Assessment of On-farm Water Use Efficiency in the Public Irrigated Schemes in the River Nile State of Sudan

ELGILANY A. AHMED[1], HAMID H. M. FAKI[2], HASHIM A. ELOBEID[3]

[1,2]*Agricultural research and Technology Corporation, Sudan*
[3]*University of Khartoum, Faculty of Agriculture, Sudan*

The problem of water scarcity worldwide is becoming severe. Water resources are also experiencing adverse trend viz rainfall rates are decreasing due to the determinant of the vegetation cover, the ground water is dropping.
River Nile State (RNS) is the most important agricultural districts in the Northern region of Sudan, with its resources endowments; the option of irrigation is mandatory in RNS from the River Nile (RN) by pumps through the surface irrigation system. The scarcity of irrigation water rose due to population pressure. The water diverted for irrigation is 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. This coupled with low crop productivity, lack of cheap source of power, more than 60% of the RN water flow only during a limited period annually from August to September and lack of tenants' awareness about the recommended amount of crop water requirements. The paper aims to assess the on-farm water efficiency under irrigated sector, the role of State, water users and market allocation manner in structuring the productivity per unit of water used equity and saving water resource of the RNS. Structured questionnaire for (70) respondents through probability proportional method. Integrated techniques involving economic and hydrologic components are used to assess water use efficiency in RNS. GAMS, Crop Wat4 and Cobb-Douglas function have been employed to evaluate the on-farm water efficiency.
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 institutions are not well qualified to handle irrigation water. Lack of tenants' awareness led to inefficient water use. These are the major challenges that might save irrigation water in the future.

Introduction

Today the competition for scarce water resources in many places is intense. Many river basins do not have enough water to meet all the demands, or even enough for their river to reach the sea. Further appropriation of water for human use is not possible because limits have been reached and in many cases breached. Basins are effectively 'closed', with no possibility of using more water. The lack of water is thus a constraint to producing food for hundreds of millions of peoples. Agriculture is the central in meeting this challenge because the production of food and other agricultural products takes 70% of the freshwater withdrawals from rivers and groundwater (FAO, 2007).

While the average amount of water available to each country remains constant, the demand for water generally is going up steady for two important reasons, first, with expanding population, more and more water required for domestic purposes, agriculture, industry and hydropower generation. Secondly, as the standard of living improves, the demand for water increases as well (Sheikh, 1995).

In Sudan, despite, the water resource is abundant; the irrigation water is the most chronic constraint facing the agricultural sector over the country. ElGamri *et al*(2002) reviewed water resources of the Sudan by concluded that, "the country is below the water poverty line of 1000 cubic meter per capita per year and it may continue to be so for the foreseeable future". These facts necessitate an adoption of various techniques of water conservation including the large meaning of water use efficiency. In Sudan, the total irrigated area expanded rapidly from 1961 to 1995, increasing from 1480 thousand hectare in 1961 to an estimated 3.78 million hectare in 2002. Most of this expansion occurred in the middle and Northern Sudan, along the River Nile flows and its tributaries.

River Nile State, the most important agricultural districts in the Northern region of Sudan, the only possible mean of irrigation is pumps irrigation from the Nile. The population pressure and the inefficient water use led to perpetuate the water scarcity problem. The most predominant constraints faced irrigation water utilization in the State are: low water use efficiency 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 a technical nature, related to socio-economic and institutional conditions. Furthermore, a recession flow of the Nile and Atbara Rivers in August and September affect the availability of irrigation water in October through February, the requirement of irrigation water is greatest through this period when Winter cash crops (wheat, faba beans, fodders, vegetables, legumes) are planted and require for irrigation water, there is less stress to apply the recommended standards of crop water requirements and this might be related to the lack of technology on irrigation water management.

Field survey and empirical findings

This study depends mainly on primary data from the study area, beside 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 data collected in season 2005/06 included demographic and socioeconomic characteristics of the surveyed tenants, the allocated crops through the farm area, crop production, and the factors affecting water use efficiency.

Secondary data which was collected from relevant institutional sources such as River Nile State Ministry of Agriculture and Irrigation, Federal Ministry of Agriculture and Forestry, Department of Planning and Agricultural Economics, Arab Organization for Agricultural and Development (AOAD), Food and Agriculture Organization (FAO), Agricultural Research Corporation (ARC), Khartoum, Gezira and Giessen Universities and Bank of Sudan and internet website.

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 El zeidab public irrigated scheme of the RNS, with considering the terms of cost, time and other relevant facilities.

Sample size: the population numbers used to achieve the formula obtained from the ministry of Agricultural and irrigation of the State as indicated in the formula below:

$$\frac{1}{P}\sqrt{\frac{P\,(1-P)}{n}} \leq \frac{1}{10} \quad or \quad n \geq \frac{100\,(1-P)}{P}$$

We assume: p= 0.590 (proportion of tenants present in the targeted group of schemes).

The co efficient of variation of the estimate =10%

By substituting: we have: $n \geq \frac{100\ (1-0.590)}{0.590} = 70$ *tenants*

Two types of constraints were noticed in the study area, first, the lack of infrastructure made the movement over the study area difficult, and the unavailability of transportation (except certain day(s) per week for some parts of the study area), second, some farmers were ignorant about the research work, and hence, they required more time to obtain the right information from them, moreover, some of them thought that the research work end to take taxes so they refused to be interviewed. Furthermore, many farmers reported that a lot of research work had been done in their areas, without tangible returns to them.

Analytical techniques

To achieve stated objectives descriptive statistical and regression analysis using Cobb-Douglas production function were used. In the descriptive part of the analysis frequency distribution, graphical and statistical analysis was used. Different forms were tried to choose the best representative model. Cobb-Douglas production function analysis using (OLS) regression was used to assess the effect of the hypothesized independent variables on water use efficiency, through its general form:

$$Y = a\ x_1^{b1}\ x_2^{b2} \ldots\ldots x_n^{bn}$$

Where:

Y = output (dependent variable).

$x_1, x_2, \ldots x_n$ = inputs (independent variables.

a = constant term.

$b_1, b_{2,\ldots} b_n$ = regression coefficient to be estimated which the partial elasticity of production with respect to individual resources.

Or in its transformed logarithmic as follows:

$$Log\ Y = Log\ a + b_1 \log x_1 + b_2 \log x_2 + \ldots + b_n \log x_n.$$

The calculation of the crop water requirements (CWR) of any crop requires estimation of its crop coefficient (Kc). Kc values could be used for estimation of CWR as a product of Kc * ETo in the RNS as well as other similar regions of the 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 has been recommended by FAO as the standard method for CWR calculation designed in the software program CROP WAT_4 as follow:

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

Where: W : weighting factors R_n : net radiation   ea : saturation pressure
ed : perfumed water   f(u) : function in wind speed   C : error factor

Results and Discussion

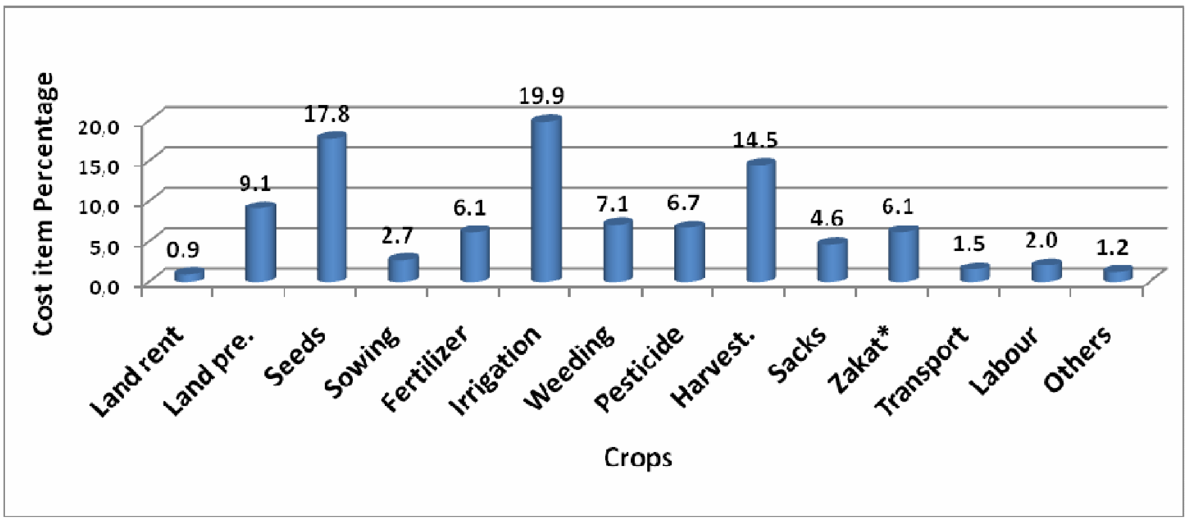
The paper investigates the socioeconomic characteristics of tenants in the study area. On average age of surveyed tenants on Elzeidab scheme is found as 39.91 years, the respondent's educational level found to be 100% of the farmers are literate and received formal and informal education, while each tenants had farming experience of 19.98 year, with some individual tenants having up 54 years of experience. The majority of the tenants 74.3% were full-time operators and only 25.7% were part-time. All farmers in the sample are males and 85.7% were married and 14.3% of them were single. Farmer family members are considered as an important source of labor force in study area, the majority of the surveyed tenants 54% were shared by less than 2 members. The family size ranged between 1 and 15 members, with average family size of 7 persons.

The majority of Elzeidab public irrigated scheme tenants of RNS are provided with 10 feddan of land called *"Hawasha"* for cultivating their suggested crop combination within the season, the land is not belonged to the tenants it is owned to the government and tenants are rented it, while the crop rotation planned by the tenants particularly after the privatization policy introduced by the central government in 1994, inanition, the crop combination was mainly determined by tenants' experiences, while the rest of land was owned, shared and mixed. The average distance from tenant's residence to farm of the surveyed tenants on Elzeidab was 2.7 km. Soils are alluvial which are generally fertile, are made up of loamy and silt deposits. The soils are deep, generally well drained non saline and non sodic. The main source for irrigation water from the River Nile (RN) by pumps directly to surface irrigation system.
The farm size averaged 8.2 feddan. The average cultivated area by crops per farm was found as, 25% of the total land devoted for wheat followed by 19% for sorghum and 14% for onion, while the lowest percentage 1% devoted for potato. The other crops were ranked as 2%, 2%, 4%, 5%, 8%, 8%, and 12% achieved by spices, dry bean, maize, fodder, vegetables, chick pea, and faba bean respectively, with absent of lentil crop area due to some technical production constraints. Market conditions, and to some extend by the State agricultural policies.

Cost of production

Production economics play a unique role in farm management. Cost of production is known as the cost of material inputs, labour force, services, and the management used in producing a certain goods or/and crops. Many studies showed that the cost of production overall the RNS has leaded to the low profit. The high cost of production attributed to high cost of numerous of production inputs, but absolutely, the irrigation water cost is considered as the most agricultural constraint and that might refer to the high cost pumping water from the RN and this is justified strict allocation among the different crops grown as investigated in figure 1.

Figure 1.0 Share percentage of the main variable cost items for RNS seasonal crops 2005/06



Source: The field survey 2006.

The result of the survey revealed that mainly about 15 cost items constituting the cost of production as investigated in the above figure.
The farmers of private and cooperative schemes bear the cost of irrigation inputs, while the tenants in the public irrigated schemes of RNS pay the cost of this item as a fixed rate for the scheme administration at the end of the season according to the type of the crop. The average total cost of irrigation for the seasonal crops in Elzeidab scheme ranged as SD 10000.00 to

39133.33 per feddan for abu70 forage and vegetable crops respectively, while the percentage of this item was 19.9% of the total cost of production as the highest percentage overall the variable items.

Assessment of on- farm water use efficiency

Assessment of the applied irrigation water under full irrigation provides important indicators for WUE in producing competing crops.

According to FAO and ICARDA studies, the concept of on-farm water use efficiency (FWUE) was developed to address this complex situation at the farm level. FWUE is defined as the ratio of the required of irrigation water 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 than, greater than or equal to one. If it is 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 one, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water are equal, as shown in the following form:

$FWUE = Wr/ Wa * 100$……….. (Equation 1)

Where:

Wr: is the amount of water required (m^3) by the crop to produce certain level of crop production.

Wa: is the amount of water actually applied (m^3) by the farmers to produce that level of crop production.

Evaluation of crop water requirements (CWR)

The study adopted the Food and Agriculture Organization (FAO) to the calculation of irrigation water requirements, from the estimation of crop coefficient to the calculation of irrigation diversion requirements. For most crops the procedures involves the use of the FAO program '$CropWat_4$' and its associated database of climate data for key stations around the world

Consumptive use of water in irrigated agriculture is defined as the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration (ETc) of crop is equal to its potential Etc, and it is defined as actual evapotranspiration of an irrigated grid cell for a given month. The evapotranspiration (ETc) of crop under irrigation is obtained by multiplying certain crop area with the summation of reference evapotranspiration (ETo) with a crop-specific coefficient (Etc=Area* sum Kc* ETo). This coefficient has been derived for four different growing stages: the initial phase (just after sowing where the Kc is low), the development phase (Kc increasing), the mid-phase (high value of Kc) and late phase (again lower for Kc) it is assumed that each phase for each crop take one except the mid-phase varies according to the type of crop (FAO, 1998)

The study assembled the required data for calculation CWR namely, location of the scheme, the grown crops, farming operation (planting and harvesting dates), and irrigation system operation (efficiency), distribution of rain-fall by month, while the important climatic parameters climatic data are potential evaporation (Eo) and potential evapotranspiration (ETo) from plants and rainfall.

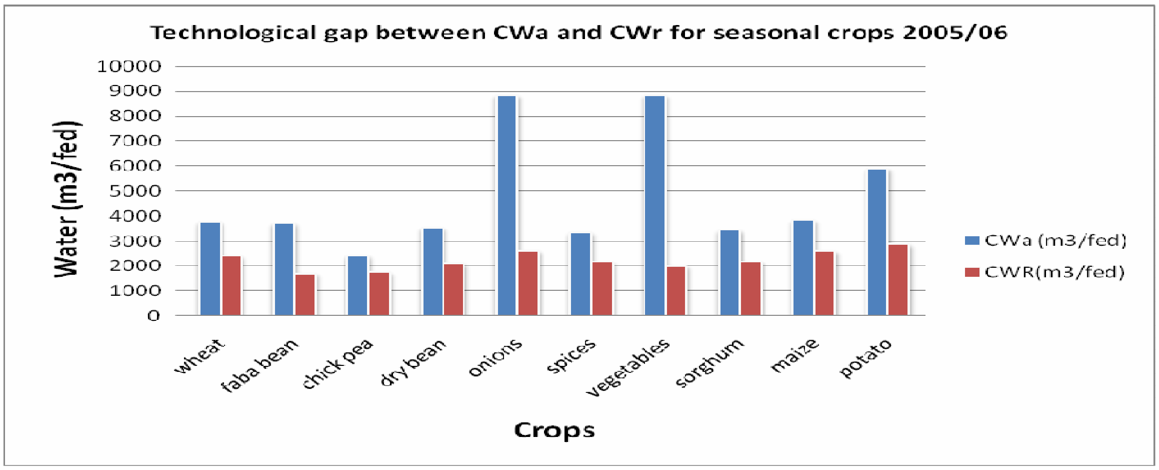
Crop water applied by the scheme tenants

The approach developed in this study relies both on the State Ministry of agriculture statistics and modeling to provide a more reliable dataset for districts and schemes irrigated water use. By combining as possible as the data of the irrigated areas, cropping patterns, socioeconomic characteristics and irrigation system to assess the amount of water applied.

The water applied amount (Wa) in equation (1) was calculated by the irrigation unit of the RNS Ministry of Agriculture and Irrigation for the state public irrigated schemes according to season

2005/06 per watering as 588 m^3 /fed and it was consisted about 3% as a loses for both seasonal and perennial crops.
Surface irrigation is the dominant system for Elzeidab scheme tenants, while the ground water is main source for the small private schemes over all the RNS. There are no impacts for the rain fall in the area of study on the irrigated agriculture due to the annually slight levels less than 100mm.
The study revealed that all the seasonal crop areas under study could be extended by using the surplus water as a big gap between the CWa and CWr as mentioned in figure 3.0. It is obvious that the devoted quantities of irrigation water were exceed the CWr of the mentioned crops under the area of the study, and that might explain the low stress and attention on water management, allocation, quantities and introduction of water saving technologies.

Figure 3.0 The technological gap between CWa and CWr for RNS seasonal crops



Source: The field survey 2006.

The above figure illustrates that the public irrigated schemes of RNS were over-irrigate their crops entirely and this might confirm the unawareness of RNS tenants on CWr of the crops, hence, that led to inefficiency of water use. FWUE for the seasonal crops were estimated at two levels namely, FWUE per watering and per season as depicted in Table 1.0.

Table 1.0 Determination of FWUE per watering and per season for the seasonal crops of the surveyed tenants in Elzeidab scheme season 2005/06

Crop	No. of irrig. Deficit (%)	FWUE-watering	Over-irrigation %	FWUE-season	Over-irrigation %
Average of seasonal crops	22	0.40	60	0.56	46

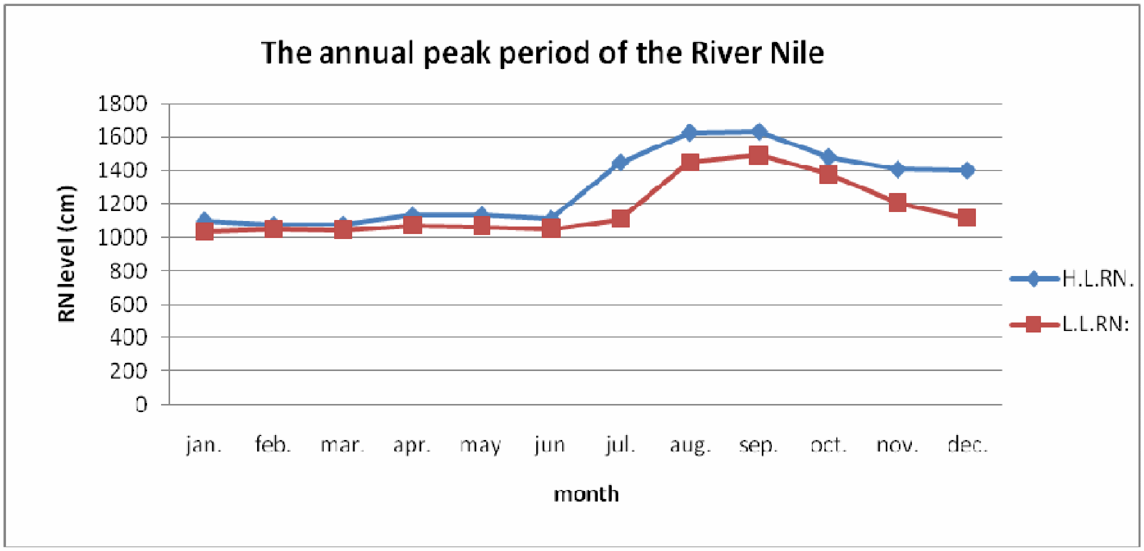
Source: The field survey 2006.

The average cultivated area of farm under the area of study found to be as 6.0149 fed. The average amount of water available to this area was over the crop water requirements, while the estimated surplus found to be sufficient for expected extension irrigated area determined as 6.779 fed equal to 112% of the farm cultivated area.

The annual peak period of the River Nile

The follow in Nile is generally even though out the year, but more than 60% of it is water flow during August and September. The smaller seasonal rivers of Dinder, Rahad and Atbara flow for about four months only from July through October (Abdella, 1995).

Figure 4….illustrates the annual peak period of the River Nile at RNS Elzeidab surveyed tenants in season 2005/06



Source: The field survey 2006.

From economical and a technical points, the recession flow of the Nile led to increase the pump-head and hence, it increases the fuel, spare parts, and losses of irrigation water output. In addition, the wasted time of replacing the pump to fit with water level, and all these contribute to irrigation inefficiency. The study revealed that, the RN recession was affected a valuable cultivated area estimated at 34776 feddan of the total cultivated area of the State 357145 fedan equal to 10%, in addition large number of small private scheme stand away as off-season area in 2005/06. Furthermore, the recession led to add new cost items for irrigation cost such as pumps, pipes and constructions for lifting water from its new levels.

Conclusion of the regression analysis

The regression analysis revealed the most factors affecting on- farm water use efficiency for Public schemes of River Nile State in season 2005/2006 were: the average of tenants' age, family labour (man-day/fed), distance from home to field (km), hired labour (man-day/fed), distance of farm to source of irrigation (km), number of irrigation (per season), term of irrigation (hour/fed), were found to be significantly at different levels and that by using wheat productivity as a dependent factor.

Conclusions, recommendations and policy implications

Based on the previous results, awareness of farm water use efficiency is a crucial factor to assess the efficiency of resource use in its different levels. The study adopted international methodologies wishing to improve water use efficiency particularly in its farm level for multi-crops and different economic situations. The over-irrigation due to misuse of water is considered as a predominant phenomenon among the RNS tenants, and it led to losses of valuable amounts of irrigation water. The stress on water losses normally regards as a cost issue, while the ignored dimension existed behind and causing negative environmental consequences.

Accordingly the study proposed the following recommendations:

- The study detected that the overall WUE in the area of study is generally low, there is a great potential for improvement to save substantial amounts of water that can be used to earn new irrigated areas and/or could be diverted to other uses.
- The socioeconomic characteristics regarding irrigation water use varies according to scheme type and crop combination and that might be due to their perspective of crop water requirements, type of irrigation system used, availability and cost of irrigation water, acreage of farm, awareness and extension services, and might be other factors.
- Accessibility of Irrigation water input is the main constraint for crop production in the study area due to the high input cost (fuel, oil, spare parts, and labor). Intervention of the State is needed to ease having irrigation water either by changing or improving the existed irrigation system by introducing modern systems, human and technical capacity particularly for the employee in the irrigation field to a level where they can improve tenants performance and also contribute positively to ongoing policy.
- Improving and implementing proper policy is probably the most feasible option not only for using water efficiency but also for earning tenants more profit and conserving environment. As known policies create most of the conditions that determine levels of water use efficiency such as: farm size, water allocation and costs, cropping pattern, input subsidies and crop marketing.
- The tenants' behaviors and the dominant traditional concepts of tenants and even to some extend for public scheme administrators increased the difficulties to improve water use efficiency. They still largely depend on conventional concepts of efficiency related to manage water under normal conditions, and that may unsuitable and water scarcity and that should be considered.
- A recession flow of the Nile in August and September affect the availability of irrigation water in October through February, this period is coinciding with apex crop irrigation water requirements particularly the Winter ones namely, grains, legumes and vegetables. The study explored that RN recession was affected negatively a valuable cultivated area estimated at 10% of the total cultivated area of the River Nile State. The way out of this water shortage should be planned and manipulated through one the water harvest methodologies or/and learning alternative such as introducing floater pump stations.

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