angaya. The art of attended watering is also to distribute water over different elevations of the angaya in such a way that each part does not receive (much) more than what it needs.

(b) Each angaya is to be separately irrigated through one jedwal, while over-irrigation of any part of the field and breakage of tagnets (in order to irrigate two angayas simultaneously) must be prevented by all means.

Water use efficiency is negatively influenced by maintenance problems of minor canals, particularly due to siltation and water weeds. The tenants feel that although they pay for maintenance, the work is not fully carried out by the authorities. This together with the earlier mentioned developments has generated a series of ever more serious problems related to the NS system, particularly during crucial periods of crop growth.\(^5\) Therefore, the tenants, the actual consumers of irrigation water, have become more inclined to use water during the night, to meet the water needs of their dura and groundnuts.\(^3,6\) In the unattended irrigation, tampering with the flows from the ABU VIs takes place. Two angayas are always irrigated simultaneously, breaking of tagnets is practised, and waters of jedwals sometimes mix.

Visually estimated depth of standing water, in the furrows of 80 cm wide and with a maximum depth of 30 cm, is used by the farmers as assessment of the irrigation satisfactions. This tends to waste irrigation water, because of differences in furrow levels. As a result of ploughing, the outer two half-angayas are normally higher than the rest of the field, unless precise levelling is carried out, which is expensive. There are natural differences as well. In fact, without close attention required when applying the NS system, some parts of the field remain continuously over-irrigated if larger areas are to be satisfied at the same time.

As a result, despite the consequences, overindenting\(^7,8\) is practised by the authorities, who raise the operation level of the main canals as much as 20 cm above the maximum design levels.

To give authorities and tenants concrete data for reasoning, in this case study on-farm data for the comparison of water use between the attended NS system and unattended day and night irrigation were collected.

II. Methodologies

2.1. Questionnaire

In the on-farm work, near Hamza Minor canal of the Tibub block (Central Division of the
Gezira), which is near the 400 mm isohyet, we started to explore the water management practices of farmers in the Scheme by questionnaire. From all 108 tenants operating from Hamza Minor, 99 replies (92%) could be used. Of these replies, 48 were by tenants, 9 were by one of their representatives, and 42 were by sharecroppers. Apart from asking for personal data and data on the tenancy itself, questions were on all aspects of water application management. The most important replies to the latter for dura and groundnuts are given in Section 3.1 below.

After establishing trust between tenants and researchers, taking into account the understanding obtained from the questionnaire, the following guidelines were used, in the preparatory season of 1986/87, to select two farmers irrigating from Hamza Minor canal and their experimental fields for the quantitative on-farm case study:

1. The farmers had to be owners or sharecroppers of two fields that did not suffer tail end problems, were irrigated from the same FOP, and had reasonably comparable yields over the preceding 10 years (1976/77-1985/86);
2. They had to believe in the value of research and had to be interested in co-operating in the field research; and
3. Among the pair of farmers selected one had to be willing, with a financial incentive, to fully perform the abandoned laborious traditional daytime attended watering.

2.2. On-farm measurements

It is widely felt these days that on-farm research with farmer participation improves the relevancy of data and results and increases adoption of advisories that emanate from such research, particularly in developing countries. We therefore chose this kind of research approach in the Gezira. To exclude other water management problems, the experiments of the period 1987-1990 were done with farmers with head fields.

The experiments determined, for the full growing seasons of dura and groundnuts, actual on-farm application depths (by two selected farmers, but each growing season on different fields) of two irrigation methods, attended and unattended watering (1988/89 (S1) and 1989/90 (S2) growing seasons). The attended method followed the NS system regulations, while continuous day and night free watering was applied in the unattended method. As water delivery to groundnuts and dura is not controlled by the authorities, dates and depths of irrigation are at the discretion of the farmers. When it rains during irrigation, the water applications will be shortened. When about 90 mm of rainfall or more occurs three days or less before the scheduled FOP opening, this irrigation is automatically skipped, because 90 mm is the recommended depth of one irrigation in the Gezira. Good rainfall, about 50 mm or more that occurs after any application and before complete dryness of the soil, increases the irrigation interval. This is not only because the farmers are satisfied with soil moisture content, but also because rainfall generally delays the weeding process, as the soil will be wet.

The flows of ABU VIs during these two growing seasons were measured manually for two hawashas, which were different each year, using a Vane Flow Meter (HRL, Wallingford), as pictured in Figure 2. Concrete tubes, 1.0 meter long and 0.35 meter in diameter, were placed horizontally in the ABU VIs and used as a flow guide, allowing no flows outside the tubes. Each tube was provided with a rectangular groove on the upper side, where the vane was placed, and the passing flow was quantified.

During steady discharges, measurements were taken every hour, reducing these times to as low as 15 minutes in unsteady flows. At night (unattended watering) measurements were done until midnight and then again near 5 a.m., about one hour before the farmers came. Any difference between these last two measurements was linearly interpolated. For discharges smaller than 5 l/s a Parchal Flume was used, and the Vane Flow Meter was later calibrated with this flume for such low
discharges. In this way the four irrigations of dura and the five groundnut irrigations for each growing season were fully followed.

Amounts lost as evaporation from standing water were obtained from the difference between the measured application of irrigation water (together with any precipitation) and the measured soil water deficit (SWD) before irrigation. To fill some gaps in the data, these amounts were calculated from the standing water surface, which was carefully observed each day, and Penman evaporation from free water. For East Africa the empirical constants in the Penman equation were earlier derived by Stigter (1963) and applied in Sudan by Abdulai et al. (1999). The meteorological data from nearby Wad Medani town were used for this purpose.

The other main data collected were irrigation dates, depths and periods of rainfall measured, soil moisture contents measured by the neutron scattering method (1963), throughout the season, and any differences between farmers in cultivation practices, such as low density intercropping at the edges and harvesting techniques. More detailed explanations, calculations, and analyses may be found elsewhere.

III. Results and Discussion of Farmers’ Present Water Management Practices

3.1. Results of the questionnaire

The replies to the questions on water management revealed that at present: (i) the tenants/farmers do not see any sense in attended watering after the first two irrigations; (ii) they normally adjust the openings of their ABU XXs, ABU VIs, and jedwals, and thus the flow of water, according to the area to be irrigated and their expected time of absence (the “art of water application”, as they call it); (iii) in this way they relieve themselves from the closely attended watering practice, which was observed to take about 18 to 24 full working hours per irrigation with normal flows (= 5,000 m³/day per Abu XX); (iv) many farmers admit the importance of adopting the NS system but they still use the continuous flow method; (v) farmers appear not to understand that most of the standing water evaporates without being used by the crop; (vi) sharecroppers, who are originally from the western states of the Sudan, Chad, or Central Africa, lack knowledge of irrigation but all tenants use sharecroppers for groundnuts and sorghum, because of the following factors:

1. Family cooperation has diminished, and most tenants can not handle all the farming aspects alone, even if they wanted to.
2. Dura and groundnut crops require hard work. Therefore the tenants prefer to take the responsibility of land and seed preparations, leaving the rest for the sharecroppers.
3. When tenants need cash to pay laborers or for other reasons, they are forced to sell their crop in advance, at about 30% below the estimated market price, if they do not adopt sharecropping.
4. Sharecropping develops good relations between the two partners. The sharecropper and his family most likely help their tenant partner with his other crops when work in dura and groundnuts is completed and before committing themselves to working for others.

Sharecroppers prefer to adopt continuous unattended free application of water, because for the private crops of dura and groundnuts opening of FOPs is uncontrolled by the authorities and they can make use of the irrigation time to work as hired labor in fields of other crops. This strongly links the necessity of sharecropping and the unattended watering to socio-economic backgrounds, and weakens the assumption that unattended watering is a mere water availability problem, as suggested by Farbrother (1963), and the conclusion that the farmers have evolved the present watering practice only out of convenience, as was claimed by Abdu. (1963) The farmers’ mistaken perception that water standing on the soil will in the course of time replace soil water used by the crop needs to be corrected.
3. 2. Field results

a. From measurements

Based on the two growing seasons of field data taken, average application depths per irrigation measured in the unattended field were from 20% to 40% higher than corresponding depths in the attended field, as given in Table 1 by $D_u/D_a$ and $G_u/G_a$. The following results can also be read from that table.

Both farmers in the experiment applied larger depths in drier seasons. However, the applications of the attended watering method in both years appear to be lower than (for $G_e$ in S1) or close to (within 10%, which is within the accuracy margins) the officially recommended irrigation depth in the Gezira of 90 mm per irrigation, while the unattended irrigation method used appreciably more water than the attended one. Using this same recommended yardstick of 90 mm, especially in the drier year much irrigation water was actually wasted in the unattended fields, where 120 mm and 125 mm were used for $D_u$ and $G_u$ respectively.

b. From observations and calculations

Table 2 shows that there are longer periods of standing water in an unattended field, where water is kept flowing for a longer time after the cracks are filled. In the Gezira, after the rapid completion of filling of the cracks by free flow downwards from surface flooding, all further downward movement practically ceases, as the hydraulic conductivity of the saturated 0-20 cm horizon falls virtually to zero. Surface water was occasionally observed to stand for 4 to 5 days, after one day of irrigation. The larger were the fields irrigated at the same time, the greater was this problem.

The methods used for determining the evaporation from standing water both have a tendency to overestimate at longer durations, due to some replacement of water evaporated by the crops. This does influence appreciably less the ratios and the differences in Table 2, in which we are actually interested. The highest seasonal estimations of standing water surface evaporation losses were 200 and 230 mm depth of water in S2 from the unattended fields, amounts which are in the order of two recommended irrigations (one being 90 mm) when overestimated by about 10 to 20%.

The difference in wasted water between the irrigation methods is not high for dura, but in the case of groundnuts it is 60 mm, because groundnut soil is kept wet for longer periods, to facilitate harvesting, and it gives appreciably less soil cover. This is, for the two cases, about 85% (S1) and 35% (S2) more in the unattended irrigation than in the attended irrigation (Table 2). Otherwise expressed, this difference of 60 mm is about 50% of an average application for unattended groundnuts in the drier year (S2) or 60% of that in the wetter year (S1) (Table 1). Minimizing

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Attended daytime</th>
<th>Unattended day &amp; night</th>
<th>Rainfall</th>
<th>Ratios</th>
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<tbody>
<tr>
<td>season</td>
<td>$D_a$</td>
<td>$G_a$</td>
<td>$D_u$</td>
<td>$G_u$</td>
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<tr>
<td>88/89 (S1)</td>
<td>85</td>
<td>70</td>
<td>105</td>
<td>100</td>
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<tr>
<td>89/90 (S2)</td>
<td>100</td>
<td>100</td>
<td>120</td>
<td>125</td>
</tr>
<tr>
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<td>1.2</td>
<td>1.4</td>
<td>1.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Table 2  Observed water (mm) retained on the soil surface and lost as free surface evaporation seasonally for Dura (D) and Groundnuts (G) in attended (a) and unattended (u) fields. The ratios were determined before rounding off.

<table>
<thead>
<tr>
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<th>Ratios</th>
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<tbody>
<tr>
<td>season</td>
<td>D_a</td>
<td>G_a</td>
<td>D_u/D_a</td>
</tr>
<tr>
<td>88/89 (S1)</td>
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<td>80</td>
</tr>
<tr>
<td>89/90 (S2)</td>
<td>180</td>
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<td>200</td>
</tr>
<tr>
<td>Ratio S2/S1</td>
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<td>2.3</td>
<td>2.5</td>
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</table>

losses of standing evaporating water will certainly improve the water use efficiency of the irrigations.

It was found that, on average over the attended and unattended irrigations of both crops, about 55 mm (1989) and 80 mm (1990) of available water were still present at the time the crop was no longer using any water. So water in the amount of about half an irrigation or more can also be saved by minimizing the last irrigation of the season, which always leaves water in the soil unused that under present conditions evaporates before the start of the next season (Ibrahim et al., in preparation).

IV. Conclusions and Recommendations

The main points that should be used in a dialogue between authorities and tenants on the necessary adaptation of present watering methods are as follows:

1) Irrigation water is limited at local and national levels, yet present irrigation practices are inefficient. However, only when clear profits or other incentives convince the farmers will water be more wisely used on-farm. Less waste will help to do away with overindenting and to maintain uninterruptedly the required commands in the minor canals; this will reduce total seasonal irrigation time by increasing FOP discharges where they are too low and will help to solve the tail end problems.16)

2) If the case study reported on is indeed representative, at least 20-40% on-farm saving in irrigation water will be obtained if more efficient on-farm application methods such as attended daytime irrigation are adopted in the scheme; minimizing the last irrigation may also contribute.

3) Poor on-farm water management can be attributed to (i) the large areas of land being irrigated simultaneously in unattended watering when the NS system is not applied, (ii) the lack of attention to the duration of within-field water flows, and (iii) the visual method the farmers use for their irrigation satisfaction. At the highest places of the fields being considered for irrigation at the same time, minimum depths of water should be used in the furrows, while water left standing at the end of the irrigation should be avoided as far as possible; this means separate irrigation of different levels in the field for appropriate periods, as is done in the traditional attended irrigation method. Occasional precise land levelling is also recommended.

4) When dealing with a sharecropper, the tenant should be sure that his partner is attending to the irrigation and is provided with the means to do so. This leads to lowest possible water costs.
Results such as those obtained in this case study will convince the authorities to set up larger-scale validations and to carry out improvements, e.g. in levelling and maintenance, to decrease the impact of factors that influence water use efficiency negatively and to satisfy tenants. In Sudan this may best be set up through farmers’ unions and production councils. Future research should improve knowledge of crop water requirements at different crop stages and demonstrate substantial profits from diminishing water use. As long as individual tenants are not yet charged for their actual water use, water waste should be seriously discouraged by establishing water quotas.

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References


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**Advanced Paddy Field Engineering**

“Advanced Paddy Field Engineering” is to present the available information relating to the engineering aspects of recent paddy field development and management in Japan in comprehensive manner.

This book is useful to scientists, engineers and graduate students in rice producing countries for planning the future research and development activities as related to paddy fields.

In spite of the importance of paddy cultivation in most of countries in Asia, not much emphasis has been evident in improving the paddy field system. It may not possible nor necessary to replicate exactly what has been done in Japan, but it is possible to make several improvements to the paddy field systems in most of the countries.

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