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Assessment and comparison of conventional and modern irrigation systems to manage irrigation water supplies in the River Nile State of Sudan

Ahmed Elgilany*, Sulaiman Jamalludin, Mohd Saidatulakmal

University Sains Malaysia, School of Social Sciences, Pulau Pinang, Malaysia
Tel. +60 4 6533888x3369; Fax: +60 4 6570918; email: algaylani@usm.my

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ABSTRACT

The increased use of irrigation water in the River Nile State (RNS) puts a great pressure on the local hydrology and ecosystem. The RNS is regarded as one of the important areas where large investments in irrigation take place for food and cash crops production. The adoption of various techniques of water conservation is becoming necessitated including the large meaning of water use efficiency. The sustainability of irrigated agriculture is questioned and the challenge is to increase simultaneously land and water productivity in the face of the limited availability of land and water in the RNS. The aim of this research is to assess the irrigation water management performance of two irrigation schemes based on the option that irrigation is mandatory in both from the River Nile by pumps and to identify options to improve irrigation water performance. The analysis was based on structured survey questionnaires, field observations, and literature from Elzeidab scheme where surface irrigation is prevalent which is known as a traditional system; and from Bashaier scheme where sprinkler irrigation exists as a modern system. Integrated techniques involving economic and hydrologic components are used to assess irrigation water use in both schemes under study. Descriptive statistics and quantile analysis for crop water applied and crop water requirements for Elzeidab and Bashier field crops are presented. Crop Wat4 and SPSS have been employed to evaluate the irrigation water performance of tow scheme administrations. The results suggest that vast irrigation water devoted for agricultural production in the state coupled with low production will need attention on water management, allocation, quantities, and introduction of water-saving technologies. Water management in the Elzeidab scheme is not well qualified to handle irrigation water. Lack of staff awareness in Elzeidab led to inefficient water use. The paper concluded that in order to improve the water management performance of the Elzeidab pump irrigation scheme, numerous challenges are needed to contribute to saving irrigation water in the future: institutional support (input supply, output marketing, and credit services), training of staff on improved crop and water management issues, regular supervision, and monitoring of scheme activities are crucial.

Keywords: Water management; Water saving

1. Introduction

The demand for good-quality water is continuously rising owing to the rise in the population, intense agricultural practices, industrialization, and overall rise in living standards [1]. Real progress for improving surface irrigation methods has been limited in several developing countries. Despite intensive programs in this region, national efforts and international

*Corresponding author.

assistance have not been commensurate with the magnitude of water problems in agriculture and efficient water use is far from being achieved on any large scale.

Advancements and new technologies have been introduced to various irrigation methods during the last two decades, in order to maximize the water application efficiency and to minimize water losses. Many of these techniques have been tested and used successfully in several developing countries. In an effort to protect current water supplies and find new ones, scientists, politicians, and environmentalists are huddling the 5th World Water Forum in Istanbul, Turkey. The top on their agenda: "new technologies that hold the promise of protecting natural water habitats." No doubt, development of water resources played an essential role in the advancement of the agricultural sector and indirectly in the economic development of the whole country. In Sudan, despite the fact that the water resource is abundant, the irrigation water is the most chronic constraint facing the agricultural sector over the country with it is enjoining with a vast irrigable land that estimated to be 2.79 million ha in 2007. The total area equipped for irrigation is estimated to be around 1.86 million ha, and only about 43% of the irrigation-equipped area is actually irrigated and most of these areas regarded located at the rivers beaches as low terrace land and to some extend as high terrace one. Most of this expansion occurred in the middle and Northern Sudan, along the River Nile flows and its tributaries.

In the River Nile State (RNS), the most important agricultural state in the Northern Sudan, the only possible means of irrigation is pump irrigation from the Nile. The population pressure and the inefficient water use led to perpetual water scarcity problem. The awareness of modern irrigation water technologies and water use efficiency (WUE) did not spread wide in the agricultural sector of the state; in other words, there is less stress to apply the recommended standards of crop water requirements (CWRs). The area that can be commanded by pumps in feddan was significantly higher than actually cultivated one. This indicated that the capacity of those pumps was underutilized. Saraf et al. [2] concluded that considerable amounts of water diverted for irrigation are not effectively used. It is estimated that on average, only 45% is effectively used by the crop, with an estimated 15% loss in the irrigation conveyance system, 15% in the field channels, and 25% in inefficient field application. The paper undertook Elzeidab public irrigated scheme and Jordanian Bashaier Company for Agricultural Investment as case studies to conduct the research. Elzeidab Agricultural Scheme is one of the oldest schemes in Northern Sudan. The scheme now belongs to the State Ministry of Agriculture, and it was established in 1904. The total area of the scheme was originally 22,000 feddans, and extended later by 6,900 feddans. While the second case study, namely, Jordanian Bashaier Company for Agricultural Investment, was established in Sudan in 1999 with a total investment area of 9,000 feddan, 8,815 feddan of the total area are devoted for the agricultural production in the Elmkabrab area of the RNS, about 300 km north of Khartoum. No doubt, the importance of the research work is growing rapidly to assess and recommend for the water resources situation in the study area, but in the RNS limited research has been conducted to establish resources of the systems to maximize the tenants' net returns. The most predominant constraints facing irrigation water use in the state are: slow introduction of modern water-saving technologies, low WUE due to lack of knowledge on the part of farmers, excessive water application rates, rising water tables and salinity, inadequate extension services and difficulties of access to existing research base, high construction, operation, and maintenance costs, poor design, and low quality materials. Commonly, the constraints of WUE are partly of technical nature, related to institutional, economical, managerial, and social conditions. Finally, this paper looks to the latter option(s), specifically to promote a more effective and integrated irrigation management performance of RNS schemes through improvement of existing systems and tenants' conceptions towards irrigation water, hence, to increase the irrigation water productivity in these schemes.

1.1. Climatic characteristics

The average rainfall does not exceed 100 mm/y. The climatic conditions of the state allow the production of a wide range of perennial and seasonal crops. Tropical and sub-tropical fruits grown include dates, citruses, mango, banana, and guava. The distinct cool climate in winter and hot in summer allows the production of a wide range of cool weather crops such as wheat, faba bean, chickpea, dry bean, lentils, onions, spices, and vegetables as well as warm weather crops such as sorghum, summer vegetables, and groundnuts. Soils in the area of the study are alluvial, which are generally fertile, made up of loamy and silt deposit, generally well drained non-saline and non-sodic. While water resources in the state mainly from the River Nile and the Atbara River as the main direct resources of irrigation water, the utilization of this water under the umbrella of Nile water agreement (1959) signed between Sudan and Egypt, the average of annual flow measured at Aswan 84 milliard m^3 shared as follows: the Sudanese share is 18.5 milliard m^3, Egyptian share is 55.5 milliard m^3, and the losses in Aswan are 10 milliard m^3. In addition, the state has huge underground water resources in Nubian Sand Stone.

2. Methodology

As previously mentioned, this study was carried in both Elzeidab and Bashaier irrigated schemes of the RNS. The farming system of the Elzeidab scheme is mainly characterized as not full-mechanized system, while the modern full-mechanized system exists in the Bashaier scheme. The production in both of the schemes is based on field crops as well as animal production activities. This study depends mainly on primary data from the study area, besides secondary data from relevant official sources. The method selected for primary data collection was direct personal interviewing of the sample respondents by using structural questionnaires. The primary and secondary data collected in season 2005–2006 consisted in information pertinences operation of the schemes under study. As precision could be achieved, stratified random sampling based on convince and flexibilities with probabilities to size was used to determine the plausible size of the targeted groups in the Elzeidab public irrigated scheme of the RNS, considering the cost, time, and other relevant facilities. To achieve the goals of the study, comprehensive secondary data were collected from the Bashaier scheme. Two types of constraints were noticed in the study area, *firstly*, in the Elzeidab scheme, the lack of infrastructure made the movement over the study area difficult. Some farmers were unaware of the research work and hence more time was required to obtain proper information from them; moreover, some of them thought that the research work aimed at taking taxes so they refused to be interviewed. Furthermore, numerous farmers reported that a lot of research work had been done in their areas, without tangible returns to them. *Secondly*, the Bashaier scheme is regarded as a new scheme in the area of study and the technical data are not prepared in a proper manner.

2.1. Analytical techniques

Descriptive statistics was mainly used to achieve the objectives stated. In the descriptive part of the analysis, frequency distribution, and graphical and statistical analysis were used. The calculation of the CWRs of any crop requires estimation of its crop coefficient (Kc). Kc values could be used for estimation of CWRs as a product of Kc × ETo in the RNS as well as other similar regions of Sudan. Recently, FAO Penman–Monteith (PM) method was developed to estimate ETo values from a hypothetical reference crop that were more consistent with the actual CWR and have been recommended by FAO as a standard method for CWR calculation designed in the software program CROP WAT4. Eq. (1) is Penman–Monteith to calculate the CWRs where any crop requires estimation for its crop coefficient (Kc). Kc values could be used for estimation of CWR as a product of Kc × ETo in different regions of Sudan. Penman equation (1948) for calculating evapotranspiration from free water surfaces was used in the calculation of crop factors (CF) by many scientists over the world. They were able to determine the CF of most filed and perennial crops in the world. Recently, FAO PM method was developed to estimate ETo values from a hypothetical reference crop that were more consistent with the actual CWR and has been recommended by FAO as the standard method for CWR calculation. The reference crop evapotranspiration ETo was calculated from the daily whether data, specifically the maximum and minimum temperature, relative humidity, wind speed at 2 m height, and sunshine duration by using CropWat4 Windows program according to the recommended Penman–Monteith formula as follows:

$$ETo = C(WR_n + (1 - W))f(\mathrm{u})(\mathrm{ea} - \mathrm{ed}) \tag{1}$$

where W = weighting factors; R_n = net radiation; ea = saturation pressure; ed = perfumed water; f(u) = function of wind speed; and C = error factor.

Eq. (2) is on-farm water use efficiency (FWUE); according to Shideed et al. [3], the concept of FWUE was developed to address this complex situation at the tenancy level. FWUE is defined as the ratio of the required irrigation water to produce a specific output level to the actual amount of water applied by farmers, as shown in the following form:

$$\mathrm{FWUE} = \mathrm{WR}/\mathrm{WA} \times 100 \tag{2}$$

where WR is the amount of water required (mm) by the crop to produce a certain level of crop production and WA is the amount of water actually applied (mm) by farmers to produce that level of crop production. The basic data used to calculate gross returns per feddan are output value, while gross margin per feddan is obtained by subtracting the average total variable cost from the total returns. Gross margin is a good indicator of how profitable a firm is at the most fundamental level. Farms with higher gross margins will have more money left over to spend on other activities such as investment, improvement of production, and marketing. Eq. (3) is the general mathematical form for the gross margin calculation per crop as follow:

$$GM = GR - TVC \quad (3)$$

where GM = crop gross margin per feddan in SDD, GR = crop gross revenue per feddan in SDD; and GM = TVC: crop total variable costs per feddan in SDD.

3. Results and discusion

This paper provides a background for water management in the Elzeidab and Bashaier irrigation schemes and investigates some results on irrigation water use, and some economic aspects in the scheme are made according to the data collected from the field survey. It has been difficult for researchers to analyze the information on irrigation water use in an accurate manner. Furthermore, you cannot adequately protect and manage water unless you can assess how that water is reacting to conditions in real time.

3.1. Current irrigation water management in schemes under study

In the world of limited resources, limited sympathy and limited rationality, competition leading to tensions and conflict can arise. In such circumstances, a key responsibility of any society is to ensure the security of its citizens [4]. The delivery of irrigation water for both schemes depends on the pump irrigation system from the River Nile through fixed irrigation stations at the river and thus via net canals. The winter season is considered as the principal season there, while the summer and autumn "Demira" seasons are ranked after it due to some environmental and economical aspects. This gives a comparative advantage for the winter crops vs. other seasonal crops. The farm management in the Elzeidab scheme is fully under the tenants' control, while the government is considered as a water seller besides preparing agricultural policies, while all agricultural activities in Bashaier are fully under administration of the company. The Elzeidab scheme consists of five pump stations employing 14 pumps with different sizes that range between 12 and 36 inches, and the total discharge of these pumps was estimated at 22 mm/s equal to 80,000 mm/h/pump lifted directly into the supply canals. About 78% of the total delivered water per watering was devoted to the seasonal crops with an area of 11,700 fed equal to 61,776 mm/h/pump, while the remaining amount is allocated to the perennial crops. The average daily pumping duration of the pump station is estimated at 8–10–12 and 8–10 h for Elzeidab and Bashaier, respectively, throughout the production season. The total quantity of the delivered water per irrigation for the Elzeidab scheme was estimated at 8,864,640 mm including water losses; this amount is devoted to the cultivated area of the scheme of 14,700 feddans for both perennial and seasonal crops when they exist simultaneously.

The amount of water supplied per watering in the Bashaier scheme was estimated at 20,000 m^3 including water losses. The water devoted to the cultivated area of the scheme of about 1,560 feddan only grown by field crops. As is known, the function of the supply canal is to carry irrigation water from the pump station through its outlet to the field, but in the Elzeidab case it has more than one function; it stores irrigation water between the head and tail of canals as an old technique used in the scheme known as the "night storage system." Irrigation water is supplied through the scheme's irrigation network to irrigate a rotational area estimated at 16,000 feddan out of 28,500 feddan. The Irrigation Department of the State Ministry of Agriculture is responsible for planning, operation, maintenance, evaluation, and monitoring of the irrigation system from the source to the tertiary canals, while the direct manager of the scheme that also represents the Ministry of Agriculture is responsible for scheduling and regulating water for the scheme tenants. On the other hand, the irrigation system of the Bashaier scheme consists of two pump stations namely, Station A is the main source of irrigation at the RN, and is characterized as a floater station which supplies the irrigation water via the main canal and along 2.5 km to Station B which is regarded as a booster station. Station B is the main water delivery station for the irrigated area of the scheme. It was started with a 16 in iron pipe along 5 km and it is tended to three major canals, each 5 km long.

3.2. Costs of irrigation water in area of the study

Postel [5] mentioned that the cost of irrigation has increased substantially since the 1970s, and more than 190 bank projects found that irrigation costs now average \$480,000/km^2. This cost varies by location. The capital cost for a new irrigation capacity in China is \$150,000/km^2, while the capital costs in Africa 7 are 1,000,000–2,000,000\$/km^2. Mexico's irrigated area has actually declined since 1985 due to lack of capital. It is clear that there is a vast gap between capital costs for new irrigation system for Africa as compared to that for Asia. This might explain the high irrigation water charges for public irrigation schemes in Sudan. It can be concluded that there are other factors besides water management that also have an impact on the development of the scheme. These factors include the cropping pattern, unwillingness on part of the tenants and the devaluation of the Sudanese currency which resulted in increasing the cost of agricultural production. According to State Ministry of Agriculture and Bashaier reports (2006), irrigation water costs for the Elzeidab and Bashaier schemes for the season are broadly differentiated into variable costs.

3.3. The operation costs in the schemes under study

The annual running expenses apply to fuels (gasoline, oil, and grease), spare parts, maintenance, staff salaries and allowances (management expenses), services, and others. The irrigation costs components of both schemes are mainly based on the variable costs as follows:

(a) *Fuels:* mainly used for operating the scheme pumps but small quantities are devoted to the scheme's vehicles and machinery. Although oil production in Sudan was started more than 10 years ago, the government kept increasing the petrol prices from time to time. This has also affected transportation costs, which increased as well and form additional irrigation costs. The results revealed that fuel costs in the Elzeidab scheme formed 56% of the total irrigation costs as the highest cost component, while it was 27% of the total operation costs as the second cost component.

(b) *Spare parts*: this component was also regarded as an annual irrigation running cost and as a complementary component for maintenance of scheme pumps, vehicles, and machinery. Costs of spare parts in the Elzeidab and Bashaier schemes were found with percentage share of 8 and 2% of the total irrigation costs, respectively.

(c) *Maintenance cost*: maintenance costs cover the two following sets of expenses; the first set is incurred by the maintenance and operation directorate in one or in the tow schemes as follows: silt removal from the scheme irrigation network, maintenance of the scheme canalization, bridges, regulators, and gates and weed control operations. The second set is prepared by the direct manager of the scheme for different engineering directorates (i.e. pumps, vehicles, and machinery). The study results show that the maintenance costs formed 4% and 13% of the irrigation cost for the Elzeidab and Bashaier, respectively. The high maintenance cost for Bashaier might be due to its sophisticated irrigation system that requests more skilled labors and expensive spare parts.

(d) *Salaries, allowances, and hired laborers:* this component of the operation costs applies to the field and office staff where both of them are partially paid by the scheme. Their values contributed 26 and 29% of the total average variable costs of operation in the Elzeidab and Bashaier schemes, respectively. The Bashaier scheme is characterized by hired laborers instead of tenants, and the result of this component was found to be 10% of the total average variable costs of operation.

(e) *Services and others:* these are considered as minor cost items in the schemes operation costs, including components such as health, social occasions, electricity, and others. Their percentage shares in the Elzeidab scheme were 5–1% for the services and all other expenses, respectively, and they formed only 1–2% for the Bashaier services and all other expenses, respectively.

(f) *Insurance*: this component is found only in the Bashaier scheme. It is associated with the modern systems and its application might be optional or compulsory according to the type of the institution. This component was found to be 10% of the total average variable costs of operation.

3.4. Agricultural production

Production relations in Elzeidab and Bashaier are absolutely different. The Elzeidab scheme was based on a water rate system under agreement between the scheme administration and the tenants. Water charges differ between seasonal and perennial crops, while in the Bashaier scheme the crop production processing was fully undertaken by the scheme administration as mentioned before. Many studies mentioned that the RNS has been assumed to have a comparative advantage with field cash and food crops production namely, vegetables, cereal, and spice crops, besides the perennial crops such as dates, alfalfa, mangoes, and citruses. This assumption is based on the state favorable climatic conditions, vast endowments such as land and the permanent sources of irrigation, and accumulative experiences of skilled farmers. Although the RNS is characterized by past comparative advantages, the last decade witnessed frequent debates about the deterioration of agricultural production, which might attribute to numerous hindrances such as low crop productivity, high cost of production, inadequate credit, and marketing and prices instability. These facts led to a convincing point that the stability of irrigation sub-sector should achieve food security and poverty alleviation, and improve the livelihood of the farmers of the scheme.

3.5. Distribution of arable land in the area of study

The tenants of Elzeidab are provided with 10 feddans of land called "Hawasha" for cultivating their crops in different seasons. Land is not owned by the tenants but belongs to the government and is rented as a long-term lease by the tenants. The crop rotation is planned by the tenants, particularly after the privatization policy introduced by the central government in 1994. The land distribution in the Bashaier scheme is based on sprinklers allocation. The scheme possesses 10 units of sprinklers, 120 feddans for each one of eight of them, while the two were allocated to cover 150 and 132 feddans. Generally, the crop combination in the state was mainly determined by the nature of season, tenants' experiences, market conditions, and, to some extent, by the state agricultural policies.

3.6. Cultivated area in the schemes of the study

The survey of the Elzeidab scheme revealed that the distribution of field crops in season 2005–2006, on one hand, was such that 25% of the total land was devoted to wheat, followed by 19% for sorghum, and 14% for onion, while the lowest percentage (1%) was allocated to potatoes. The other crops were ranked as 2, 2, 3, 4, 5, 8, 8, and 12% occupied by spices, dry beans, alfalfa, maize, fodder, vegetables, chick pea, and faba bean, respectively, on the other hand, the research unveiled that the allocation of the field crops in the Bashaier scheme was 39% of the total cultivated land occupied by wheat; followed by 15% for sorghum, forage, and alfalfa; and 8% for onions and barley. The paper observes that most of the cultivated area was covered by cereal crops which are known as very exhaustive for soil fertility, while legumes and vegetable crops formed a limited area of the scheme indicating an ignorance of land improvement, producing the food security products and soil conservation. The majority of these crops are cultivated as winter crops with exceptional cases for some crops that could be produced in winter and summer seasons, namely maize, fodder, and vegetables. Furthermore, the sorghum crop in Elzeidab scheme usually is sown at the end of the summer season (September) to be harvested at the middle of the winter season (January), while sorghum and onions are grown in April after wheat harvest and to be irrigated with wheat units. The harvested crops are used either for domestic consumption and/or as cash crops.

3.7. Yield of field crops under study

The profitability of adopting new irrigation technologies depends on the level of productivity improvement [6]. The paper focuses on some of the main food and cash crops in the study areas, namely, wheat, sorghum, onions, fodder (Abu70), and alfalfa. Crop yields achieved by the Elzeidab tenants were generally low when compared by research yields reported by the Agricultural Research Corporation (ARC). Yield gaps of 26, 41, 66, 76, and 80% apply for alfalfa, sorghum, wheat, onions, and fodder crops, respectively, while crop yields obtained under the Bashaier scheme were also low for the majority of field crops except for alfalfa which was higher when compared with alfalfa yield of ARC; but at the same time, crop yields of field crops in Bashaier are considered better than under the Elzeidab scheme. Although the ARC crop yields were estimated under the surface irrigation system, they achieved better productivity for most crops when compared to the crop yield obtained by the Bashaier scheme, indicating that a big gap exists to increase the scheme's yields of all Elzeidab field crops and the majority of Bashaier.

3.8. Production cost of field crops of the study

Production economics plays a unique role in farm management [7]. Cost of production is known as the cost of material inputs, labor force, services, and the management used in producing a certain goods or/and crops. Many studies showed that the high cost of production in the RNS has led to low profit. The high cost of producing field crops is attributed to high cost of numerous production inputs, but irrigation water is considered as the most expensive item due to the high cost of water pumping from the River Nile, particularly for the traditional irrigation system which justifies strict water allocation among different crops grown. The paper revealed that the cost components of producing field crops in both schemes of the study clearly varied for all variable cost components. No doubt, this difference was referred to the applied irrigation system in each scheme as presented in Fig. 1. The study illustrated that most of the farm operations in the Elzeidab scheme were done by tenants and/or their family labor, while hired labor was usually required for difficult operations such as harvest. In the Bashaier scheme, where farm machineries took a large place, farm operations were based on little skilled labor, so the scheme administration of Bashaier could restrict the cost of this component more than under the Elzeidab scheme. For the two schemes, there are different cost components to be applied for some different services of farm operations.

The research results described in Fig. 1 show the cost components within the sequence of field crop production operations in two schemes of the study namely, the Elzeidab and Bashaier schemes. It is clear that all the variable cost components of producing field crops in the Elzeidab scheme exceed the Bashaier ones except for seeds, fertilizers, and sack cost components, and their high cost could be justified by the increase in seed costs in Bashaier due to scarcity and high cost of improved seeds in RNS, particularly in sowing dates of winter field crops, while the high cost of fertilizer in Bashaier can be attributed to vast quantities of this input, and sack cost might be due to the high yield of Bashaier field crops. Generally, the Bashaier scheme is characterized as a full-mechanized scheme with large-scale production; these have contributed significantly to decreasing the operation cost of the scheme, in contrast to the Elzeidab scheme.

4. Water use efficiency

4.1. Field crops under study

The paper focused on the important field crops in the area of study, namely wheat, sorghum, onions,

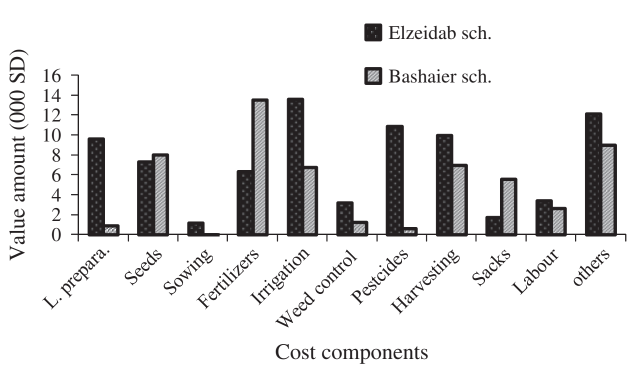

Fig. 1. Average variable cost components for field crops in both schemes.

abu70 forage, and alfalfa to assess their WUE. The alfalfa can remain as a perennial crop for more than 30 months, while onion stays 141.8 days with the longest duration among the seasonal field crops in the Elzeidab scheme, followed by wheat crop at 114 days, and sorghum occupying the land for 112, while 75 day were reported for abu70 forage with the shortest duration. The crop durations varied among the prevailed crop combination in the area of the study. The average number of irrigations varied from 4 to 10 for Abu70 fodder, sorghum, wheat, and onions, respectively; while it was 24 for alfalfa. The average time taken per irrigation was 3 and 5.4 h for Abu70 fodder and alfalfa, respectively. The maximum irrigation interval was 15 days for all field crops under study, except 11 days for onions. The water charge per season ranged between 34,700 SD/feddan and 10,000 SD/fed for alfalfa and abu70 fodder crops, respectively. The general characteristics of the field crops in the Bashaier scheme were similar due to the dominant system in the scheme. The duration of alfalfa was the same in the Elzeidab scheme, while onion stayed for 150 days, exceeding the onion duration in the Elzeidab scheme, followed by wheat and sorghum crop at 135 and 130 days respectively, while 75 day were reported for abu70 forage with the shortest duration and similar to abu70 in the Elzeidab scheme. The crop durations varied among the crop combination in the Bashier scheme. The number of irrigations also varied from 6 to 12 for abu70 fodder, sorghum, wheat, and onions, respectively; while it was 35 for alfalfa. The time taken per irrigation ranged between 6 and 12 h for Bashaier field crops. The maximum and minimum irrigation interval was 7–14 days for all field crops of Bashaier.

4.2. Assessment of on-farm WUE in the study area

Sustainability of providing water for irrigation with perfect management under a reliable irrigation system should achieve efficient irrigation that would further lead to expansion in the irrigated area under cultivation and consequently increase agricultural production. Inadequate management practices contribute to low efficiency of water use and frequent waste. Assessment of the applied irrigation water under full irrigation provides important indicators for WUE in producing competing crops. According to ICARDA (2001), the concept of on-farm WUE (FWUE) was developed to address this complex situation at the farm level. FWUE is defined as the ratio of the irrigation water required to produce a specific output level to the actual amount of water applied by farmers.

With this definition, FWUE may take the value of less, greater, or equal to one. Less than one implies that farmers over-irrigate their crops, while the value greater than one implies that farmers under-irrigate their crops. However, if the value of the calculated FWUE is equal to one, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water are equal.

4.3. Crop water requirement of the field crops in the RNS

As is known, irrigation requirements (IRs) refer to water that must be supplied through the irrigation system to ensure that the crop receives its full water requirements. If irrigation is the sole source of water supply for the plant, the IRs will always be greater than the CWRs to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the IR can be considerably less than the CWR. The study adopted the Food and Agriculture Organization (FAO) [8] method for the calculation of irrigation water requirements; from the estimation of crop coefficient to the calculation of irrigation diversion requirements. For the crops under study, the procedures involve the use of the FAO program "CropWat.4" and its associated database of climatic data for key stations around the world. The CWRs for the crops under study were determined by using the mentioned software program, namely CropWat4 Windows Version 4.3 released by the FAO as illustrated in Table 1. Table 1 represents the results obtained by using Crop Wat.4 program. The CWR for the different field crops according to the predominant of the climatic factors of RNS in season 2005–2006 varies from one crop to another as shown in Table 1.

The calculation of rainfall was not considered in the above account because rainfall for RNS is variable, does not exceed 100 mm per year, and is unpredictable.

Table 1
Determination of CWR per feddan∗ through CropWat4 for main field crops in RNS

Crop	ETo (mm)t	Kc	CWR (mm/fed)
Wheat	0.753	0.758	2,396
Sorghum	0.719	0.72	2,171
Onions	0.75	0.868	2,606
Abu 70	0.49	0.82	1,697
Alfalfa	2.469	0.702	7,275

Feddan∗= 0.42 hectare.
Source: The field survey 2006.

4.4. Water application in Elzeidab and Bashaier

Numerous studies revealed that irrigation in agriculture represents about 70% of global water use. Yet, experiences show that many countries where agricultural water is monitored with sufficient accuracy are limited. The obtained style of irrigation in most cases is that gross irrigation areas are multiplied by an average unit of water use to obtain an estimation of the area's or district's water use in irrigation. While compilation of national statistics is necessary to benefit from local knowledge, their use in global assessment has proved to be unreliable to allow for meaningful analysis. The approach developed in this study relies on the State Ministry of Agriculture statistics, Bashaier scheme reports and modeling to provide a more reliable data-set for districts and water use in irrigated schemes by combining as far as possible the data of the irrigated areas, cropping patterns and irrigation system to assess the amount of water applied. The amount of crop water applied was calculated by the irrigation unit of the State Ministry of Agriculture and Irrigation for the state public irrigated schemes according to season 2005–2006 as 588 mm /fed per watering and it consisted of about 3% as losses for both seasonal and perennial crops, while the applied irrigation water quantities were calibrated for the grown crops in the Bashaier scheme and adjusted according to type of crop. The River Nile is the main source of irrigation for both Elzeidab and Bashier schemes. Surface irrigation is the dominant system in the Elzeidab scheme, and sprinkler irrigation is the prevailed one in Bashaier, while ground water is considered as the main source for small private schemes throughout the RNS. There are no impacts for rainfall in the study area on irrigated agriculture due to its small amount. FWUE of field crops under study was estimated at two levels; namely, FWUE per watering and per season in the Elzeidab and Bashaier schemes, respectively. The annual average water application for alfalfa in Elzeidab was 9,023 mm exceeding all other field crops due to its long period as a perennial crops compared to the other seasonal crops, while the average water application for the other field crops per season was 8,820 m^3 for onion as the highest amounts, followed by 3,756 mm and 3,426 mm for wheat and sorghum respectively, while the water amounts for abu70 forage crop was 2,352 mm. FWUE for Elzeidab field crops is relatively high and very water demanding through their growing season. Furthermore, the estimated FWUE of the Elzeidab scheme indicated a wide technological gap between the required utilization and actual water application. The study unveiled that the FWUE for the Elzeidab field crops

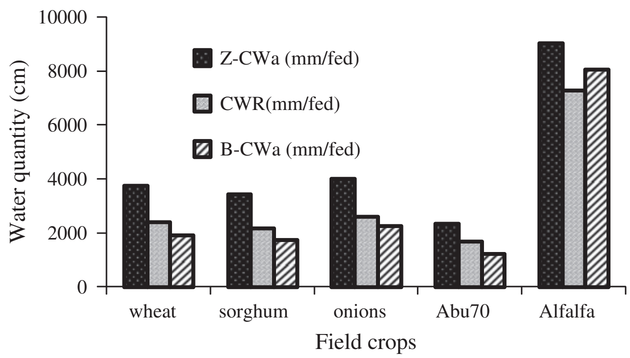

Fig. 2. Physical gaps of CWR and CWA for Elzeidab (Z) and Bashaier (B) schemes of RNS.

per watering was found to be 0.46 for alfalfa as the highest FWUE, followed by 0.41 for both wheat and sorghum, and 0.38 for abu 70 forage while it was 0.37 for onions as the lowest one. On the other hand, FWUE per season amounted to as high as 0.81 for alfalfa; followed by 0.72 for Abu70, and 0.64 and 0.30 for wheat and sorghum, respectively, while it was as low as 0.30 for onions. This implies that farmers over-irrigate their crops by 28% as in the case for Abu70 and by 70% for alfalfa. Fig. 2 shows that farmers within the Elzeidab surveyed sample over-irrigated entirely their seasonal crops. The research also found that the annual average water application for alfalfa crop in the Bashaier scheme was 8,050 mm exceeding all the grown field crops in the scheme due to the same justification in the Elzeidab scheme, while the average water application for the other field crops per season was 2,275 mm for onion as the highest amounts, followed by 1925 mm and 1,750 mm for wheat and sorghum respectively, while the water amount for abu70 forage crop was 1,225 mm. FWUE for Bashaier field crops is relatively low when compared to Elzeidab field crops and also to their water requirements, except the case of alfalfa indicating water shortage through their growing season. Furthermore, the estimated FWUE of the Bashaier scheme indicated negative technological gaps between the required utilization and actual water application for most of field crops, while FWUE for Bashaier field crops per watering was found to be 0.89 for alfalfa as the lowest FWUE, while it was 1.4 for abu70 forage as the highest FWUE, followed by 1.3, 1.2, and 1.1 for wheat, sorghum, and onions respectively. On the other hand, FWUE per season amounted to as high as 1.3 for abu70 forage; followed by 1.2 for both wheat and sorghum and 1.1 for onions, while it was as low as 0.9 for alfalfa. This implies that the administration of the Bashaier scheme under-irrigated its field crops by 20% as the cases of wheat and sorghum and by 30% for abu70 forage, while the administration of the scheme over-irrigated alfalfa crop by 10%. Fig. 2 also shows that field crops under study fluctuated in their water.

In this study, the overall average FWUE in the Elzedab scheme was calculated as 0.41 per watering and 0.62 per season, while it was calculated as 0.10 for both per watering and per season in the Bashaier scheme. Table 2 shows that Elzeidab scheme tenants exceeded the field CWRs per watering by 59% and by 38% for the entire season, suggesting high potential for irrigation water use, once FWUE is improved vs. Bashaier scheme that the administration of the scheme decreasing the field CWRs by 10% per watering and for the entire season suggesting a shortage for irrigation water use as depicted in Table 2.

This has important policy implication such that improving FWUE for these crops can contribute to the overall FWUE in the study area. The result presents the CWR and CWA balance and land allocation for field crop combination undertaken by Elzeidab tenants. The estimated surplus water at the Elzeidab scheme would be sufficient for potential extensions in the irrigated area of the scheme. The research also reveals that the average cultivated area of onions grown by the scheme tenants was found to be 2.117 fed, and its CWR and CWR as 5517.11 mm and 18,672 mm formed the highest physical gap among the crop combination, while alfalfa ranked as the lowest one by 1.43 fed and its CWR and CWA as 10402.82 mm, 12902.55 mm respectively. The irrigation water supply in Bashaier is characterized by irrigation

Table 2
Determination of FWUE/watering and season for both Elzeidab and Bashaier field crops scheme

Crop	FWUE/watering	Over/under irrigation %	FWUE/season	Over/under irrigation %
FWUE Elzeidab	0.41	(+) 59	0.62	(+) 38
FWUE Bashaier	1.1	(−) 10	1.1	(−) 10

Source: The field survey 2006.

shortage for most field crops, which looks different from Elzeidab. FAO [8] reported that the inefficient and ineffective water use leads to crop production levels which are often below the potential, due to reductions in cropped areas and in crop yields per unit area. Thus, good management of irrigation water is generally considered to be of crucial importance for raising agricultural outputs closer to the farmer's field.

4.5. Productivity per unit water at area of the study

According to ICARDA research on WUE, water productivity is defined as the ratio of crop production (kg) to the unit of water used (mm) or as the amount of food produced per unit volume of water used. High water productivity can be achieved through promoting WUE techniques, adopting efficient on-farm water management, selecting proper cropping patterns and cultural practices, and developing suitable crop varieties. WUE and productivity would differ according to different systems of irrigation, crop mix, and environment, and are comprised of different dimensions, crop consumptive use (water requirement), an efficient crop mix (maximum irrigable area for given water resources), and maximum output and value per unit of water. There are several different ways of expressing water productivity such as pure physical productivity, combined physical, and economic productivity, but the majority of the researchers frequently use the term water productivity as the ratio of physical yield of crop and the amount of water consumed (including both rainfall and supplemental irrigation). Yield is expressed as a mass (kg or ton) and the amount of water as a volume (mm). The determination of productivity per unit water for Elzeidab and Bashaier field crops under study was based on physical productivity of water. Water productivity in physical terms in kg of output per m^3 of water is computed to provide more indicators. As depicted in Fig. 3 and on the basis of the previous calculations of water productivity for different crops, water productivity in technical terms has important implications on the assessment and ranking the field crops under study.

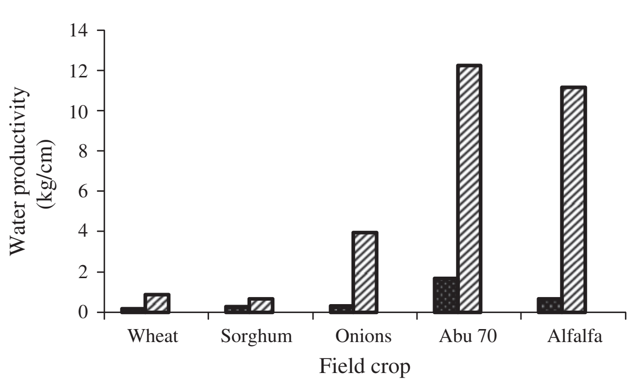

Fig. 3. Assessment of productivity per unit water in physical terms in Elzeidab and Bashaier.

From Fig. 3, physical water productivity (technical method) is derived as kg of output per m^3 of water was generally low for Elzeidab field crops while it is high in Bashaier scheme ones. Fig. 3 shows that water productivity was high for Bashaier field crops as compared to Elzeidab ones, particularly for abu70 forage and alfalfa crops indicating very high irrigation WUE under modern irrigation systems represented by the sprinkler system. Thus, the ability to efficiently manage water systems is crucial and will become even more so over the next few decades.

5. Conclusion and policy implications

This paper represents some of the findings of the field survey for areas of the study in the RNS; it describes the prevailed irrigation systems and emphasizes the importance of irrigation water for producing main food and cash crops in the public irrigated schemes of the RNS; and conclusion drawn are obtained from numerous analytical tools:

(1) Results revealed that fuel cost in the Elzeidab scheme formed the highest cost item of irrigation reaching 56% of the total irrigation costs, while it was 27% of the total operation costs ranks as the second cost component.
(2) The land distribution in the Bashaier scheme is based on sprinklers allocation. Crop combination in RNS public schemes of the state was mainly determined by the nature of season, tenants' experiences, market conditions, and to some extent by the state agricultural policies.
(3) Wheat crop confirmed that it is an important crop achieving the highest percentage over all the area of study. The paper observes that most of the cultivated area was covered by cereal crops which are known as very exhaustive for soil fertility, while legumes and vegetable crops formed a limited area of the scheme indicating an ignorance of land improvement, producing of the food security products and soil conservation.
(4) Crop yields achieved by Elzeidab surveyed tenants were generally low when compared with reported by the ARC, and those obtained by Bashaier scheme management were also low for the majority of field crops, except for alfalfa

which was higher when compared with alfalfa yield of ARC, but at the same time, crop yields of field crops in Bashaier are regarded better than in the Elzeidab scheme.

(5) Although the ARC crop yields were estimated under surface irrigation system, they achieved better productivity for most crops when compared to the crop yield obtained by the Bashaier scheme, indicating a great potential gap for increasing the scheme's yields of all Elzeidab field crops and the majority of Bashaier.
(6) The variable cost components of producing field crops in the Elzeidab scheme exceeded the Bashaier ones except for seeds, fertilizers, and sack cost components.
(7) Elzeidab scheme tenants exceeded the field CWRs per watering by 59% and by 38% for the entire season, suggesting high potential for irrigation water use, once FWUE is improved, while it looks vs. in Bashaier scheme that the administration of the scheme decreasing the field CWRs by 10% per watering and for the entire season suggesting a shortage for irrigation water use.
(8) Physical water productivity (technical method) derived as kg of output per m^3 of water was generally low for Elzeidab field crops while it was high in the Bashaier scheme.

Based on the obtained results the study proposed the following recommendations:

(1) There is a high potential for improving and saving valuable amounts of water that can be used to increase new irrigated areas. Intervention of the State is needed to ease irrigation water availability and improve WUE either by changing or modernizing the existing irrigation system, adoption of the recommended water use technologies, and introduction of modern irrigation technologies.
(2) The study confirmed the introduction of modern irrigation technologies like sprinkler and drip systems which are more economical and efficient than the surface one. Since it lowers the water costs, it releases more financial resources to adopt and update other modern irrigation technologies. In the short run, adoption of an irrigation regime according to CWRs will save more irrigation water resources and hence will allow tenants to add new irrigated areas.
(3) Adoption of a participatory approach by the scheme administrators and tenants in the public scheme of the state to manage irrigation water is a big challenge and incentive at the same time for tenants to adopt modern water- saving technologies.
(4) Raising and updating the administrators and tenants' awareness in both conventional and modern irrigation systems about the importance water for agriculture, life, and environment through efficient structure that can be applied by the extension system.
(5) The study unveiled crop yields achieved by Elzeidab surveyed tenants and Bashaier scheme was generally low when compared to those reported by the ARC. Incentives should be provided to make these crops more profitable due to their importance for food security. Relevant policies may include reducing production costs or interventions to purchase them at reasonable prices.

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