5th International Conference on Water Resources and Arid Environments (ICWRAE 5): 347-361
7-9 January 2013, Riyadh, Saudi Arabia

Tenants' Conceptions in Using Irrigation Water in River Nile State of Sudan

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Abstract: River Nile State (RNS) of Sudan can rightly be considered as a River Nile born nation that a high population density (90%) exists in the settled areas along the River Nile. The sustainability of irrigated agriculture is questioned and the challenge is to increase the available irrigation water productivity. The research undertook Elzeidab pump irrigated scheme of RNS as study area. The study aims to assess the social and economical performance of tenants and to identify options that can improve irrigation system and water resource management in RNS. To realize these objectives structured survey questionnaires, field observations and literature were used. A total of 70 randomly selected respondents from Elzeidab scheme were interviewed. Integrated techniques involving economic and hydrologic components were used in analyzing water-use and efficiency in crop production in RNS. A descriptive statistics analysis and quantile models for crop water applied and crop water requirements for field crops in the scheme are presented. GAMS, Crop Wat4 and Stochastic Frontier have been employed to evaluate the social and economical performance of the scheme tenants. The results suggested 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. The paper concluded that, to improve the economic and environmental performance of RNS' schemes, numerous challenges are needed such institutional support (input supply, output marketing and credit services), training of tenants on improved crop and water management issues, regular.

Key words: Tenants' conceptions · Irrigation water-use · Water saving

INTRODUCTION

Rivers environment has not only strongly influenced the nation's overall social structure but has also dictated to a considerable degree the manner in which the development of agricultural resources affected the total economic growth of the nation. The Food and Agriculture Organization of the United Nations (FAO) has estimated that by 2025, close to 1.8 billion people will be living in countries or regions with absolute water scarcity and two-thirds of the world population could be under stress conditions [1]. Thus water is the most critical factor which has influenced the pattern of agricultural production, the productivity of land and the economic behavior of tenants. Hence, the development of water resources has played essential role in the development of the total agricultural sector and indirectly in the economic development of the whole nation. 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 also increases [2].

Sudan is rich in water resources that if efficiently used can generate sufficient food and cash crops for the country and even for the other neighbouring countries. Water from the River Nile and its tributaries, underground sources and impressive rainfall in the centre and south enable cropping and herding at various degrees. Of a total arable area of about 85 million ha, only 20% is currently under cultivation but with inter-seasonal variation [3]. River Nile State, the most important agricultural State in the Northern Sudan where large investment in irrigation take place for crop production depends on irrigation in

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valley areas close to the River Nile covering approximately 124.000 km^2 (29.5 million feddans) out of which about 3.201.300 feddans is suitable for agricultural production. The community based small-scale irrigation farms *'Hawasha'* and the predominant option of irrigation is mandatory from the River Nile (RN) by pumps through the surface irrigation system. The competition for irrigation water and land increases resource management complexity and puts a great pressure on the local ecosystem. The population pressure and the inefficient water-use led to perpetuate the water scarcity problem. The awareness of water-use efficiency not spread wide in most of the public schemes of the State and less attention to apply the recommended standards of crop water requirements (CWR). 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. In Northern Sudan the irrigation needs are designated in terms of numbers of irrigations, not actual quantities and it is likely that reduction in amounts per irrigation or even number of irrigations may be possible without reducing yield [4].

This study is based on research on Elzeidab public irrigated scheme of RNS. The tenants of the scheme are fully responsible for the management of their tenancies, with the government selling water and setting policies. Although numerous researches have been conducted there, research on irrigation water-use efficiency has been limited. Commonly the problems of irrigation water-use efficiency are partly of a technical nature, related to socio-economic and institutional conditions such, inadequate extension services, difficulties of access to existing research base high construction, operation, maintenance costs, poor design and low quality materials, lack of tenants' awareness regarding advanced technologies of farming system and rising water tables and salinity. Finally, this paper aims to promote a more effective social and economical performance of RNS tenants and looks into options to maximise tenancies irrigation water productivity from food and cash crops under sustainable farming system.

Methodology: RNS is considered as one of the developing States in the country, although, with its relatively cooler weather and fertile alluvial soils, has a comparative advantages over other parts of the country in producing relatively high-value crops. The study was carried out in Elzeidab public pump irrigation scheme of the State in 2006, where field crops cereals, pulses and vegetable as well as perennial crops (wheat, faba beans, citruses, mangos, dates, certain spices and medical plants) are grown, while livestock and oil cash crops have recently stretched. The research based on primary data collected from seventy randomly selected tenants through structured questionnaire and probability proportional sampling. The cost route approach was adopted in collecting data. Data collection involved personal interviews and the use of structured questionnaire.

Analytical Techniques: Analytical techniques comprised linear programming and water-use efficiency models, as well as simple statistical methods using General Algebraic Modelling System (GAMS), CropWat4, Stochastic Frontier Analysis (SFA), Excel and SPSS software programs. Data were collected on socioeconomic characteristics, crop mix and existing irrigation water-use manner. In this study, LP technique was used to achieve the optimal solution for the avialable irrigation water devoted for the existed crop combination in Elzeidab farming system. From the collected data, the average irrigation water and other farm resources, yield and gross margins by feddan were computed and entered in the General Algebraic Modeling System (GAMS) software program for optimization analysis. The model was specified with gross margins maximization as the objective function as:

$$\text{Max } Z = \sum_{j=1} CjXj \qquad (1)$$

Such that:

$$\sum \alpha ijXj \le bi, \text{all} = \overset{n}{\underset{j=1}{1}} \text{ to } m \qquad (2)$$

And:

$$Xj \ge 0, \text{all } j = 1 \text{to } n \qquad (3)$$

Where:

- Z = Objective function value.
- Xj = Level of the jth the farm activity, such as the acreage of wheat grown. Let n denote the number of possible activities; the j=1 to n.
- Cj = Objective value, in this case the forecasted feddan) gross margin of a unit of the jth activity (SDD per feddan)
- Aij = Quantity of the ith resource available (i.e., days of labour or other required quantities of inputs) required to produce one unit of the jth activity

M = Denote the number of resources; then i = 1 to m
Bi = Amount of the i^{th} resource available (e.g. cubic meter of water, feddan of and, days of labour or other required quantities of inputs).

The objective is to find the cropping system (defined as a set of activities levels X_j, j = 1 to n) that has the highest possible total gross margin, Z, but doesn't violate any of the fixed resource constraints or involve any negative activity levels.

Equation (1) is the objective function, which maximizes the gross margins from one feddan of prennial crops. Equation (2) shows the limits on the levels of the available resources (i.e., cubic meter of water, feddan of land, days of labour or other required quantities of inputs) that tenant can apply to produce the mentioned crops. Equation (3) which is a non-negativity condition, states that all resources used in the production process and output must be equal to or greater than zero, meaning that negative use of resources and negative of production is impossible. The coefficients represent the average requirement of the i^{th} activity (enterprise), calculated on per feddan basis.

Equation (4) is Penman- Monteith to calculate the crop water requirements (CWR) where any crop requires an 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. Pen-man 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 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. The reference crop evapotranspiration ETo was calculated from the daily whether data specifically the maximum and minimum temperature, relative humidity, wind speed at 2m height and sunshine duration by using CropWat4 windows program according to the recommended Penman-Monteith formula as follow:

$$Eto = C\,(WR_n + (1- W)\,f(u)\,(ea-ed) \qquad (4)$$

where:

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

Equation (5) is on-farm water use efficiency (FWUE); the concept of FWUE was developed to address this complex situation at the tenancy level [5]. 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:

$$FWUE = WR/ WA * 100 \qquad (5)$$

where:
WR: is the amount of water required (m^3) by the crop to produce a certain level of crop production.
WA: is the amount of water actually applied (m^3) by farmers to produce that level of crop production.

The Stochastic Frontier Analysis (SFA) investigates farm specific determinants of productivity. The model computes efficiency values as indicators of productivity and determinants of efficiency. This approach was adopted to determine the effect of irrigation water use by farmers on the output of Wheat. Equation (6) is the general stochastic production frontier model as follow:

$$\text{In}q_j = f(\text{In}x) + v_j - u_j \qquad (6)$$

where q_j is the output produced by firm j, x is a vector of factor inputs, v_j is the stochastic (white noise) error term and u_j is a one-sided error representing the technical inefficiency of firm j. Both v_j and u_j are assumed to be independently and identically distributed (iid) with variance $\square_v^2$ and $\square_u^2$ respectively. Equation (7), given that the production of each firm j can be estimated as:

$$\text{In}\tilde{q}_j = f(\text{In}x) - u_j \qquad (7)$$

While the efficient level of production (i.e. no inefficiency) is defined in Equation (8) as:

$$\text{In}q^* = f(\text{In}x) \qquad (8)$$

Then technical efficiency (TE) can be given by Equation (9) as:

$$\text{In}TE_j = \text{In}\tilde{q}_j - \text{In}q^* = -u_j \qquad (9)$$

Hence Equation (10) found to be as:

$$\text{TE}_j = e^{-u_j} \qquad (10)$$

The constrained should be between zero and one in value. If u_j equals zero, then TE equals one and production is said to be technically efficient. Technical efficiency of the *j*th firm is therefore a relative measure of its output as a proportion of the corresponding frontier output. A firm is technically efficient if its output level is on the frontier, which implies that q/q* equals one in value. One aim in SFA is to explain inefficiency/efficiency in terms of exogenous determinants; some models are summarized to explain inefficiency/efficiency of a producer. The generalized efficiency equation is given as:

$$U_i = g\ (zi;\ \gamma) + \varepsilon i \qquad (11)$$

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. Equation (12) is the general mathematical form for the gross margin calculation per crop as follow:

$$GM = GR - TVC \qquad (12)$$

where:

GM = Crop gross margin per feddan in SDD,

GR = Crop gross revenue per feddan in SDD.

GM = TVC: Crop total variable costs per feddan in SDD.

RESULTS AND DISCUSSION

Tenant' Socioeconomic Status in Area of the Study: Water resource conservation is substantial in ensuring a sustainability of agricultural sector of rural areas especially in arid and semi arid States such RNS of Northern Sudan. A farming system mechanism pertains to a complex interaction of a set of components such land, water, crops, livestock, labours and other resources within an environmental setting. The socioeconomic status of tenants is expected to have a tremendous effect on the production process in the study area. In addition to increasing farm production and family incomes, improved irrigation access significantly contributes to rural poverty alleviation through improved employment and livelihood within region activities [6]. The collected socioeconomic data of field work was mainly on tenants' education level, marital status, interplay between socio-economic characteristics such as age, household size, farm and off-farm incomes, irrigation water, farm size, level of education, accumulated experience (years), scheme- farm distance and place of tenant's residence, land tenure, tenants' occupation, social status, crop yield and farm location have significant indicators and affect on-farm irrigation water-use (Table 1).

Table 1: Tenants' socioeconomic characteristics in area of the study

Indicator	Mean	STD
Average age	39.9	9.8
household size	6.5	3.2
Accumulated experience (years)	20	12.3
Farm size (fed[1])	8.2	6.9
tenants' resident to farm (km)	2.7	3.2
Number of family labor	2	1.8

Fed[1]= Feddan = 0.42 Hectare

The major socioeconomic characteristics of the scheme tenants indicated that all samples found to be males and 86% were married, while 14% of them were single. Further socioeconomic characteristics illustrated below.

Average Age of Tenants: The average respondents age of 40 years. Of course, averages are not everything, but tenants' age is one of the demographic characteristics, which influences the quality of his/her decision and his/her attitude towards accepting new ideas and usually there are hindrances between a farmer's age and his/her rate of adopting innovations and advanced technologies. The factors that trigger adoption of new technologies comprise of progressive, young and educated farmers. However, not all farmers adopted technologies introduced because it they are new to them. They were feeling hesitated in application of new technology because they do not believe that the new technology can ensure the high yield. These farmers are usually old age and work based on their own experience [7]. The paper unveiled that there were no tenants older than 61 years, tenants younger than 30 years constituted 11% and the age groups 30-45 and 46-60 years constituted 69% and 20%, respectively. It's clear that younger tenants were formed the lowest percentage among the scheme tenant indicating negative consequences for adopting new irrigation technologies.

Household Size: The farm production is also dependent on other factors such as household size and farm size. These two variables were found to have significant effects on household living standard. Water has obvious advantages in that it increases farmer's yields, promotes diversified farming enhances household food security and increases household incomes. Farmers who are on irrigation projects are more likely to be food secure than dry-land farmers. With concerted support from government and all stakeholders, food security can be enhanced at the household levels [8]. The average household size of surveyed tenants was 7 members and the range between 15-1 members, small families constituted the highest percentage of 43% while the medium and large ones were 35.7% and 21.4%, respectively (Table 1). Water consumption was also found to be significantly correlated with explanatory variables such as ‘‘household size’’ and ‘‘age of household’s head’’ [9]. The Sudanese extended families include uncles and cousins going back several generations. For people in the north who are farmers and herders, family status still depends on the size of the farm and herd. In settled villages, certain families hold the rights to own land. In the past, colonial governments sometimes gave powerful positions to certain families. These family groups have gradually become part of the modern political system, but traditional ideas about power and status endure [10]. According to this background, the small family's percentage 43% indicates to low efficiency of farm operation, hence inefficiency of irrigation water use.

Years of Experience in Agriculture: Years of experience in agriculture are an important indicator to a farm output. Africa is the source of much of the world's agricultural knowledge and biodiversity. African farmers represent a wealth of innovations. This rich basis of biodiversity still exists in Africa today, thanks to the 80% of farmers in Africa (Kenya, Ethiopia and Sudan) who continue to save seed in a range of diverse eco-systems across the continent [11]. The average number of years of experience of surveyed tenants was about 20 years, ranging between one and 54 years. The research revealed that a high cumulative experience in farm management in study area, but this not enough to handle on-farm water use efficiently unless the scheme administration to undertake any assistance necessary for the farmer to make full use of the irrigation water. In addition education and extension training are essential for farmers to adopt new technologies. On-farm development work is frequently left to the farmers' initiative and their own responsibility. However, in most cases, this is not a simple undertaking that can be carried out without any financial and technical help. If this happens, the result is often that farms are poorly prepared to apply the irrigation water which leads to severe water wastage and low crop production [12].

Land Tenure: In many countries land tenure system combines private use rights with public ownership to private economic incentives for farm household, while stopping short of allowing full land ownership and alienable rights [13]. In such areas, the land itself is of secondary importance, its only value being derived from its productivity which, in turn, depends on irrigation rights attached there to. As water becomes scarcer, it becomes more essential to soil fertility and gradually develops into an object of ownership independent of the land. In this case, water becomes the main object of ownership. It is purchased, sold, allocated or constituted in charity, often along with and sometimes independently of, the land it irrigates [3]. The paper unveiled that the majority (50%) of surveyed tenancies were rented while those owned, shared and mixed land were 27.1%, 2.9% and 20%, respectively.

Distribution of Farm Size: It is commonly assumed by many observers and critics of the EBID that the irrigation practices of the large, commercial farms must be improved in order to release water for other uses. However, the results of this and earlier study, the prevalence of deficit irrigation practices and other techniques or technologies currently used on large farms to increase the physical efficiency of irrigation water indicate that marginal increases in efficiencies on many large farms are likely to be small and come at a high cost [14]. Differences in quantities of irrigation water applied and time spent irrigating would exist between farms of different sizes. Also, differences in soil types and on-farm irrigation water turnouts might be factors that would influence water applied and time spent irrigating. The farm size or the farmer's holding significantly affects crop productivity. Operated farm size rises with level of economic development, especially in the 20th century [15]. Thus, the survey results unveiled that the average farm size in Elzeidab scheme was 8.2 feddan per farm household with a range of 28-1 feddan, categorizes tenants' holding into small farm (owning less than 3 feddan), medium farm (owning 3-8 feddan) and large farm (owning more than 8 feddan). Last decades the RNS witnessed an increase in the numbers of farms in the smallest acreage categories grew dramatically as a result of land splits. The small size of these farms resulted from land fragmentation under private and cooperative schemes due to the inheritance laws of Islam and recently in the public schemes due to increasing of tenant's family size constraining applying of numerous technologies implies modern irrigation system.

Levels of Educational: Educational standards have become substantial factors in determining farmers' living standards. Education also improves the ability of farmers to appreciate the potentials of new technologies and usage of modern inputs that lead to a more efficient transfer process. The size of landholding, access to irrigation water, on-farm land and water conservation practices, literacy of the household head and years of education of adults are all significant determinants of household welfare [16]. In Sudan generally, there are two type of education, namely formal and informal. Formal education includes four levels (foundation school, high school, university and post graduate education) while informal education consists of only one level namely '*khalwa*'. The paper found that all surveyed tenants are educated where the level of education at a certain point can influence the adoption of modern technologies especially the irrigation one and improve the farm system.

Occupation At Tenancies: The fully occupation of tenants in the irrigated scheme is critical to improve on-farm water use efficiency as well as crop yields, while lack of proper on-farm works in the irrigated areas may contribute significantly in poor water use efficiency particularly at the farm-level. In Sudan, the State policies for irrigated schemes often look to keep the tenants of schemes fully occupied with their tenancies. However, off-farm occupations among others are quite common. From an historical perspective, the number of full-time farm operators in numerous developing countries has fallen by 24% since 1982, while the number of part time farm operators has fallen by 18% [17]. The paper found that 74% of the respondents were fully occupied with their tenancies while 26% of them were part-time farmers. Thus, increasing of devoted time to occupy in farm might raise the efficiency of the applied irrigation water.

Contribution of Family to Farm Production: Farmers' families encompass various affiliates that offer a variety of financial products and services in addition to insurance [17]. Families can enhance their relationships and trust levels by building skills in communication, goal-setting, decision-making, role negotiation, problem-solving, conflict resolution and strategic planning. The research unveiled that the majority of surveyed tenants reported that about 84.3% of their family members contribute to farm work while for a few of them 15.7% of family member didn't contribute to farm production. However, family members not only can they agree on a shared family vision with shared economic and social goals, but they also can develop a team effort. A team effort can help accomplish a shared family vision that can increase net profitability [18]. The average number of family's labour of surveyed farmers was 2 members. The majority 54% of the surveyed farmer's family's labour contribute to the farm work by less than 2 members, while the contribution of family's labour share for the other categories non-family's labour, 2-4 members and greater than 4 were 15.7%, 28.6% and 1.4%, respectively.

Scheme-Farm Distance and Place of Tenant's Residence: The scheme- farm distance factor is related directly to the tenant performance and thus farm production. Farm distance affects negatively farmer's productivity. It affects on farmer's production decisions and farm performance indicators such as farm profit and technical efficiency [16]. Farm distance, inadequate road infrastructure and transport modes translate into a waste of productivity to farmer. The average distance from tenant's place of residence to farm found to be 2.7 km with maximum and minimum distances of 20 and 0.2 km, respectively in the study area. Thus increases of farm distance often affect negatively farmer's irrigation water use efficiency.

Tenants' Conceptions Vs. On-farm Irrigation Water-Use: No doubt fresh water resource conservation is one of essential components of sustainable development and should incorporate not only environmental, but also social and economic dimensions. In Sudan, nnumerous constrains pertain to irrigation water-use in public schemes administrations and more complex at local levels. Inefficiency of on-farm irrigation water use due to lack of tenants' awareness in the scheme, it resulted in excessive water application rates, rising water tables and salinity. This might be due to inadequate extension services and difficulties of access to existing research. Commonly the constraints of WUE are partly of a technical nature, related to socio-economic and institutional conditions. Farmers did not to be trained for most of technologies related to agricultural production [7]. The human element is characterized by exogenous (community structures, external institution, etc.) and endogenous factors, which can be controlled by the farm household. At the centre of this interaction is household member. The household ultimately decides on the farming systems on whether or not to adopt technologies and how to assign resources to support it [7]. This fact necessitates an adoption of various techniques of natural resources conservation including the large meaning of natural resources use efficiency.

The study summarized the general characteristics of tenants' field crops as average quantities and it detected the number of irrigations and average water applied by interval for each crop. The tenants of the scheme carried out a crop combination, it implied 25% of the total land was occupied by wheat, followed by 19% for sorghum and 14% for onion, while the lowest percentage (1%) formed by potatoes. The other crops were ranked as 2%, 2%, 3%, 4%, 5%, 8%, 8% and 12% occupied by spices, dry bean, alfalfa, maize, fodder, vegetables, chickpea and faba bean, respectively. The pattern of water application to the field crops is similar across the scheme. The distribution of crop growing period revealed that the onions remain as 141.8 day as a long age among the field crops under the study, followed by the vegetable crops as 130 day and 114, 112, 112, 110 for wheat, sorghum, maize and potato respectively, while 75 day for fodder crop as the lowest crop age. The crop ages ranged between 90 -104 days. The minimum maximum tendency number of irrigation is 4-10 irrigation for fodder and potato, vegetable, onion crops respectively, while the term of irrigation ranged between 2-5 hours for dry bean and potato crops, respectively and the maximum interval was 18.30 day for chick pea crop, while the minimum interval as 10 day for potato crop. The fixed rate of irrigation per season ranged between 39133.33 SD/fed- 10000 SD/fed for vegetable and fodder crops, respectively.

Time Spent for Tenancy Irrigating: Prior to data analysis, it was hypothesized that differences in amounts of irrigation water applied and time spent per irrigation would exist between areas of different crops. Differences in soil types and on-farm irrigation water nets also were assumed to be factors that would influence water applied and time spent per irrigation. The scheme's 2005/2006 accounting of water delivered does not reflect measurements in the field. The water delivery data analyzed are based on engineering estimates of canal deliveries. As known, the function of the supply canal is to carry irrigation water from the pump station through its out-let to the field, but in Elzeidab case it has more than one function; that it stores irrigation water between the head-tail of the canal as conventional technique used in the scheme called night storage system. The scheme data included start and stop times for water deliveries and spreadsheet functions were used to estimate total irrigation durations and irrigation durations per feddan. Irrigation duration (i.e., hours/fed/irrigation) is an indicator of field level irrigation efficiency and is particularly useful when measurements of water applied are unreliable. Descriptive statistics and quantile analysis representing irrigation durations with comparing to the crop water applied in Fig. 1 for Elzeidab field crops. Differences in average irrigation duration per season exist across all field crops of the scheme.

Figure 1 represents that dry bean is formed the lowest irrigation duration, while potatoes and onions regarded as the longest irrigation durations. It also indicates the gap between the total crop water applied for the field crops and the irrigation duration implies three categories. It's clear that the greatest gap was achieved by vegetables, onions, legumes and fodder crops respectively as the first category, ranked by cereal crops as the second category including wheat, sorghum and maize as moderated crops, while the smallest gap was formed by potatoes crop as the third category. The cumulative distributions in Fig.1 consists the gap of total irrigation hours and crop water applied as discussed above under this research might suggest a correlation between them. The length of time spent to irrigate the tenancies justified by the majority of respondent due to inefficient delivery system. The scheme tenants' have no responsibility or authority for maintaining irrigation nets and they recognized many problems such as siltation, weeds and canal breaks. Overall, the levels of irrigation technology and water management found on

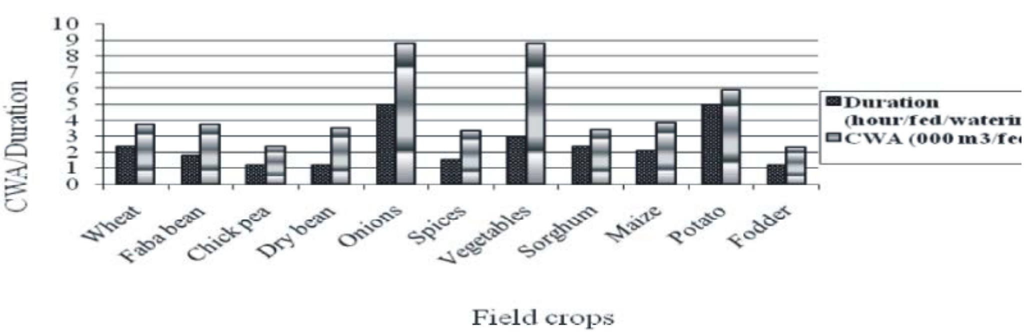

Fig. 1: Time spent per watering and total water applied per tenancy

surveyed area were extremely low and often a consequence of inadequate irrigation design. Further, that the irrigation needs are designated in terms of numbers of irrigations, not actual quantities and it is likely that reduction in amounts per irrigation or even number of irrigations may be possible without reducing yield [4]. Thus, lack of awareness regarding irrigation scheduling based on crop water requirements contributes significantly to on-farm water use inefficiency. Conventional irrigation timing practices and methods (i.e. interval) contribute to over-irrigation at the beginning and end of the irrigation season, plant stress at peak crop water use periods and may affect negatively on crop yields and quality.

Calculation of On-Farm water-use (FWUE) and Crop Water Requirement (CWR): Sustainability of providing water for irrigation with perfect management under reliable irrigation system should achieve efficient irrigation that would further lead to expansion in the irrigated area under cultivation and consequently increases agricultural production. Thus, on-farm irrigation water use efficiency (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 [5]. 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 one, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water are equal. However, the study adopted the Food and Agriculture Organization (FAO) method for the calculation of irrigation water requirements; from the estimation of crop coefficient to the calculation of irrigation diversion requirements. For the crop water requirements (CWR) 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 study focused on the important field crops of the scheme namely, wheat, faba bean, chickpea, dry bean, onions, spices, vegetables, sorghum, maize, potatoes and abu70 forage. The CWR for the different field crops according to the predominant of climatic factors in RNS for season 2005/06 varies from crop to another as shown in Table 2. The calculation of rainfall was not considered into the above account because rainfall for RNS is variable, does not exceed 100 mm per year and is unpredictable. While the approach developed in this study relies on both the State Ministry of Agriculture statistics and modeling to provide a more reliable dataset for districts and water use in irrigated schemes by combining as far as possible the data of the irrigated areas, cropping patterns, socioeconomic characteristics and irrigation system to assess the amount of water applied. The applied water amount (WA) in equation (5) 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 as 588 m^3 /fed per watering and it consisted of about 3% as losses for both field and perennial crops. Surface irrigation is the dominant system in Elzeidab scheme, while ground water is main source for the small private schemes overall the RNS (Table 2). Table 2 represents the results of CWR obtained by using CropWat4 computer program as well as on-farm water applied (CWA).

Table 2: On-farm irrigation water-use efficiency of tenants' crops in area of the study

Crop	CWR (m^3/f ed)	CWA (m^3/fed)	FWUE /season	%Over irrigation
Wheat	2396	3756	0.64	36
Faba bean	1700	3708	0.46	54
Chickpea	1746	2411	0.72	28
Dry bean	2099	3528	0.59	41
Onions	2606	8820	0.3	70
Spices	2153	3332	0.65	35
Vegetables	2000	8820	0.23	77
Sorghum	2171	3426	0.63	37
Maize	2590	3822	0.68	32
Potato	2870	5880	0.49	51
Abu 70	1697	2352	0.72	28

The CWA per season for onions and vegetables found to be 8820 m^3 formed the highest amounts among the annual crops, followed by 5880 m^3 for potatoes, while the water amounts for the other crops ranged between 3822 and 2352 m^3 as evident from Table 2. FWUE for some seasonal crops is relatively high given that onions, vegetables and potatoes crops are very water demanding through their growing season which took about 141, 130 and 110 days, respectively. The estimated FWUE of Elzeidab scheme indicated a wide technological gab between the required utilization and actual water application, as depicted in the Table 2. The study revealed that FWUE tenants' crops per watering was found to be 0.46 for maize and spices as the highest FWUE, followed by 0.45and 0.43 for dry bean and chickpea, respectively.

It was found to be similar for wheat, faba bean and sorghum at 0.41, while it was 0.34 for vegetables as the lowest one. This implies that farmers over-irrigated maize and spices by 54% and vegetable by 66%. On the other hand, FWUE amounted to as high as 0.72 for chickpea and Abu70, followed by 0.68, 0.64 and 0.63 for maize, wheat and sorghum, respectively, while it was as low as 0.23 and 0.30 for vegetables and onions respectively. This implies that farmers over-irrigate their crops by 28% as the case for both chickpea and Abu70 and by 77% for vegetable crops. The results also show that farmers within the surveyed sample over-irrigated entirely their field crops. Generally in this study, the overall average FWUE was calculated as 0.40 per watering and 0.56 per season. The study also unveil that Elzeidab scheme tenants exceeded the field crops water requirements per watering by 60% and by 46% for the entire season, indicating that the surveyed tenants over-irrigated entirely their field crops, suggesting high potential for irrigation water use, once FWUE is improved. This has important policy implication such that, improving FWUE for these crops, can contribute to the overall FWUE in area of the study.

Yield and Water Productivity: Cropping pattern is one of the most important parameters involved in irrigation command areas. It is directly related to the productivity of irrigation systems and greatly contributes to improved soil and water utilization. Crop planning in irrigated agriculture has traditionally been based on the concept of maximization of net benefit [20]. The profitability of adopting new irrigation technologies depends on the level of productivity improvement [21]. The crop combination adopted by the scheme's tenants is as illustrated in Table (3). It represents the crop yields achieved by the surveyed tenants were generally low when compared by study yields reported by the Agricultural Research and Technology Corporation (ARTC). Yield gaps of 47% and 81% apply for dry bean and vegetable crops respectively indicated that much potential gap exists to increase the scheme's yields of field crops. While, water productivity is defined by ICARDA in several different ways, such as pure physical productivity as the ratio of crop production (kg) to the unit of water used (m^3) and in a monetary term is also computed in Sudanese Dinars (SDD) of output per m^3 of water to provide it more indicators.

As depicted in Table 3 and on the basis of the previous calculations of water productivity for different crops, water productivity in technical or economic terms has important implications on the assessment and ranking the field crops. Physical water productivity (technical method) derived as kg of output per m^3 of water. Table 3 also shows that the highest water productivity was 0.680 kg/m^3 for potatoes, followed by onions at 0.330 kg/m^3, while it was, in descending order, 0.290, 0.224, 0.210, 0.190, 0.180, 0.172, 0.153 and 0.132 kg/m^3 for sorghum, maize, vegetables, spices, wheat, chickpea, dry beans and faba bean respectively, was generally low, it ranged between 5.452 and 2.471 SDD/m^3 reported for spices and onions, respectively.

FWUE Captured by Stochastic Frontier Model: The tenants' productive efficiency was captured using Stochastic Frontier Model. For this the frontier 4.1 computer software program developed in 1994 by Colli [22]., it is used to estimate tenant's technical efficiency (TE). The distribution of TE scores was analyzed and the average values of TE are compared between groups of tenants using appropriate tests.

Table 3: Crop yields and productivity per unit water in monetary terms

Crop	Yield (kg/fed)	ARTC Yield (kg/fed)	Yield gap (%)	Water product (kg/m^3)	Water productivity (SDD^2/m^3)
Wheat	675.9	2000	66	0.18	3.619
Faba bean	488.7	1500	67	0.132	4.027
Chick pea	414	1250	67	0.172	5.143
Dry bean	540	12000	55	0.153	3.685
Onions	2880	1200	76	0.33	2.471
Spices	630	Na	Na	0.2	5.452
Vegetables	1852.5	10000	81	0.21	4.437
Sorghum	1005.3	1700	41	0.29	3.594
Maize	855	1700	50	0.224	3.009
Potato	4000	10000	60	0.68	2.891

SDD^2= Sudanese Dinar= $0.30

Table 4: Physical gap of CWA and CWR for farm cultivated area compared to wheat area in the scheme

Category	cultivated area (fed)	CWA (m^3)	CWR (m^3)	Irrigation gap (m^3)	Expected extension area (fed)	Expected extension area (%)
Farm size/ fed (8.509)	6.0149	28573	13432	15140.59	6.779	112
Wheat	3.672	13792	8800	4991.72	2.083	57

In the model of Stochastic Frontier wheat was taken as a case for the field crops to assess the on-farm irrigation water use efficiency due to it is biggest area share (25% of the total cultivated area) and because it is one of the most strategic crops in Sudan. It is Sudan's second most important cereal food in terms of consumption after sorghum. Over the past few years, wheat production, which is almost entirely irrigated, has been declining due to diminishing yields, soaring irrigation water and inputs costs.

The study revealed that at the local level of the public irrigated schemes of RNS, the awareness pertaining to perfect irrigation water-use efficiency found to be very lack and the linkages between research and extension services also looked very weak. Furthermore, the training services for transferring of knowledge of new technologies to the scheme tenants for increasing on-farm water-use efficiency also observed to be very poor. Based on this background the research in this section aims to assess the FWUE per watering and per season as a result of tenants practices. The research detected that the gap between the actual applied water (CWA) and the water requirements (CWR) for Ezeidab field crops. The average cultivated farm area in the area of study was approximately 6 fed. The average amount of water available to this area was 28573.05 m^3; while the average crop water requirements was 13432.46 m^3. The estimated surplus water at 15141 m^3 would be sufficient for potential extensions in the irrigated area by 6.779 fed, which would be 112% of the farm cultivated area. Table (4) shows the detailed results of field crops water application and requirements. It also presents the CWR and CWA balance and land allocation for field crops combination that undertook by Elzeidab tenants.

Table 4 illustrates the average water applied per season for wheat was found to be 3756 m^3/fed. The analysis revealed that FWUE for wheat is not the highest when compared to some field crops which consume relatively high amounts such onions, vegetables and potatoes. While the average area of cultivated wheat was 3.672 fed, or 61% of the total cultivated farm area. Wheat growers in the scheme exceeded the CWR by 41% per watering and 64% for the whole season, suggesting the need for improving the FWUE. Further, the study quantified the amount of water supplied by the scheme and the quantity required for wheat production as depicted in Table 4. The table also shows the average amount of water available to wheat within the farm amounted to 13792 m^3. The average quantities of crop water requirements were 8800 m^3 with an estimated surplus water of 4992 m^3; this sufficient for a possible extension in irrigated area of 2.083 fed equivalent to 57% of cultivated area.

Determinants of Efficiency in Wheat Production: The frontier results of the determination of efficiency are shown in Table 5. The model statistics estimated are all valid.

The value of gamma (g) indicates the proportion of variation in the model that is due to capacity production factors included in the model. The value is relatively high, 0.75% and is statistically significant at 1%. The implication is that most of the variables included in the model are necessary in accounting for the output of Wheat in Sudan. The generalized likelihood ratio statistic (also known as the LR test) is high 14.62 which led us to conclude that the production frontier is identical to the production function. Table 5 depicts the results obtained; they are valid and not spurious. Water price for irrigation and fertilizer are the significant determinants of output of wheat. While water price is negative and significant at 1%, fertilizer is a positive determinant of output and is significant at 5%. The economic price of irrigation water is not charged and this has resulted in large volumes of water been wasted. This situation created adapted conception at tenants' level to improve their farm production. Tenants of Elzeidab scheme are not charged on the basis of volume used and once they pay subject to use the way they want. Wheat growth depends on high soil fertility and as such there is heavy application of fertilizer for high productivity. Tenants enhance the productivity of land through the application of fertilizers.

Four factors were significant in the inefficiency model viz farming experience, extension visits, irrigation distance and off-farm income. In the inefficiency model, a negative coefficient implies an increase in efficiency while a negative coefficient leads to reduction in efficiency other things being equal. As the tenant gets older he becomes less innovative and takes little risk. This accounts for the impact of farming experience.

Table 5: Results from maximum likelihood estimation

Production factors	Coefficient	t-value
Constant (βo)	5.397***	8.3
Land (β_1)	-0.031	-1.26
Seed (β_2)	0.005	0.47
Water Price (β_3)	-0.051***	-3.74
Capital (β_4)	-0.026	-0.08
Fertilizer (β_5)	0.001**	2.21
Animal Power (β_6)	0.001	1.51
Labour cost (β_7)	0.001	1.12
Efficiency factors		
Education of household head (δ_1)	0.127	0.81
Household size (δ_2)	-0.129	-0.5
Farming experience (δ_3)	0.352*	1.82
Age of household head (δ_4)	-0.111	-0.29
Extension Visit/Access (δ_5)	-0.289*	-1.78
Irrigation distance (δ_6)	0.695**	2.09
Home to field distance (δ_7)	-0.409	-0.73
Off-farm Income (δ_8)	-0.624*	-1.95
sigma-squared	0.49**	2.51
Gamma (g)	0.75***	5.06
log likelihood function	-52.69	
LR test of the one-sided error	14.62	

Table 6: Determination of wheat productivity per unit water in monetary terms for the surveyed tenants

Crop	Water price (SDD[2])	CWA (m^3/fed[1])	Water productivity (SDD/m^3)	Water productivity (kg/m^3)
Wheat	13592.59	3756	3.619	0.18

Fed[1]= Feddan = 0.42 Hectare and SDD[2]= Sudanese Dinar= $0.30

Extension visits impacts positively on efficiency. Tenants sometimes receive advices of modern techniques and advices about the best way to handle farm problems, optimizing farm resources and availability of modern seeds and seedlings. The further away the source of irrigation, the more difficult tenants make use of the service. Tenants provide their own transport and as such when the source is far away, they spend more money on transportation and use less of the services. This accounts for while distance impacts negatively on efficiency. People who earn off farm income and get remittances often do not concentrate in terms of following all the farm agronomic practices and this often decreases crop productivity hence water inefficiency.

Technical Efficiency of Wheat Tenants: Water resources use efficient for sustainable farm production has become the top priority in arid and semi-arid zone requiring crucial and urgent routes in view of the high competition for increasingly scarce fresh water resources. Cropping pattern is one of the most important parameters involved in irrigation command areas. It is directly related to the productivity of irrigation systems and greatly contributes to improved soil and water utilization [23].

Crop planning in irrigated agriculture has traditionally been based on the concept of maximization of net benefit. Determination of productivity per unit water of wheat here was assessed for both economical and physical productivity of water. Water productivity in monetary terms in (SDD) of output per m^3 of water and in physical (or technical) water productivity that measures kgs of output per m^3 of water as depicted in Table 6. From Table 6 water productivity for wheat in monetary term was only 3.619 SDD/m^3, while physical water productivity formed only 0.180 kg/m^3, which very low when compared to water productivity for potatoes derived at 0.680 kg/m^3 in area of the study.

The frequency distribution of the technical efficiency indices derived from the analysis of the stochastic production is provided in Table 7. Irrigation development requires the mobilization of often scarce resources, including arable land, adequate water and financial capital [24].

Table 7: Distribution of economic efficiency

Efficiency Range	Mean	Percentage
0.14 – 0.30	0.208	7.14
0.31 – 0.47	0.421	15.71
0.48 – 0.64	0.582	32.86
0.65 – 0.81	0.722	31.43
0.82 – 1.00	0.866	12.86
Grand Mean	0.611	

Table 8: Gross margin analysis of wheat in Elzeidab scheme

Production cost (SD/fed)	70054
Average yield (kg/fed.)	676
Average price (SDD/kg)	110
Gross return (SDD/fed.)	74349
Gross marginal revenue (SDD/fed)	4295

The technical efficiency of the sampled tenants was less than one (or 100%) indicating that all the wheat tenants sampled were operating below the frontier. The best performing farm had a technical efficiency of 0.95 or 95%, while the least performing farm had a technical efficiency of 0.14 or 14%. The mean technical efficiency of the Wheat tenants was 0.61 or 61%. This implied that the Wheat tenants were able to obtain about 61% of optimal output from a given set of production inputs suggesting that there is the scope for increasing wheat production by 39% if they were to operate at the frontier or by 5% if all wheat tenants would adopt the technology and production techniques currently used by the most technically efficient farmer. In general, the results suggested that the sampled tenants were fairly technically efficient.

Gross Margin Analysis: According to the survey results, wheat production costs were less than its gross returns resulting in a positive gross margin of SDD 4295 in season 2005/06 (Table 8). The Table also shows that, although the gross margin of wheat was positive, it was nevertheless low, especially if the forgone opportunities of using winter land and water are considered, given the wide range of opportunity for other winter crops that can be produced.

One reason for the low gross margin is the increasing input prices faced in the State in the last decade. According to this fact, wheat could be assessed as infeasible crop unless improvements are made.

Optimal Annual Production Obtained by River Nile State Model: Cropping pattern is one of the most important parameters involved in irrigation command areas. It is directly related to the productivity of irrigation systems and greatly contributes to improved soil and water utilization [20]. The integrated modelling approach was useful for linking biophysical and socio-economic factors influencing decision making on small-holder farms and evaluating trade-offs for resource use in terms of nutrient balances, labour use, food sufficiency and cash balance [25]. The agricultural background of RNS tenants offers a promising option for improving the farm system and livelihood of people. The output from the model run is the objective function value (returns), the optimal crop combination and utilised resources accompanied by their respective marginal value productivities. The model suggested the optimal land use is chickpea and dry bean only (on 8.62 and 1.38 feddans, respectively), due to these crops' high returns when compared to other annual crops in the area of study. Actual returns from crop production were SDD 399,487.28, while the optimal returns are SDD 811,596.73 (a 103% increase on current levels).

The average tenant had up to 10 feddans of land, 28,573 m^3 water, 191 work-days of labour and SDD 179,532 (about US$ 870) as capital available for the cropping season. The levels at which these resources were used in food legume crops were achieved. According to these results achieved by the system are indicating that, the rest of the crops could be assessed as unfeasible unless improvements are made. However, these crops are regarded as strategic (important for food security and household income), so incentives should be provided to make them more profitable. The study designed a scenario based on model solution to confirm the importance of crops that did not appear in the optimal plan. The model was assumed that, a decline in prices is happen for both chickpea and dry beans as a dominant phenomenon in the State markets. The model predicted that the decline of prices for chickpea and dry bean would lead to a fall in gross margins, but the margin would remain positive. Table 9 shows the results of the new model solution. The scenario analysis here provides the changes of chickpea and dry bean prices in the optimal solution.

The optimal return was SDD 845,495.61, which is more than the basic solution by 112%. The optimal levels of the resources used were 10 fed (all the available land), 17,644.94 m^3 of water, 133 work-days of labour and SDD 202,608.4 of cash capital are less than the actual quantities in the basic solution. The distribution of the cultivated area per fed was diverse, including all crops except maize (Table 9). The study concluded that the obtained results led to a conviction point that crucial manipulation is needed to stabilise resources sub-sectors to achieve food security, poverty alleviation and improve the livelihood of the farmers of the State.

Table 9: Impacts of low prices of chickpea and dry beans

Item	Actual	Optimal	Units
Resource use:			
Total land	10	10	fed1
Total irrigation water	28,573	17,644.94	Cubic meter (m3)
Total labour	191	133	Man-day
Total capital	267,118	202,608.40	SDD
Returns: objfn2 value (Z)	399,487.28	845,495.61	SDD
Crop:			
Wheat	1.1	1	fed
Faba bean	1.1	0	fed
Chick pea	0.3	1	fed
Dry bean	0.6	1	fed
Onion	0.6	1	fed
Spices	0.9	0.5	fed
Vegetables	0.8	1.5	fed
Sorghum	1.7	1.7	fed
Maize	0.7	-	fed
Potato	0.4	1.3	fed
Fodder	1.8	1	fed

Source: model results- (fed[1]= Feddan = 0.42 Hectare and [2]objfn = Objective function)

Challenges: Climate change has affected numerous regions over the world and raise the attention of the issue of water security. Extreme weather conditions that could result in difficulties to anticipate wet or dry spells and other adverse impacts of climate change, pose major challenges to effective water resources management. The Food and Agriculture Organization of the United Nations (FAO) has estimated that by 2025, close to 1.8 billion people will be living in countries or regions with absolute water scarcity and two-thirds of the world population could be under stress conditions [1]. River Nile State of Sudan is concerned front tremendous water management challenges due to the lack of adequate infrastructure, inadequate of public investment in infrastructure development, lack of awareness regarding modern water conservation technologies, delay in updating agricultural system and inefficient State policies. Furthermore, rapid population growth and urbanization also exacerbate existing water security and governance issues, creating particularly negative impacts for peri-urban and rural residents.

CONCLUSION

The research demonstrates that River Nile State has the opportunity to take a lead in investment of advanced irrigation water technologies due to its high-quality and quantity fresh water resources and other agricultural resources. This paper explores some of the findings of the field survey and it describes the interaction between tenants and on-farm irrigation water-use for agricultural production. We are able to draw the following conclusions: Surface irrigation is regarded as inefficient and expensive. The farming system is dominated by wheat production which occupies 25% of the farm land. Overall lack of awareness about crop water requirements and on-farm water-use efficiency led to high amount of water wastage among tenancies of the scheme of scheme might be due to the inefficiency factors namely: farming experience, extension visits, irrigation distance, illiteracy, aged tenants and off-farm income, therefore, building capacity of of tenants and technicians of the schemes for huge water savings. This capacity should be utilized for expansions in uncultivated areas in the State through State intervention and adoption of participatory approaches involving scheme administrators and tenants to manage irrigation water and sensitizing to adopt modern water saving technologies. Young educated tenants in the scheme often more furnish to adopt modern technologies, while the old illiterate usually believe and work based on their own conventional experiences.

The estimated on-farm water-use efficiency indicated a wide technological gap between the crop water requirements and the actual applied water; reaching 41% per watering and 64% for the entire season and the average efficiency for the scheme is 61% showing that tenants are producing below the frontier output level. The estimated wasted amounts of irrigation water would be sufficient for expected irrigated-area extension that is determined as 57% of the average grown area of wheat and 112% of the average cultivated area of the scheme tenancies. Also, water productivity of productivity of the crops in monetary and physical terms was generally low in area of the study, while wheat was more low when compare to some other crops.

Based on the foregoing conclusion and the obtained results, the paper pointed to numerous opportunities as follow:

- The policy makers of the State should consider the economic and technical use of the scarce fresh water resources to sustain farm production.
- Reducing the need for purchased inputs and (eventually) developing tenants' market-orientation for earning additional income will be conducive to farm resource use optimisation contributing to tenants' living standard. Thus, appropriate combination of land, water, labour and capital resources for producing annual crops in area of the study is very important and should be well designed and applied.

- The study detected that the tenants considered the misuse of irrigation water as a normal practice, while they ignored the negative consequences on environment. Raising tenants' awareness regarding environmental conservation issues is necessary.

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